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Research Article

Collecting and cataloguing the world: the botanical collections of Hans Sloane (1660–1753)

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Botanical collections assembled before the widespread adoption of the 'Linnaean' system of binomial naming often have nomenclatural significance, are increasingly utilized to investigate genetic and environmental change, and are important sources for the history of science and medicine. However, such early collections may be difficult to access and interpret, and few have machine-readable metadata or images. The natural history collections of Hans Sloane (1660–1753), assembled between the 1680s and his death in 1753, constitute the *de facto* foundation collections of the Natural History Museum, London. This study analyses Sloane's Herbarium and 'Vegetable Substances' which make up the largest surviving components of Sloane's natural history materials and the largest pre-Linnaean botanical collection in existence. The collections contain specimens contributed by hundreds of people from over 70 countries and territories worldwide. New data sets are presented that enable novel research and a comparison of their parts. The data provide details of the people and places mentioned in these sources, along with a complete transcription of the Vegetable Substances catalogue, and new folio-level metadata for the entire Herbarium. The results provide precise estimates of the scale of the collections (8812 surviving specimens of the Vegetable Substances, and 121 506 specimens in the herbarium) and demonstrate their heterogeneity, reflecting their complex histories. Aspects of the collections' histories can be read from the data and reveal some of the organization and management practices that shaped the collections as we have them today. However, we show that there is frequent ambiguity and uncertainty in the provenance of specimens, while the human histories connected with their assembly are often opaque, embedded in the trading networks of colonialism and enslavement. These data permit analyses of the collections at scale for the first time, yet also suggest that multi-disciplinary approaches are required to fully unlock such historical collections.

Key words: historical collections, limits of data, manuscript catalogues, provenance, Sloane

Introduction

Provenance data are an essential component of current large-scale digitization programmes (e.g. Haston et al., 2023). Nevertheless, it is widely recognized that data associated with natural history specimens may be 'biased, fuzzy, haphazard, unstandardized, non-random, incomplete, and unique' (James et al., 2018). This is particularly true for specimen data from the early modern period that are often ambiguous, difficult to determine, and frequently not inscribed with the objects themselves. If labels are present at all they may be cryptic and abbreviated, written in difficult hands, and, if named, usually bear pre-Linnaean polynomials. Furthermore, the plants may be mounted in bound volumes (*horti sicci*, 'dried gardens'), which themselves may have complicated bibliographical histories (Costa et al., 2018; Dietz, 2024; Stefanaki et al., 2018, 2021; Ward, 2007). For these reasons, most historical botanical collections are only partially researched, and typically do not have extensive accompanying machine-readable metadata, or images.

The botanical collections of Hans Sloane (1660–1753) form the largest assemblage of pre-Linnaean plant materials in the world and exemplify these challenges.

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Accumulated from a variety of sources, they comprise a 'collection of collections' (Delbourgo, 2012). Of more than 130 000 specimens, around 3000 were gathered by Sloane himself, while the remaining were gathered by a range of people from around the world. Many were bought by Sloane, and others were given or bequeathed to him. They were carefully added to the collections, and catalogued by Sloane and his assistants (Cannon, 1994; Reveal et al., 1987).

Born in the north of Ireland, Sloane moved to London as a young man and trained as an apothecary and physician, travelling in Europe before taking his degree at Orange. Returning to England, he was appointed personal physician to Christopher Monck, the second Duke of Albemarle, and accompanied him to Jamaica in 1687 on the latter's appointment as lieutenant-governor of the island. Though Sloane had collected plant and animal specimens in England and on his European travels, his journey to the Caribbean resulted in the acquisition of hundreds of additional specimens, many previously unseen in Europe. After returning to England in 1689, his wealth steadily increased, in part due to his lucrative medical practice, as well as his marriage to Elizabeth Langley Rose, the heiress (through her late husband) of several Jamaican plantations. Sloane's financial situation meant that he could readily afford to acquire and collect throughout the rest of his life. Elected a Fellow of the Royal Society in 1685, Sloane served as the society's Secretary from 1693, eventually succeeding Isaac Newton as President in 1727. From 1719 he was also President of the Royal College of Physicians (Delbourgo, 2018).

Sloane's overall collections were vast and comprised much more than just plants. Alongside the botanical specimens were thousands of other natural history objects, books, manuscripts, coins, medals, and prints and drawings. The scale of the collections at Sloane's death was remarkable and he made provision in his will for the collections to be offered (at a price) to the nation, whereupon they became integral to the foundation of the British Museum, along with the 54 catalogue volumes he and his amanuenses had created to describe them (Caygill, 1994, 2012; Jones, 1988).

While little of the animal, mineral or fossil collections survive, the botanical collections have remained remarkably intact, and are now found in the Natural History Museum, London (NHM). These historical plant collections comprise two distinct parts: the Herbarium and the 'Vegetables and Vegetable Substances' (VS; see Fig. 1).

The Herbarium is made up of 337 numbered *Horti Sicci* (HS), bound in 265 volumes. The contents of the Herbarium was briefly described at the *Hortus Siccus* level within Sloane's eight-volume books and manuscripts catalogue (Blakeway, 2011), and partly cross-

Figure 1. Hans Sloane's botanical collections. (a) The enumeration of Sloane's collections in *Authentic Copies of the Codicils Belonging to the Last Will and Testament of Sir Hans Sloane, Bart. Deceased, Which Relate to his Collection of Books and Curiosities* (Printed by Daniel Browne, 1753). (b) Bound volumes of Sloane's herbarium stored behind his portrait. (c) Hortus Siccus 3, folio 35 in Sloane's herbarium, containing a specimen of *Renealmia antillarum* collected by Sloane during his travels to Jamaica in 1687–9 with an original illustration by Everard Kick on the facing verso. (d) A specimen from Sloane's Vegetable and Vegetable Substances collection (VS 1715 'A walnut from Caribes?') with the corresponding catalogue entry. (e) and (f) Two examples of Sloane's Vegetable Substances collection. (e) is VS 1304, catalogued as 'True senna seeds. Sena vera ex Barbados. P.' (f) is one of 251 items in the collection labelled with more than one Vegetable Substance catalogue number, in this case VS 1142 ('Virginia Juniper berries. Juniperus novae Angliae. Sabina baccifera novae Angliae. Graine de cedrede Canda dont le bois est rouge & de bonne odeur.') and VS 1398 ('Sabina baccifera novae Angliae. | Cedar berries from Maryland. | Bermudas cedars?').

referenced to Sloane's personal copy of John Ray's *Historia Plantarum* (Ray, 1686–1704), which thereby serves as a nominal index to some of the specimens (Cannon, 1994). Detailed examination of the Herbarium began in the late nineteenth century, and a descriptive catalogue based on that work was edited and assembled by James Dandy (1958), building on earlier work by researchers at NHM including James Britten.

The Herbarium is an anomaly among the rest of the natural history collections that Sloane bequeathed to the nation as the number of specimens in it was not explicitly recorded. The published lists of the collection that Sloane had amassed by 1753 (Fig. 1*a*) provide precise figures for the number of natural objects within it (e.g. 173 'Stellae, marinae, &c.', 1555 specimens of 'Fishes, and their parts', etc.). The Herbarium, however, was treated differently. Grouped together as the 'Hortus Siccus, or Volumes of dried Plants', it then amounted to 334 volumes, and no count of the number of objects (specimens) within them was provided.

There were no estimates of the number of specimens in the Herbarium for well over a hundred years after Sloane died. The earliest known attempt to quantify the Herbarium was as part of the evidence given to a parliamentary inquiry in 1901. In his submission, the then Keeper of Botany, George Murray (1858–1911), asserted that the 'Sloane and other pre-Linnean Herbaria' amounted to 'about 90,000 specimens' ('Minutes of Evidence', 1901). Though Murray's statement is ambiguous, his estimate likely included other early modern herbaria at NHM, separate from those assembled by Sloane, such as those of John Ray (1627–1705), Paul Hermann (1646–1695), Samuel Dale (1659–1739), George Clifford (1685–1760), John Clayton (1694/5–1773), and probably others. A much higher estimate of the size of Sloane's Herbarium was offered in 1975 by botanist William T. Stearn. He added a pencil note to the back endpaper of the copy of Dandy (1958) that now resides in the Historical Collections Room (HCR) at NHM, to the effect that the 'Sloane Herbarium contains about 300,000 individual specimens'. This is at odds with the estimate printed in the book itself, which suggests 'in the neighbourhood of 120,000' (Dandy, 1958). It is this latter number that has been recorded as the 'official' measure of the Herbarium for at least the last seventy years (Carine, 2020; Dandy, 1958, p. 18; Edwards, 1961), although more recently Jarvis (2020) suggested the number may be closer to 70 000.

The Vegetable Substances are markedly different to the Herbarium in their form, organization and description. Documented in a three-volume handwritten catalogue, largely in Sloane's own hand, are entries, numbered 1–12523, describing seeds, leaves, pieces of bark, roots, gums and plant fossils (Fig. 1*e,f*), of which more than eight thousand survive (Ogborn & Pickering, 2019). Several hundred specimens are stored in *materia medica* trays, but the majority are stored in individual boxes (Fig. 1*d–f*), that have glass tops and bottoms and wooden sides and are sealed with decorative, often marbled, papers glued down to seal the edges (Ogborn & Pickering, 2019).

The catalogue to the Vegetable Substances contains a plethora of information and connections to people, places, uses, common names, bibliographic references and more, but the entries are extremely varied in the information that they contain. They can be brief and record descriptive elements such as 'A large bean in the form of a kidney' (VS 3214) or 'A pod large like the cocoon of a triangular shape containing one bean' (VS 800), and they vary in the granularity of their detail about provenance. Broad geographical regions can be mentioned such as 'the East Indies' (e.g. VS 1359), but more precise localities are also sometimes provided (e.g. 'Witney quarries in Oxfordshire'; VS 10476). Person names may also be present while local plant names and uses are also sometimes included (e.g. 'A seed called Dockonari in Persia w[hi]ch boyl'd in water makes a cooling drink'; VS 671). Well-defined groups of objects are also found listed in the catalogue. There are, for example, hundreds of samples that were sent from the 'East Indies' by 'Dr Adair'. The catalogue is thus the key to searching, using and unlocking the Vegetable Substances.

Sloane's botanical collections were the focus of various studies following his death in 1753 (e.g. Goodenough, 1794; Salisbury, 1817). More recent studies using the collection have emphasized the nomenclatural importance of specific specimens (Jarvis, 2007) and provided valuable evidence of the 'discovery' of local and regional floras (Baker, 1865; Bellis, 2009; Blackwell & McMillan, 2013; Broome et al., 1987; Bryce, 2005; Hinz, 2001; Lindberg, 1874; McMillan & Blackwell, 2013; Pearman, 2017; Reveal et al., 1987; Santos-Guerra et al., 2011; Sequeira et al., 2010), and of the status of species (e.g. Rumsey & Spencer, 2012). The range of recent users of the collection is as broad as that for herbarium collections more generally (Carine et al., 2018), with specimens from the collection used in molecular analyses to investigate genetic change and extinction (de Vries, 2023), and domestication processes (Ames & Spooner, 2008; Gutaker et al., 2019). Furthermore, these collections are an important source for research in the history of science and medicine, as well as in the history of collecting, and their relationships with colonialism, trade, and enslavement (Carine,

2020; Coulton, 2020; Kriz, 2000; Murphy, 2023; Rose, 2018; Walker et al., 2012).

Just as 'specimen' and 'provenance' may be problematic concepts in these historical collections, so is the notion of a 'collector'. The term 'collector' can apply to a wide range of roles in the specimen 'supply-chain' (Lucas & Lucas, 2014), each of which can result in the creation of a 'collection'. In this paper the term 'collection' is used in two senses: first, to refer to either the Herbarium or Vegetable Substances in the broadest sense; and second, to refer to a group of plant objects assembled by a specific (usually named) individual prior to their being acquired by Sloane.

Despite the scientific, historical and cultural significance of these plant collections, there has hitherto been no collection-level data set that describes their constituents in their entirety. Access to information on the contents of the collections has been limited, and answering even basic questions about the collections such as the number of specimens they contain, the scale of contribution of individuals and the geographic scope of the material has not been possible with any degree of precision or confidence.

This paper presents two new data sets that describe Sloane's Herbarium, and his 'Vegetables and Vegetable Substances'. We use the data sets to investigate heterogeneity in their physical composition and the data associated with specimens. Focusing on the people and places recorded, we investigate how collecting in different ways—as herbarium specimens or Vegetable Substances—impacts the composition of these collections. Finally, we provide examples and contexts that illustrate the challenges of working with such early material and demonstrate how complex historical botanical collections such as those of Hans Sloane require further layers of research, analysis, documentation and visualization to inform and support their use and digitization.

Methods

Vegetable substances

Two distinct resources were generated to describe Sloane's 'Vegetables and Vegetable Substances'. The first was a digital transcription of the three-volume manuscript catalogue to the material in which references to places and people were standardized to enable searching and quantitative analysis. The second was a database of the 8812 surviving Vegetable Substances, to which the catalogue transcription was cross referenced using Sloane's individual object numbers.

An initial transcription of the entire catalogue was produced by Pickering (2016). This comprised the different elements of the catalogue including volume number, page number, object number, and the descriptive textual content of the entry itself, which could include marginal annotations such as location codes and prices paid for the specimens. This transcription, in a tabular (spreadsheet) format, was then edited, corrected, and transformed into a public-facing data set as part of the current study (Pickering, 2024). During this process, data such as the abbreviations used by Sloane, a common characteristic across his manuscript catalogues (Sloan & Nyhan, 2021), were enhanced to make the data set more easily searchable. Sloane consistently wrote entries at the top of catalogue pages that had details of people and place, and then used abbreviations for the entries that followed. These appear in forms including 'from the same', 'Id', 'Idem' and 'Ib'. For example, VS 7668 appears as 'Round cyporus root. From Jamaica by Mr. Barham' and the following item, VS 7669, appears as 'Long cyperus root. From the same.' The people and place name data, including those represented by the terms described above, were extracted and inserted into a new, normalized column. As part of this digital transformation, people names were also standardized. For example, Al. B; Al. B.; Al. Br; Al. Br.; Al. Brown; Alex. Browne; Alex.r. Browne; Alexr. Br.; Alexr. Brown, were all identified under the name 'Alexander Brown'.

When a name appears in a catalogue entry, such as 'From Mr Barham', it suggests that an active form of knowledge exchange took place in which Sloane received an object and information from a person and/or place. However, Sloane also amassed a great number of objects through acquiring substantial collections created by other natural historians, such as those of James Petiver (ca. 1663–1718), Leonard Plukenet (1642–1706) and Nehemiah Grew (1641–1712) (Cannon, 1994). This method of collecting was catalogued differently by Sloane. He used phrases such as 'From Grew's Collection' or abbreviations to indicate material acquired in this way. At the very beginning of the Vegetable Substances catalogue, Sloane writes the following:

G. & Gr. Dr [Nehemiah] Grew mus[aeum] S[ocietatis] Reg[alis] & collection of seeds fruits &c. which I bought.
P & Pet. are Mr. James Petivers collections of all sorts w[hi]ch, I bought likewise.
P. & PL. Dr. Plukenets collections w[hi]ch. I likewise bought from Dr. Moor B[i]s[ho]p. of Norwich who bought them of his Exe[cutor]s.

Information on such named collections was also captured as a separate column. The following named

collections were identified: 'Albertus Seba's Collection'; 'William Courten's Collection'; 'James Petiver's Collection'; 'Leonard Plukenet's Collection'; 'Lowther Collection'; 'Mr Thornton Collection'; and 'James Petiver or Leonard Plukenet's Collection', the latter since, as noted above, 'P' could refer to either Petiver or Plukenet's collections. In some instances, a question mark was used by Sloane to indicate uncertainty regarding the collection to which it was assigned, and this was also recorded, following the text with which it occurred.

Place names were resolved to modern equivalents ('sites') in an 'interpreted location' column and those were georeferenced. Sites assessed as having an area of less than 10 000 km^2 were differentiated from those with a larger area to allow those sites describing large geographical regions and territories to be more readily identified. For each interpreted site, we also provided details of the political territory within which it is currently designated (e.g. China, Jamaica) and assigned the locality to a geographical region that broadly followed the geographical filing system in the NHM General Herbarium, albeit with some modifications (see Table 1). We included two broader regions where it was not possible to more precisely locate the place named: 16. [America]; 17. [East Indies]. A small number of places could not be resolved and were recorded as '18. [Unresolved]'. Finally, where multiple sites were recorded in a catalogue entry, we recorded this in the 'interpreted location' column as 'Multiple sites'. If all such sites could be assigned to a single country or region we did so. Otherwise, the region was recorded as '19. [Multiple regions]'.

Other data recorded were: the *historical location code*, a pencil annotation, typically in the left hand margin of the catalogue that is thought to indicate the cabinet or drawer number in which the objects were stored in Sloane's house (Caygill, 2012); the *price*, listed in the right-hand margin of some objects which suggests the amount paid by Sloane for the object; and *cross references to other* Vegetable Substances where these were determined by Sloane or one of his amanuenses. Finally, where a surviving Vegetable Substances object has been matched with a catalogue entry, we included the object registration number, which is encoded as a machine-readable barcode physically associated with the object at NHM.

An inventory of the surviving Vegetable Substances was created in the NHM Collections Management System (Axiell K-Emu) using a bespoke Sapphire Application designed by the NHM Data Management Team. For each item, the NHM object registration number and Sloane catalogue number(s) relating to the item were recorded and paired. We subsequently enriched the records with the corresponding catalogue descriptions from the catalogue transcription dataset. Of the 90 drawers that now contain the Vegetable Substances, 11 contain *materia medica* trays as opposed to individual boxes. We used the inventory data to establish which samples were preserved in each category.

We examined heterogeneity across the Vegetable Substances in two ways. First, we investigated the word count for catalogue entries as a proxy for the amount of detail contained in the descriptions of individual

Table 1. Geography of the Vegetable Substances and Herbarium: number of sites represented in the Vegetable Substances and Herbarium by geographical region, and the number of catalogue entries (Vegetable Substances) or folio references (Herbarium) from the region. The average number of catalogue entries or folio references per site is also given.

Region	VS sites	VS catalogue entries	VS catalogue entries per site	Herbarium sites	Herbarium folio references	Herbarium folio references per site
01. United Kingdom	95	208	2	36	276	8
02. Europe	65	258	4	51	721	14
03. North Africa	4	13	3	2	2	1
04. West Africa	10	98	10	8	138	17
05. Atlantic Islands	3	14	5	8	76	10
06. East Africa	1	2	2	0	0	–
07. Southern Africa	1	49	49	2	158	79
08. Indian Ocean	4	14	4	2	37	19
09. Western Asia	13	93	7	7	58	8
10. South Asia	15	378	25	13	221	17
11. East and Southeast Asia	23	808	35	18	362	20
12. North America	24	565	24	15	528	35
13. Central America	7	41	6	2	4	2
14. Caribbean	18	937	52	11	353	32
15. South America	12	93	8	5	67	13
16. [America]	1	74	74	0	0	–
17. [East Indies]	1	532	532	1	67	67

specimens. Second, we organized the VS catalogue descriptions in order of volume and folio on which they appear and then by catalogue number and placed those in bins, each containing 50 catalogue records, which served as a reasonable sample size for analysing trends across the material. For each bin, we then plotted the number of: (i) catalogue entries with surviving Vegetable Substances; (ii) catalogue entries assigned to a named collection; (iii) catalogue entries containing information on people; (iv) catalogue entries containing information on place; (v) catalogue entries with a code indicating a historical location in Sloane's collection; and (vi) occurrence of samples in *materia medica* trays, to investigate heterogeneity across the Vegetable Substances.

Herbarium

A folio-level survey of the entire Herbarium was constructed as a spreadsheet, a 'folio' in this instance designating an individual sheet of paper in a bound volume (*Hortus Siccus*) that may contain any number of botanical specimens as well as additional manuscript annotations (including foliation numbers). Most folios contain specimens and annotations on their 'recto' sides, but some are blank (although typically foliated), and a few contain specimens and annotations on their 'verso' sides. The spreadsheet contained a row for each numbered folio (and verso, if not blank) in the Herbarium, recording the number of specimens, illustrations and 'manuscripts' present, together with an indication of the presence/absence of: specimen labels; cross references to Sloane's annotated copy of John Ray's *Historia Plantarum*; common/local names in any language; information on plant use; names of people or places; and any modern (binomial) determinations. As with the Vegetable Substances, we examined material and provenance heterogeneity across the Herbarium, examining the presence/absence of these data at the level of each *Hortus Siccus*.

Many *Horti Sicci* have complicated material histories, understanding which can provide valuable evidence for reconstructing the provenance of the specimens within them. A number of *Horti Sicci* comprise several smaller, discrete units, often from disparate places and collecting dates, which are here named 'sub-*Horti Sicci*'. These sub-*Horti Sicci* were assigned unique identifiers. Furthermore, some parts of the Herbarium include multiple foliation schemes, which were also recorded using unique identifiers, so that references from other resources that point to the Herbarium (e.g. the annotations in Sloane's copy of Ray's *Historia Plantarum*) can be more readily resolved.

Data on people and places associated with folios from Dandy (1958) were also included in the data set. A text file of Dandy (1958) was derived from digitization of the volume for the Biodiversity Heritage Library (www.biodiversitylibrary.org) by the NHM Library and Archives Digitisation Unit. This was copyedited and subsequently transformed into a structured XML file, capturing as much descriptive content as possible that could be explicitly tied to any given folio.

Some data enrichment was also undertaken. During the folio-by-folio survey of the Herbarium it became apparent that some names of people and places recorded on folios were not included among the lists published in Dandy's text (although many such 'omissions' were recorded in the Dandy text at the volume level, rather than itemized by folio). By comparing the Dandy data with the folio survey, it has been possible to pinpoint where such omissions occur and begin to add the details to the data set. Such data additions are themselves annotated with metadata explaining their provenance, including any evidential assumptions that have been made (for example, where personal names have been inferred from handwriting evidence). This enrichment is not yet complete, and future data releases will add to this provenance information.

Almost all places mentioned in Dandy (1958) were georeferenced and were placed in a modern country and geographical region following the approach used for the Vegetable Substances (see above).

The subsequent data workflow resulted in a large XML data object (c. 33 MB) representing the Herbarium corpus, which conforms to the standard of the Text Encoding Initiative (TEI, n.d.). For this current study, a tabular dataset providing details of each folio from the inventory, together with information on sub-*Horti Sicci*, and people and places from Dandy (1958), was generated from the XML using a simple program written in XSLT (eXtensible Stylesheet Language Transformations).

Comparing data sets

We compared georeferenced sites recorded in the Vegetable Substances catalogue with those recorded in Dandy (1958) for the Herbarium. For the latter, we included not only sites associated with individual folios but others not directly associated with folios by Dandy (1958) and often documented only at the *Hortus Siccus* level. Georeferenced site centroids were visualized on a map created using QGIS (www.qgis.org). Sites recorded for items in both the Herbarium and Vegetable Substances collections were differentiated from those found in only one of the two data sets.

Table 2. Overview of Hans Sloane's collection of vegetables and Vegetable Substances and the catalogue describing it.

Item	Count (%)
Entries in the catalogue	12 750
Specimens in the collection	8812
Specimens in the collection with VS number(s)	7771 (88%)
Specimens in the collection stored in *materia medica* trays	441 (5%)
Catalogue entries for which there is a surviving specimen	7913 (62%)
Specimens assigned multiple Vegetable Substance catalogue numbers	251 (3%)
Catalogue numbers assigned to multiple specimens	48 (0.6%)
Catalogue entries assigned to a named collection	2971 (23%)
Catalogue descriptions including named people	4923 (39%)
Catalogue descriptions including named places	4614 (36%)
Catalogue descriptions including both named people and places	3250 (25%)

We similarly analysed the contributors documented for each of the two collections, to establish the extent of overlap between the provenance of the Herbarium and of the Vegetable Substances.

Results

The two data sets are available from the NHM Data Portal: (a) Vegetable Substances, https://doi.org/10.5519/lp5a5t1d (Pickering et al., 2023) and (b) Herbarium, https://doi.org/10.5519/3arpif46 (Scott et al., 2024).

Vegetable substances

Table 2 provides an overview of the Vegetable Substances catalogue and collection. The items in the catalogue to the Vegetable Substances are numbered from 1 to 12523 but there are several duplicate numbers, distinguished by an asterisk, and so the total number of catalogue entries is 12 750. There are 8812 surviving objects, of which 1040 have no VS object number and one has an Insects catalogue object number. Thus, there are 7771 surviving VS objects with a corresponding entry in the catalogue. Of these, there are 441 samples preserved in *materia medica* trays (5% of surviving objects).

The connection between Sloane's Vegetable Substances catalogue entries and the surviving objects is not a simple one-to-one relationship. Some objects are associated with multiple catalogue entries and, conversely, some catalogue entries are associated with multiple objects. There are 48 catalogue entries that are referrable to two objects in the collection, while there are 251 objects which have multiple catalogue numbers associated with them. Of the latter, the majority (202) have two associated catalogue numbers (e.g. Fig. 1*f*), but there are 26 items with three catalogue numbers, 12 with four catalogue numbers, six with five catalogue numbers and two with six associated catalogue numbers. There is also one object with 10 associated VS numbers, one with 11, and one with 12. Taking these complexities into account, there are 7913 entries in the catalogue (62% of catalogue entries) that can be associated, through the catalogue number, with surviving objects.

Twenty three percent of catalogue entries (2971 entries; Fig. 2*a*) are referrable to one of the named collections identified, of which 1551 of those are referrable to Nehemiah Grew's collection which forms the largest component within the Vegetable Substances. In addition, 171 entries are linked to Petiver, 77 to Plukenet, and 1168 to either Petiver or Plukenet. The collections of Albertus Seba (11), 'Mr Thornton' (4), Courten (1) and Lowther (1) are also referenced in this way. Uncertainty in the assignment of catalogue entries to these component collections is also evident via three records denoted with a question mark, and one record that is assigned to both Petiver or Plukenet's collection and to Nehemiah Grew's collection.

There are 4923 catalogue entries (39%) that contain references to individuals. In most instances, a single person is identified but in 674 catalogue entries two individuals are named; seven catalogue entries refer to three individuals; and one refers to four. When abbreviations and spelling variants were resolved, the number of unique contributors totals 318, with entries including multiple people resulting in 334 combinations of individuals (see Supplemental Material 1).

The most-frequently named contributor to the Vegetable Substances is Robert Millar who is cited in 537 catalogue entries (4%) and associated with 474 catalogue entries matched with surviving objects (6%). Jean Rodolphe Lavater is named in 481 catalogue entries (4%), two of which also name Edward Lhwyd. Lavater's name is recorded on 5% of entries that have surviving objects associated with them (432 items). Mary Somerset, Duchess of Beaufort, contributed the third largest number of objects. She is associated with 399 catalogue entries (3.1%). In 326 of those she is the

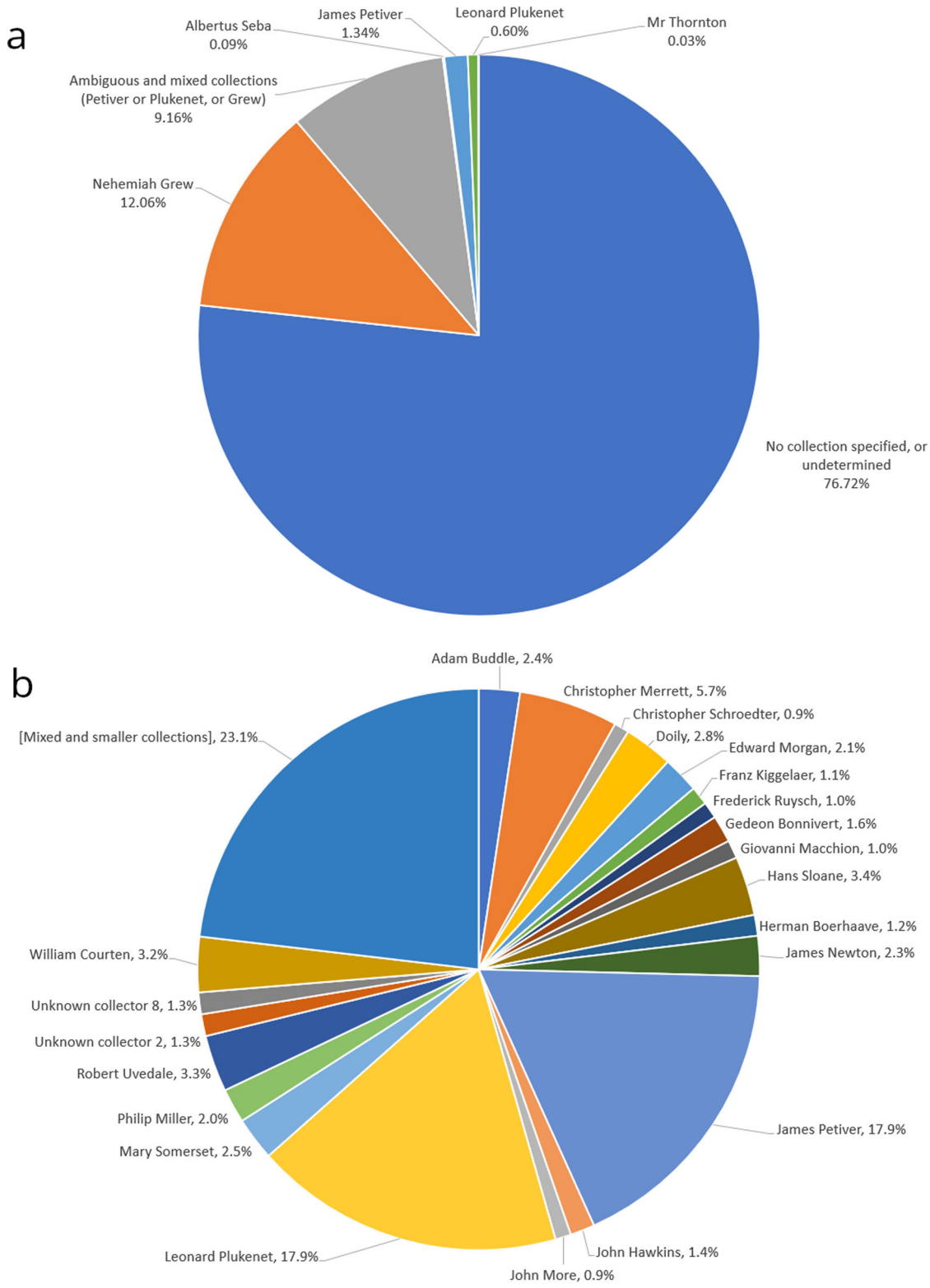

Figure 2. A collection of collections. (a) Collections in the Vegetable Substances. (b) Collections in the Herbarium, showing all distinct collections with more than 1000 specimens.

sole person named, while she is named along with Richard Bradley in 51; with James Petiver in 17; and with 'Mrs Pem', 'Mr Landen', 'Mr Doyley' and 'Mr Landa' in one catalogue entry each. Of the catalogue entries with surviving objects, 309 (4% of the total) refer to Somerset.

Places were mentioned in the catalogue descriptions of 4614 entries (36%). Of those, 468 catalogue entries reference multiple sites. For example, the description of the first entry in the catalogue is 'Opobalsamum or balm of Gilead from Mocca by the way of Surrate' in which both Mokha and Surat are mentioned. From the remaining entries, 588 different 'location statements' were identified, and these were resolved to 289 sites (see Supplemental Material 2).

Of the interpreted localities, 95 were from Britain and Ireland, and 65 from Europe (Table 1). Those regions accounted for 208 and 258 specimens, and an average of two and four catalogue entries per site, respectively. There were more specimens from the Caribbean (937) than from any other region. There were 18 interpreted sites for this region, given an average of 52 catalogue entries per site. A similarly high average number of catalogue entries per site was also observed for other regions with extensive representation in the Vegetable Substances: for East and Southeast Asia there were 808 catalogue entries and 23 interpreted sites (average of 35 per site) and for North America there were 565 catalogue entries and 24 sites (average of 24 per site). There were 534 specimens described as from the 'East Indies' and 74 from 'America' with no more precise geographical source given.

Catalogue entries range in length from a single word (466 entries)—typically a plant name (e.g. 'Catamentha', VS 10989; 'Tulip-Tree', VS 10937) and including many collected by Robert Millar—to 350 words in the case of VS 6754, which contains a detailed account of Paraguayan tea (Yerba mate; *Ilex paraguariensis*). The average word length for catalogue entries is nine, the mode is three, and just 122 entries are 50 or more words long.

Figure 3 illustrates the heterogeneity of the Vegetable Substances collection and associated catalogue data. There is variation in the collection in the extent to which samples have survived, with fewer collections surviving among those items listed earlier in the catalogue (Fig. 3*a*). The most prominent section of the collection for which little material survives is between VS 2651 and VS 3550: there are only 59 specimens bearing catalogue numbers in this 900-entry sequence, i.e. 6% of these catalogue entries have been paired with a surviving object. This contrasts to the overall average of 62%.

Named collections occur sporadically throughout the Vegetable Substances (Fig. 3*b*). The largest block of catalogue entries referring to a named collection is that between VS 5351 and VS 6800. This describes the collections of the Royal Society received from Nehemiah Grew, which appears to have been largely accessioned in a single sequence although some samples from Grew's collection are catalogued both before and after.

The recording of the names of people (Fig. 3*c*) and places (Fig. 3*d*) varies across the Vegetable Substances. Early catalogue entries are not rich in data on people although they do contain more information on places. For both people and places, there are sections of the catalogue where information is recorded extensively but also other parts of the catalogue for which this detail is entirely absent. The absence of information on names of people or places is particularly striking for the Grew collection (VS 5351–VS 6800).

Historical locations in Sloane's collection, i.e. cabinet and drawer numbers, are typically provided for most items, but there are conspicuous absences (Fig. 3*e*). The two sections of the catalogue for which historical location data are most obviously absent are those between VS 1101 and VS 1700 and between VS 3501 and VS 5200. Among the 2300 catalogue entries included in these two sections of the catalogue, only 23 entries have historical location codes. The objects described within these parts of the catalogue largely survive intact and are highly heterogeneous in terms of other data associated with them (notably relating to people, places and named collections). There is thus no obvious explanation for the omission of historical location codes from these entries.

Descriptive entries associated with specimens currently stored in *materia medica* trays (Fig. 3*f*) are distributed across the catalogue although some clusters are evident, particularly at the beginning of the catalogue. For example, between VS 2201 and VS 2650, 188 entries are associated with specimens in *materia medica* drawers, 45% of the total collection stored in this way. Many of these entries include an indication of their medical use, notably through their description as 'off.' (i.e. officinal). A second prominent group can be observed between VS 4651 and VS 4850. This section of the catalogue describes a series of 'Indian drugs' from Siam (Thailand), sent by 'Dr. [Robert] Uvedale'.

Herbarium

Table 3 shows summary statistics of Sloane's Herbarium based on the folio-level inventory of the collection. The number of folios recorded in the inventory survey was 37 852 and the total number of specimens

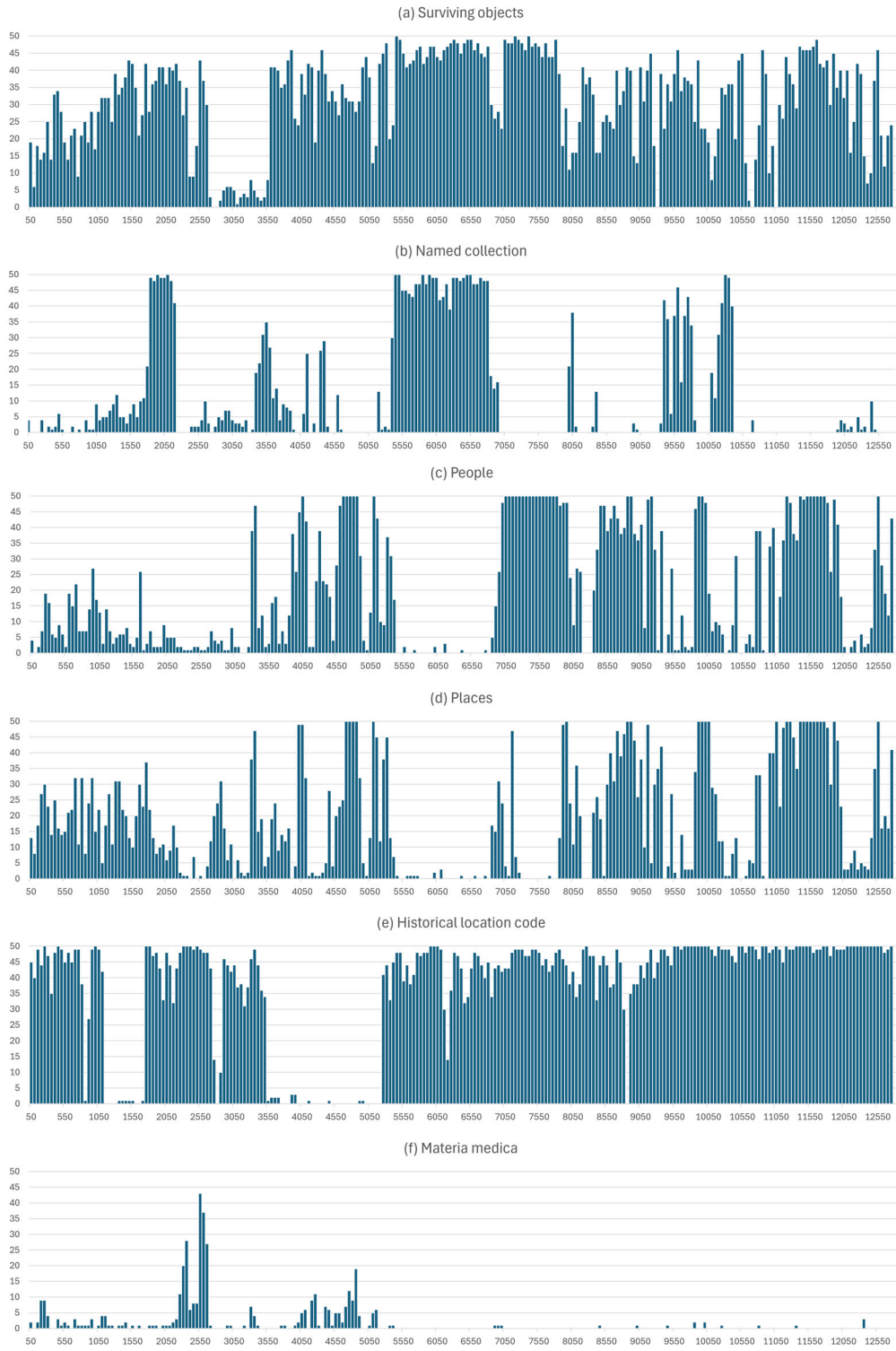

Figure 3. Heterogeneity of the Vegetable Substances. The x axis represents sequential bins of fifty entries in Sloane's numbered catalogue to his collection of Vegetables and Vegetable Substances. There are 12 750 entries in the catalogue and thus 255 bins. The x-axes show the bin maxima for every tenth bin. From top to bottom, the histograms show the following: (a) the number of entries for each 50-entry bin with surviving objects, (b) the number referred to a named collection, (c) the number in which other individuals are mentioned, (d) the number in which places are recorded, (e) the number for which a code indicating a location in Sloane's collection is recorded, and (f) the number that are presently stored in *materia medica* trays.

Table 3. Overview of the Sloane Herbarium.

Item	Total (%)
Horti Sicci	337
Numbered folios (rectos)	37 852
Specimens	121 506
Illustrations	736
Manuscripts	845
Average number of specimens per folio	3.2
Folios with specimen labelling	28 964 (76%)
Folios with cross reference to Ray	19 658 (52%)
Folios with vernacular names	5120 (14%)
Folios with uses	339 (0.9%)
Folios with location data	4212 (11%)
Folios with collector data	4848 (13%)
Folios with Linnaean binomial name(s)	4401 (12%)

was 121 506. There are an average of 3.2 specimens per folio, often of different taxa, although this average number conceals a very disparate range in the number of specimens per folio. Of those folios containing specimens, 34% have just one, 17% have two and 14% have three. Nearly 6000 folios (5922; 14%) have six or more specimens, and 24 folios had 30 or more specimens mounted on them.

There are relatively few illustrations within the Herbarium (736), comprising both drawings and prints, the latter often from Petiver's works, along with a small number of prints of pressed, inked plants among the Leonard Plukenet collection. The 845 manuscripts inserted within the volumes are predominantly lists of plant names, although they also include letters and more extensive descriptions of plants, their properties and uses. Some 77% of these 'manuscripts' occur within the James Petiver material.

Most folios (76%) have at least one label and 52% have at least one cross-reference to John Ray's *Historia Plantarum*, Sloane's copy of which served as the taxonomic index to the Herbarium. Less frequent are non-Latin names and details of plant uses: 14% of pages have vernacular names, the majority in English, and a relatively small proportion of the folios (0.9%) have information on plant uses. A small but significant proportion of folios contain the names of people (13%) or places (11%) associated with the specimens. That many botanists have worked with parts of the collection since Sloane's death in 1753 is evident from the 12% of folios that bear a Linnaean binomial name.

Figure 2*b* shows the number of specimens grouped by collection, where a 'collection' is a group of specimens originally assembled and arranged by a specific individual, then subsequently acquired by Sloane and maintained as a distinct unit within his Herbarium. The largest of these collections are those of James Petiver (17.9%) and Leonard Plukenet (17.9%). Only 3.4% of the specimens in the 'Sloane Herbarium' were gathered by Sloane himself.

Practically, Sloane and the other collectors often combined sets of plants when they bound them in volumes. The survey of the Herbarium revealed that 51 *Horti Sicci* (15%) comprise smaller, discrete components (sub-*Horti Sicci*; Supplemental Material 3). In total, 254 sub-*Horti Sicci* were identified, each containing an average of 95 specimens, ranging in size from 1 specimen (e.g. 'Calceolus Mariae Norway'; HS296f) to 1481 specimens in Kaempfer's collection of Dutch plants (HS213d).

Figure 4 plots simple metrics for each *Hortus Siccus* in their numerical sequence, which closely approximates the chronological sequence in which Sloane acquired and catalogued them (see Supplemental Material 4 for data). The different coloured groupings show the main collections, the acquisition dates of many of which are known: Courten (1704); Plukenet (1710); Browne (1710); Buddle (1715); Duchess of Beaufort (1715?); Petiver (1718); Newton (1718?); Kiggelaer (1722); Uvedale (1738) (Dandy, 1958). Most of the smaller collections (in brown) came to Sloane before 1710.

The number of folios (Fig. 4*a*) and specimens (Fig 4*b*) contained in *Horti Sicci* and the average number of specimens per folio (Fig. 4*c*) differ markedly across the Herbarium. For example, the Mary Somerset collection has consistently fewer folios, specimens, and specimens per page than the Leonard Plukenet collection.

Many collections are well labelled, with most folios (and specimens) supplied with some accompanying information (e.g. the collections of Sloane, Edward Browne, Buddle, Somerset, Miller, Uvedale, Hawkins, Fig. 4*d*), although others such as Kiggelaer are more sporadic in their labelling and still others lack any labelling.

The extent of cross referencing to Ray's *Historia Plantarum* differs markedly across the Herbarium (Fig. 4*e*). In some collections, such as those of Plukenet and Somerset, cross referencing is extensive; for other collections, such as that of Petiver, it is more variable. Many volumes in the Herbarium have no cross-referencing to Ray.

Local names are infrequent (Fig. 4*f*) although Adam Buddle's collection includes many English names, and a number of other volumes include names that suggest future opportunities for researching local plant knowledges across a range of territories.

The extent of recording of people (Fig. 4*g*) and places (Fig. 4*h*) is variable across the Herbarium. No people are recorded on folios for 112 *Horti Sicci,* while geographical data are entirely absent from the folios of 105.

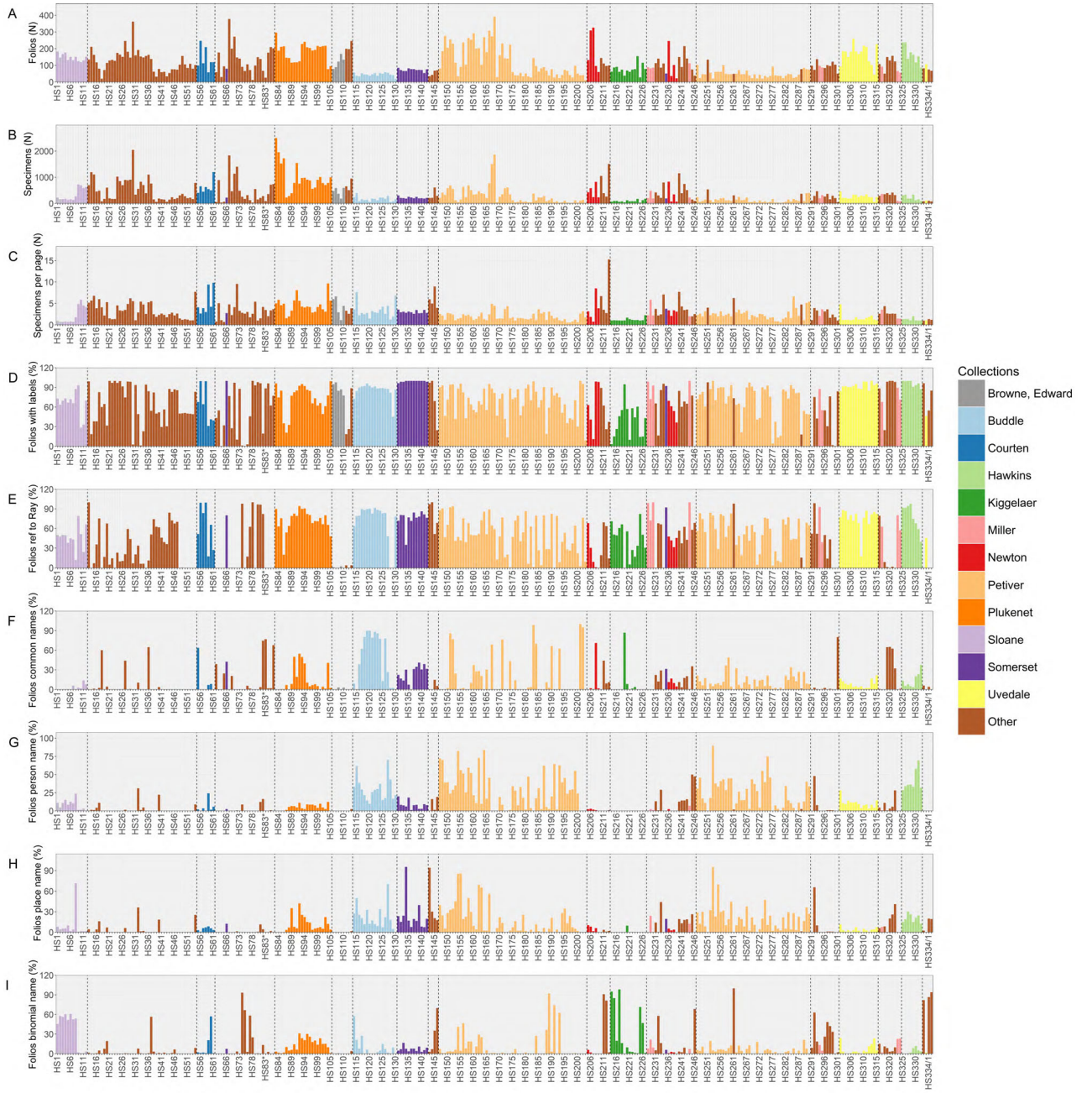

Figure 4. Heterogeneity of the Herbarium. Each *Hortus Siccus is* arranged in ascending numerical order on the x-axis, and each row shows a different metric for each *Hortus Siccus*. The different colours denote distinct collections within the herbarium that were assembled by different individuals. (a) Number of folios. (b) Number of specimens. (c) Number of specimens per numbered page. (d) Percentage of numbered pages with labels. (e) Percentage of numbered pages with cross references to Ray's *Historia Plantarum*. (f) Percentage of numbered pages with vernacular names. (g) Percentage of numbered pages with named 'collector'. (h) Percentage of numbered pages with location. (i) Percentage of numbered pages with Linnaean binomial. The vertical dotted lines group together the larger collections within the Herbarium. Note: the x-axis gives the HS number for every fifth *Hortus Siccus* for clarity. The full data are available in Supplemental Material 4.

Eighty-nine *Horti Sicci* lack data on both people and places. People are recorded most extensively, although inconsistently, in *Horti Sicci* belonging to the collections of Buddle, Petiver and Hawkins. Those collections are also relatively rich in information on places, with Plukenet's collection richer in place data than people data, while for Uvedale's collection the converse is true.

Finally, the incidence of binomial names (Fig. 4*i*), which can serve as a proxy for interest in a collection after Sloane's death, points to the taxonomic or other botanical importance of certain collections, especially those of Sloane, Plukenet and Kiggelaer, and of individual *Horti Sicci* such as those of Kaempfer (HS211) and Catesby (HS212 and HS232). The extraction from Dandy (1958) of data and its subsequent enrichment has identified 264 named people associated with folios. James Cuninghame was identified as a contributor on 526 folios, more than any other individual. Jacob Bobart (328 folios), Richard Richardson (326), Sebastien Vaillant (255), Samuel Doody (233), William Sherard (221), Mathew Dodsworth (212) and Edward Bulkley (210) were also significant contributors.

In total, 181 named places were associated with folios (see Table 1). The greatest number of sites was from Europe (51 sites; Table 1) followed by the United Kingdom (36 sites). There were 721 and 276 folio references to these regions, respectively, with an average of 14 and eight folio references per site, respectively. North America (521 folio references, 15 sites, 35 folios per site on average) had the highest number of folio references after Europe. This was followed by East and Southeast Asia (362 folio references, 18 sites, average of 20 folio references per site) and the Caribbean (352 folio references, 11 sites, average of 32 folio references per site).

Within the Herbarium data set, 4847 folios currently have one or more people associated with them (13%) while 4211 (11%) had one or more places associated with them. There are 2031 folios that have both people and places associated with them. An additional 1308 folios (3%) have been identified as containing names of people that have not yet been recorded despite the incorporation of folio-level data from Dandy (1958) and data enrichment undertaken to date. For 37 *Horti Sicci*, data is missing from a single folio and for 101 *Horti Sicci*, information is missing on ten or fewer folios. HS164 has the largest number of folios with missing people information (100 folios), followed by HS162 (88 folios), HS159 (66 folios), HS156 (65 folios), HS166 (65 folios), HS148 (56 folios), HS160 (55 folios) and HS149 (53 folios).

For place data, the number of folios for which information is not yet recorded is 2784 (7%). These are distributed across 209 *Horti Sicci*. The number of instances of place names missing per *Hortus Siccus* ranges from 1 to 179. Place information is missing from a single folio in 37 *Horti Sicci* and for ten or fewer folios for 141 *Horti Sicci*. Ten volumes contained more than 50 folios with unrecorded place data: HS166 (179 folios), HS162 (126 folios), HS8 (106 folios), HS163 (88 folios), HS151 (78 folios), HS152 (71 folios), HS159 (67 folios), HS134 (63 folios), HS153 (52 folios) and HS322 (51 folios).

Combined data

Figure 5 shows the distribution of georeferenced sites from the Herbarium and Vegetable Substances data. Many of the sites plotted away from continental margins outside of Europe are highly uncertain and correspond with places including 'America', 'Canada', 'Greenland', and 'Brazil'; they do not indicate precise sources of specimens. At a global scale (Fig. 5*a*), the two parts of the collection are sourced from similar parts of the world, with a high incidence of sites in Britain and Ireland, together with Europe, the eastern seaboard of North America and the Caribbean, west Africa, Atlantic and Indian Ocean islands on the trade routes, and the 'East Indies'. However, as the details of sites from Britain and Ireland (Fig. 5*c*) and America (Fig. 5*b*) illustrate, there are considerable differences in named collecting sites between the Herbarium and Vegetable Substances. In Britain, for example the Herbarium has more sites from the north of England and East Anglia represented, whereas the Vegetable Substances have more Midland sources, reflecting the different contributors to each.

Of the 544 people named across the two data sets (Supplemental Material 1), only 64 (11.7%) are known to have contributed material to both the Herbarium and the Vegetable Substances (Fig. 6). Most known individuals supplied specimens which are assembled in just one part of the botanical collections: 231 (42.5%) are named sources solely for the Herbarium; and 249 (45.8%) solely for the Vegetable Substances.

Discussion

The data presented in this paper allow us to estimate the full extent of Sloane's botanical collections for the first time. We show that the Vegetable Substances amounted to approximately 12 750 items as catalogued during Sloane's lifetime, of which 8812 survive. Furthermore, there are 37 852 folios containing a total of 121 506 specimens in the Herbarium. The folio count is 12% lower than previously estimated (Dandy, 1958), which was based on the numbered foliation of each *Hortus Siccus*. This discrepancy reflects both the large number of folios that were apparently removed at various points in the collection's history (especially in parts of the James Petiver material), and the somewhat arbitrary use of both folio and page numbering systems in the constituent *Horti Sicci* which was not considered by Dandy.

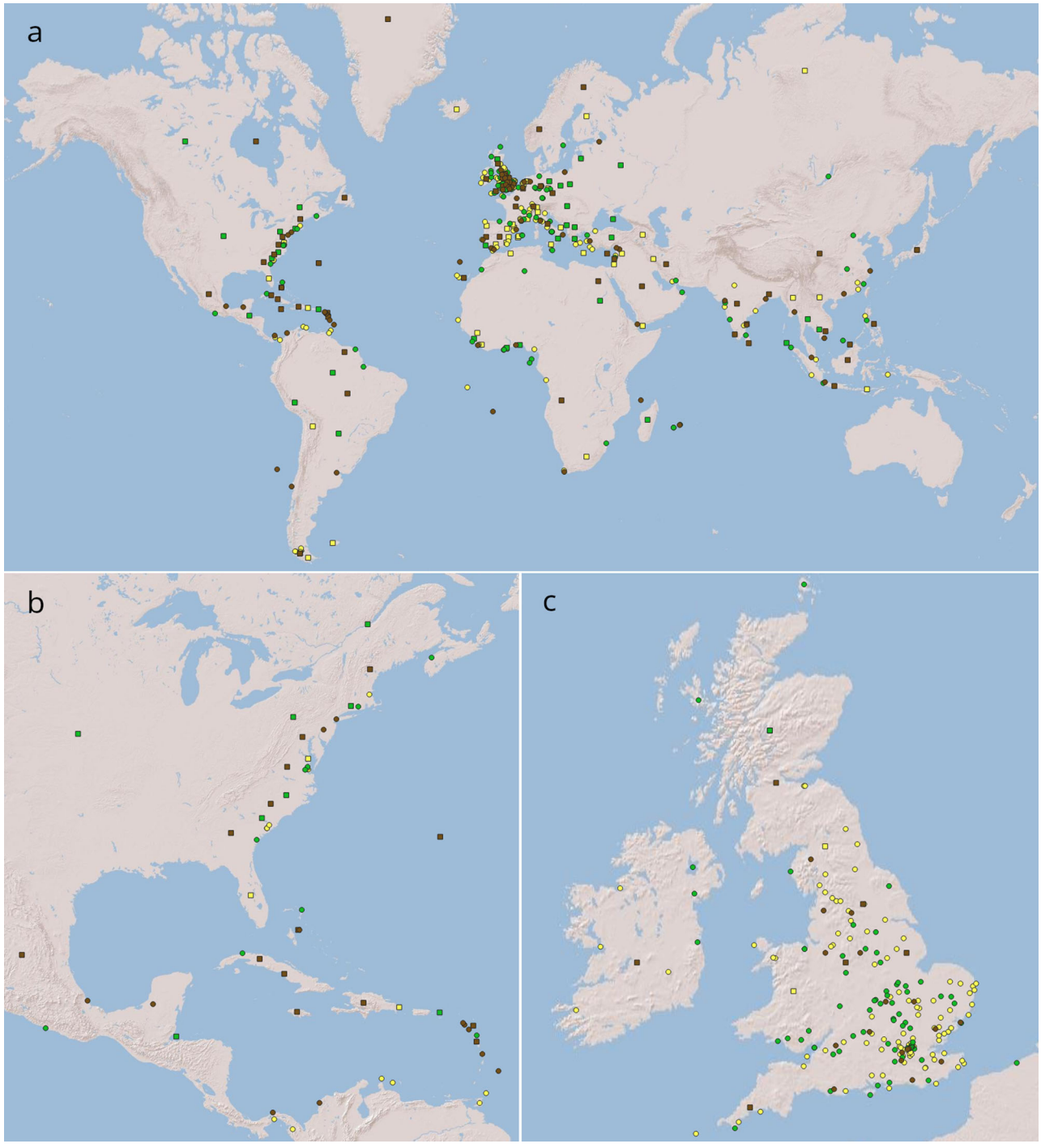

Figure 5. Distribution of named locations within Sloane's botanical collection: yellow, only in the Herbarium; green, only within the Vegetable Substances; brown, found in both parts of the collection. Circles indicate locations with a precision of 10 000 km^2 or less; squares indicate less precise locations. (a) Global distribution. (b) Caribbean and the eastern seaboard of America; (c) Britain and Ireland.

While we give a precise figure, any count of herbarium specimens in the Sloane Herbarium remains an estimate since, for folios on which the labelling of specimens is inadequate or the material integrity of specimens is now poor, it can be difficult to establish with certainty how many specimens are present. Nevertheless, our estimate is remarkably close to that of 120 000 made by James Britten in the early years of the twentieth century as reported in Dandy (1958). This suggests that Britten's survey of the collection had also included a specimen count. The estimate presented here is significantly higher than the 70 000 estimated by

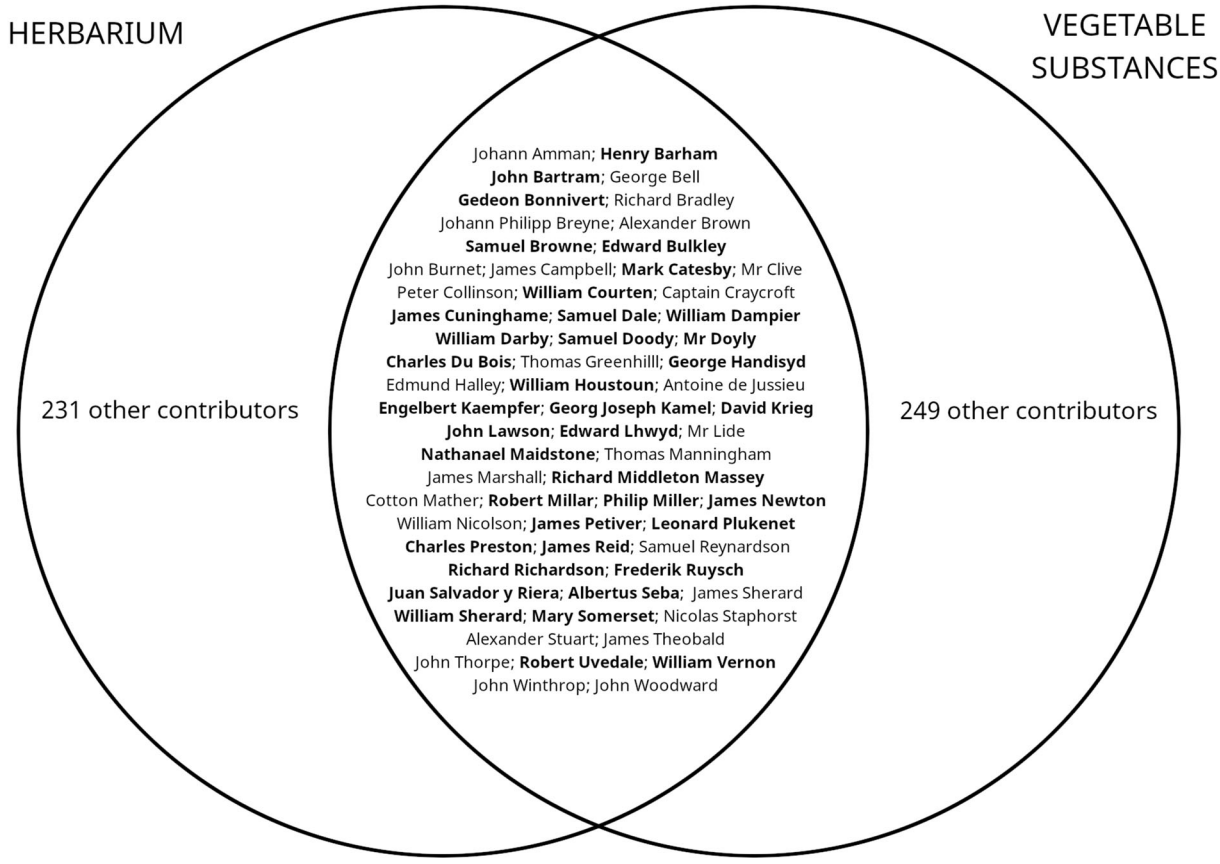

Figure 6. Comparison of the groups of named individuals associated with both parts of the collection. Names in bold are those associated with at least 100 specimens.

Jarvis (2020) based on the Petiver material, wherein blank as well as missing folios are more frequent than in other major parts of the collection. The figure is also significantly lower than the unpublished estimate of William Stearn, but the method used to arrive at that figure is unknown.

Earlier work has indicated that the Herbarium and Vegetable Substances included distinct collections which Sloane acquired from third parties (Cannon, 1994; Dandy, 1958; Pickering, 2016). This current work reveals the extent and granularity of these collections. Whereas Dandy (1958) highlighted 17 collections in bold type in his *Horti Sicci* summaries, we show that there are at least 45 such divisions within the Herbarium as a whole (Fig. 2*b*). Furthermore, the collection of James Petiver itself comprises numerous distinct entities, and many of the 254 sub-*Horti Sicci* identified in this work are yet smaller collections with their own provenance and histories.

The results confirm the significance of the Petiver specimens in the Herbarium (Jarvis, 2020). However, while accounting for 106 of the 337 *Horti Sicci* (31%), Petiver's collection accounts for only 18% of specimens (Fig. 2*b*), a contribution equal to that of Plukenet, the scale of which has not previously been considered comparable.

While there are many distinct collections within the Herbarium, their presence is less frequently observable among the Vegetable Substances (Fig. 2*a*). Sloane's catalogue of these objects shows that there were sizeable groups sourced from the collections of James Petiver, Leonard Plukenet and Nehemiah Grew. Alongside these were smaller assemblages of items from the other collections recognized, as well as items marked with an abbreviation, possibly designating a collection from which they derived (e.g. 'B.', 'H.', 'O.', 'M.', and 'S.C.'). The different frequency of collections within the Herbarium compared with the Vegetable Substances may be related to the physical differences between the two over-arching collections themselves. Herbaria were a well-established technology for the long-term preservation of botanical specimens by the late seventeenth century when Sloane started to assemble his collection (Cristofolini, 2024; Flannery, 2023; Thiers, 2020).

'Cabinets of curiosities' that were broader in scope, flourished in the sixteenth and seventeenth centuries (Impey & Macgregor, 1985; Zytaruk, 2011), and Sloane was also not alone among his contemporaries in possessing samples of *materia medica* preserved in trays (Duffin, 2019). However, and in contrast to the Herbarium, it would appear that other substantial collections of vegetable substances were not available for Sloane to acquire and assimilate.

Sloane's innovation in developing an apparently unique method for the preservation of botanical samples may also have been significant. The sealed wood and glass boxes that house much of the surviving Vegetable Substances enable close examination while also preventing damage from insect pests or mishandling. The method developed by Sloane—though costly in resources and labour—was, as Jarvis et al. (2012) suggested, a 'clever solution to the curators' dilemma of allowing access but ensuring long-term preservation'. No collections comparable to the Vegetable Substances survive among the large, early modern botanical collections held in Oxford (Clokie, 1964; Serena Marner, pers. comm). Sloane's innovative approach to the storage of barks, seeds, fruits and similar plant samples that were not amenable to preservation in herbaria, may have been essential for the long-term preservation of a collection of such materials.

It is notable that, among the surviving Vegetable Substances, samples stored in *materia medica* trays, while dispersed throughout the collection, are most evident among the earlier-numbered entries (Fig. 3). This could suggest a shift in Sloane's preservation method as his collection developed, perhaps as the scope of the collection broadened. Further analysis of the location codes in the Vegetable Substances (Fig. 3) might provide additional insights into the relationship between storage technique and their long-term preservation.

While Sloane's storage solution may have facilitated the long-term survival of specimens, only 62% of entries in the Vegetable Substances catalogue currently have surviving specimens associated with them (Table 2). Explanations for this absence are likely several-fold. In some cases, specimens may have been lost, destroyed or misplaced during Sloane's own lifetime, for example if they were damaged by insects or fungi. Losses may have occurred during moves of the collection that have taken place since 1753. It is known that some wood specimens were disposed of to the Royal Botanic Gardens, Kew and World Museum, Liverpool when NHM closed its xylarium. Dispersal within NHM may also be a factor. Some of Sloane's Vegetable Substances are dispersed across the Palaeo- and neobotanical collections that are stored separately. Few palaeobotanical specimens collected by Sloane are documented but others may survive that have not been attributed to Sloane. In the case of the neobotanical collections, some Vegetable Substances have been curated taxonomically in the main carpological collection. Indeed, Vegetable Substances are still occasionally found among those collections and reunited with the rest of the collection although the number that remain is likely small.

Finally, the loss of specimens and of data as a result of bomb damage to the botanical collections in 1940 is also a contributing factor. Over one thousand specimens in the collection do not have a Vegetable Substances number associated with them. In some cases, they are in decorative boxes and may represent samples being processed towards the end of Sloane's life. However, others are fragmentary, bomb-damaged specimens for which the label data is lost, meaning that they cannot be linked to the Vegetable Substances catalogue. This may explain why so few of the samples in the catalogue number range VS 2651 and VS 3550 survive (6%), in contrast to the 62% that survive overall.

The results presented in this paper indicate the highly heterogeneous documentation and management of Sloane's botanical collections, across both the Herbarium and Vegetable Substances (Figs. 3 and 4). In the Herbarium, some collections are well labelled, with most folios (and specimens) supplied with some accompanying information (Sloane, Edward Browne, Buddle, Somerset, Miller, Uvedale, Hawkins), while others are irregular and sporadic in their labelling (Fig. 4*d*). This latter group typically comprises *Horti Sicci* containing plants from places which were hitherto poorly documented by European botanists (e.g. many of Petiver's *Horti Sicci*, and those of Kiggelaer), but also include collections from European sites that are simply unlabelled, or those from horticultural sources (e.g. plants from the Leiden physic garden (HS31), and a small collection of tulips (HS64)). The data accompanying specimens varies markedly. While some are rich in information with details of the site of collection, the collector, uses and local names, others lack this information.

For the Vegetable Substances, the act of describing individual specimens in the catalogue allowed for a systematic management of information relating to botanical material that came to Sloane by a variety of means, albeit with considerable variation in detail, as is evident by the variation in the length of descriptions (from 1 to 350 words). While the manuscript catalogue describes the contents of boxes, a proportion of specimens have additional labels that include more information (such as references appearing in William Courten's cipher, e.g. VS 5092; and VS 1510/VS 1688).

In both his Herbarium and the Vegetable Substances, Sloane was managing the organization of knowledge that came from different sources. Information may have been directly associated with specimens, in accompanying lists or embedded in sources such as correspondence. That the collections were assembled by dozens of individuals, with varying expertise, different ways of collecting and for different ends is evident from the highly heterogeneous data that is associated with the collections.

The heterogeneity of data accompanying the collections that Sloane acquired may also have shaped how Sloane and his assistants assembled the taxonomic catalogue to the Herbarium using Ray's *Historia Plantarum*. When a *Hortus Siccus* contained a low proportion of folios cross-referenced to Ray's *Historia Plantarum* (Fig. 4*e*), it may indicate a group of specimens which were difficult to determine, or which required more work. It could also suggest a low priority for a given *Hortus Siccus*, especially in the earlier part of the sequence (e.g. a collection of plants from Holland, HS48–53, and those from Edward Browne). However, pragmatism may also have played a part. Those parts of the collection most extensively cross-referenced include collections that were already arranged according to Ray's taxonomy (e.g. Uvedale), those that were made up in large part from relatively well-known floras accounted for in the *Historia Plantarum* (e.g. Buddle), and those created by individuals whose published taxonomic works were incorporated into the *Historia Plantarum* (Petiver, Plukenet). Assimilating the details of those specimens into the taxonomic index would have been comparably straightforward. Given the scale of the task of cataloguing the entire collection, this could reflect a pragmatic collections management approach that largely obviated the need for the critical determination of specimens on the basis that their arrangement already observed the sequencing of plants in Ray's work (and in some instances formed part of the taxonomic basis of Ray's text).

Though the numbering sequence of the *Horti Sicci* broadly follows the order in which Sloane acquired the various collections, the folio survey and associated archival research have revealed a more nuanced history of the Herbarium. Sloane never reorganized his Herbarium at scale, but he clearly worked with and managed it throughout his life. This is most evident in the data among what we have termed the 'sub-*Horti Sicci*', the discrete, smaller plant collections which were often combined and bound together. The most obvious of these are various groups of specimens from Petiver's collections, which were acquired by Sloane in 1718, and were still being worked on in 1753. For example, there is Petiver material collated with otherwise very early *Horti Sicci*, such as HS11b (Samuel Browne specimens from Madras), and HS32b-f (including specimens from India, Asia and Africa). Similarly, the small collection of plants from Smyrna (İzmir) supplied by William Sherard in 1705 were added by Sloane to the much earlier collection in HS17 (see also Jarvis, 2020).

Some analogous management activities can also be seen in the Vegetable Substances. For example, items described as originally being part of Petiver and/or Plukenet's collections, are found scattered throughout the catalogue, suggesting that it took many years to incorporate these objects into the Vegetable Substances. Furthermore, when Sloane acquired objects that appeared to him to be the same as previously catalogued items, he often metaphorically combined them in the same container by cross-referring the entry to a single, 'originary' object that had already been sealed closed. In one case, 12 distinct catalogue entries point to a single object. Where this was done, cross referencing to entries describing the other gatherings was typically included in the catalogue. Sloane's management of 'duplicate' material, in this way, however, was inconsistent since he did not always place objects he described as 'the same' in one box, as both the inventory and transcription show. The International Code of Nomenclature for Algae, Fungi and Plants (Turland et al., 2018) defines a specimen as 'A gathering, or part of a gathering, of a single species or infraspecific taxon, disregarding admixtures, mounted either as a single preparation or as more than one preparation with the parts clearly labelled as being part of the same specimen or bearing a single, original label in common'. Such a definition is evidently not applicable to all of Sloane's Vegetable Substances. For natural collections from this period that may combine material from different people and places, there may be ambiguity in applying a distinct, modern, concept of 'specimen'.

Similar uncertainty may also be found in people and place data. Multiple names may be attached to a specimen, indicating either the range of people from which it was sourced or reported, or the places where it was observed. This can render the provenance of the preserved object unclear, as is the case with the *Luzula* from 'Geneva & Montpellier' in Petiver's European collection (HS147, f. 89).

When the names of individuals and places are mentioned on folios in the Herbarium, these are typically in collections comprising specimens from many different sources and suppliers, though even then they are often incompletely recorded (e.g. in the collections of Petiver, and especially Plukenet and Uvedale). The practice of recording provenance information for each specimen

was not universal; plants raised from seed in horticultural collections in Europe rarely detail the source, and some *Horti Sicci* of complex provenance may bear almost no information at all (e.g. 'plants gathered in Several places of the Indies &c.'; HS76). For the Vegetable Substances, place data is missing for 64% of entries and details of people from 61%. This means that summaries and analyses of people or places relate to a subset of the material and are not in reference to the collection as a whole.

This limitation notwithstanding, the data presented in this paper highlight the broad geographical patterns of natural history knowledge exchange and extraction. While Britain and Europe were significant sources for material in Sloane's botanical collections (Table 1), wider global connections to eighteenth-century European trading networks—including economies predicated upon enslavement—are clearly evident (Fig. 5). As Murphy (2023) has shown, 'the infrastructure of long-distance trade, including its routes, personnel, and systems of trust and credit, made possible the extraction and transportation of flora, fauna, and natural knowledge'. Among the Vegetable Substances, Caribbean provenance appears in 937 entries, the largest source, while over 500 entries describe places in colonial North America. Such specimens and natural history observations would have been regularly transported alongside enslaved people as part of the British transatlantic trade.

Unlike other commercial vessels, a slave ship typically included a surgeon and his mate (assistant), both of whom might well collect natural historical materials (Murphy, 2023). As part of these trading routes, collections were made in West Africa, represented in the VS data by 98 catalogue entries referring to localities in that region. This includes objects collected 'From the Duke of Chandois who had it from Guinea' (e.g. VS 8119). James Brydges, 1st Duke of Chandos (1674–1744), was one of the Royal African Company's most powerful investors (Murphy, 2023). The 21 catalogue entries for the specimens he contributed contain detailed information on plant names and uses in West Africa (Pickering et al., 2023), with an average length of 78 words, considerably higher than the nine-word average word length across the VS catalogue as a whole. The Royal African Company sought to diversify its income streams following the loss of its monopoly on the trade in enslaved peoples in 1697. One focus was the potential to exploit useful plants (Murphy, 2023). The specimens contributed by Brydges and the descriptions of them are a direct result of that endeavour.

Similarly, significant numbers of specimens were collected along trading routes in the Indian Ocean world. For example, over 800 Vegetable Substances originated from East and Southeast Asia, 500 of which are described as from the 'East Indies', i.e. along the trading routes used by European powers. Of the *Horti Sicci*, 48 (14%) contain East Indies plants, rising to 66 *Horti Sicci* (20%) if we include the Cape of Good Hope, a Dutch colony in southern Africa at the western limit of the British East India Company's commercial monopoly. The British and Dutch East India Companies both operated as colonial (as well as commercial) enterprises, their trading success predicated upon establishing 'Factories' in strategically chosen ports (notably in India by the English Company and Indonesia by the Dutch East India Company) before securing political control over entire territories. The majority of East Indies specimens in Sloane's collection represent areas settled by these two Companies; indeed, acquiring knowledge about the diversity, properties, and cultivation of regional flora was fundamental for European colonisers (Subramaniam, 2024). This supported the creation of essential infrastructure (not least building materials and subsistence agriculture) and identified new goods for the market (medicines and foodstuffs especially). Moreover, enslaved labour was directly employed at and moved between European factories across the continent: at least 449 800 enslaved persons from South and Southeast Asian as well as from East African communities were forcibly transported around the Indian Ocean by European merchants between 1500 and 1800. The true figure is probably higher by several factors (Allen, 2015). Not only might these labourers have contributed their own plant knowledges on occasion (Winterbottom, 2016), their work surely made viable the settlements where prominent naturalists including Edward Bulkley, Samuel Browne, and James Cuninghame made many of their botanical collections.

Over 500 named individuals are known to have had some role in the gathering, sourcing and transmission of the plant materials that are now in the Sloane botanical collections (Fig. 6). Yet, the groups of individuals who supplied specimens for the Herbarium and for the Vegetable Substances were really very different. Surprisingly, only 12% of these people are represented in both parts of the collection, and of those who are, many are associated with only a limited number of specimens (e.g. 'Captain Craycroft', Cotton Mather, George Bell, John Thorpe), or predominantly contributed to just one part of the collection (e.g. Albertus Seba, James Theobald, John Woodward). Many of the significant collectors are represented in either just the Vegetable Substances (e.g. Nehemiah Grew, Peter Hotton, John Lowther), or just the Herbarium (e.g. Christopher Merrett, Franz Kiggelaer, George London). These differences may be due to the particular collecting

interests of a given individual, or the instructions given to them (Burnett, 2023; Carey, 1997; Coulton, 2024), but they are also shaped by the different practical requirements of pressing, drying and transporting herbarium specimens, compared with gathering and transmitting seeds and barks. Technically, the latter could easily be placed in a small twist or fold of paper and enclosed within a letter, or contained in a small parcel. In turn, the different logistical and infrastructural requirements in creating and then sending large fragile plant specimens on paper sheets around the world may have informed an individual's choice about what sorts of objects they collected and sent to Europe (Nadim et al., 2024).

The current work has demonstrated that there are thousands of instances where details about the provenance of specimens in Sloane's botanical collections was not reported, or else was recorded obscurely. These range from information that would have been available to Sloane, or is associated with the objects themselves, through to details that can now be determined using other methods. Provenance omissions from Dandy (1958) that can now be supplied include place names associated with a number of specimens, many of which are from England, such as among Adam Buddle's collection, and some of James Petiver's *Horti Sicci* (e.g. the three-volume *Hortus siccus Anglicanus*), though are also to be found in some European collections (e.g. the *Hortus siccus Hispanicus* (HS166)) and occasionally elsewhere, such as the grass from 'Cap. Comorin' at the southern tip of India in the Plukenet collection (HS93, f. 187). Other Dandy omissions include the provenance data that William Courten added to his collections in his own cipher (e.g. in HS55, HS57, HS59, HS61).

For the thousands of objects in Sloane's botanical collections, these data help to shape a sense of the constituent collections, such as the 'great many' of Georg Kamel's plants that form a distinct group within one of the volumes of Petiver's collection (HS165b). Nevertheless, these data relationships barely hint at the complex interactions, exchanges and ambitions within which Kamel's specimens have been framed and understood (Kroupa, 2015, 2019). A full understanding of the objects requires a familiarity with the 'cultures of collecting' in which they were gathered, organized, managed and discussed (Driver et al., 2021; Marples & Pickering, 2016).

Both the Herbarium and the Vegetable Substances include details of local plant names and uses. This demonstrates that local plant knowledge and expertise was utilized in the gathering and documenting of the specimens, though the names (or even presence) of the people imparting such information is rarely visible. Rarely, the name of a non-European collector can be determined from other sources, as is the case with Genemon Imamura who gathered the Japanese plants in HS211 for Engelbert Kaempfer (Bodart-Bailey & Massarella, 1995, p. 40). Equally rarely, an individual may be mentioned, though not named, such as the 'Indian druggist' from whom 'Dr Adair' received 173 specimens now among the Vegetable Substances. But, for the most part, the agency of indigenous people and enslaved people in the making of these collections remains invisible, or at best implicit. Other sources and methods will be required to understand those plant knowledge-worlds and labour.

Conclusion

The creation of these datasets has only been possible as a result of a close, physical engagement with the objects themselves. This process has served to underscore our appreciation that, valuable as these data are for interrogating and analysing these collections, they are only partial proxies, and omit or obscure many facets of the contexts and histories of the specimens themselves. At the same time, these data suggest opportunities for new research and collaboration. These are difficult collections to work with, which challenge conventional assumptions about provenance, specimens and the nature of collecting, and inevitably require multi-disciplinary approaches. As we have worked with the objects and the data, we have often reflected on what we invariably do not know: about the rationale and justification for making these collections; the political, economic, geographic, social, cultural and temporal constraints on collecting; and the many unnamed individuals who have had agency in gathering plant materials and mediating them prior to our own work.

This parallel working on the collections, as both digital and archival objects, draws attention to how their physical and material form is an essential facet without which understanding of their contexts and histories would be incomplete. Early modern collections present particularly significant challenges to the delivery of data that conform to the expectations of biodiversity data. If most future users encounter biological specimens as digital (image) objects, there is a risk that these material contexts and histories will barely be discernible. We must therefore aspire to support the addition of such contextual metadata to developing models of the 'extended specimen' (Lendemer et al., 2020; Webster, 2017).

These data are a step towards better understanding the specific colonial and other contexts in which these collections were assembled. The data also raise new

questions about the nature of Sloane's collections. Why is there so much variation in the extent of provenance data recorded? Why is there so little overlap between those individuals who contributed Herbarium specimens and those who contributed Vegetable Substances? And, to what extent can we even consider a 'specimen' in Sloane's botanical collection comparable with a modern botanical specimen?

To date, while records of surviving Vegetable Substances have been made available through the dataset described here, only ca. 7% have associated images. For the herbarium, just over 2% of specimens have been data-based and imaged, with the focus on nomenclaturally significant parts of the collection (HS1–7, Sloane's collections from Jamaica; HS211, Kaempfer's plants from Japan; HS212 and HS232, Catesby's plants from Carolina and the Bahamas; HS332* and HS334, Bartram's plants; see ca. for specimen records). The data presented in this paper provide a framework for further digitisation and imaging of the collection. Furthermore, they begin to make the collections visible, not only to botanists, but also potentially to diverse global stakeholders and publics, thereby helping to facilitate mutually productive collaborative work (Kaiser et al., 2023; Mabry et al., 2024).

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Authors' contributions

Following the Contributor Role Taxonomy (CRediT): BS, VP, MC led on Conceptualization, Data curation, Investigation, Methodology, Formal analysis and Writing – original draft; MC, JN and RC were responsible for Funding acquisition, Project administration and Supervision; all authors contributed to Writing—review & editing.

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