

FROM THEORY TO PRACTICE: A PHOTOGRAPHIC INVENTORY OF MUSEUM COLLECTIONS TO OPTIMIZE COLLECTION MANAGEMENT

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Abstract.—The digitization of museum specimens is a key priority in the Digital Era. Digital databases help to avoid unnecessary manipulation hazards to delicate collections, increase their accessibility to third party researchers, and contribute to the ongoing documentation of global biodiversity. Time, workforce and the need of specialized infrastructures limit the processing of the vast number of specimens in natural history collections. Cheaper, easy-to-use methods and volunteer programs are developing quickly to help bridge the gap. We present the results of combining citizen science for the digitization of an entomological collection in conjunction with the cooperation of a taxonomic expert for the remote identification of samples. In addition, we provide an assessment of the avoided monetary costs and the time needed for each step of the process. A photographic inventory of specimens belonging to the leaf beetle genus *Calligrapha* was compiled by volunteers using a low-cost compact camera and the species were identified using these images. Using digital photographs allowed for a rapid screening of specimens in the collection and resulted in an updated taxonomic identification of the *Calligrapha* collection at the Royal Belgian Institute of Natural Sciences. The pictures of the specimens and their original labels, as well as the new information from this endeavor were placed in an online public catalogue. This study demonstrates a worked example of how digitization has led to a practical, useful outcome through cooperation with an end user and highlights the value of museum collection digitization projects.

Key words: Mass digitization, Volunteers, Collections, Stakeholder Engagement, *Calligrapha*

INTRODUCTION

In the Digital Era, one of the challenges that museums must face is being able to sort and digitize the vast number of specimens stored in their repositories. Many different approaches are being implemented toward this end, including projects run by museum staff (Mathys et al. 2015) and projects which rely on volunteers (Holmes 2003; Flemons and Berents 2012). Considering the dimension of the problem and the typically reduced number of staff in museums, the latter is a promising solution. However, the digitization approach is still dependent on the infrastructure and equipment available to the institution, which can be expensive (Brecko et al. 2014) and generally not available to a sufficient number of volunteers. Recently, the image quality and speed necessary for macro photography have improved significantly in compact camera technology (see e.g. Pratt 2015), allowing for low-budget approaches to museum collection digitization (Mertens et al. 2017).

Thus, the combination of cheaper and easy-to-use methods and volunteer programs holds the potential for fast and qualitative mass digitization.

Photographic inventories of specimen collections and curated collection of individual specimen photographs with any accompanying taxonomic or geographic data hold great potential for the documentation of biodiversity. Such inventories aid in species recognition and identification and provide with permanent digital copies of the specimens for future generations (Joger 2018). This could increase accessibility of museum collections to third party researchers via online platforms or shared digital storages, and augment the documentation of biodiversity in general (Beaman and Cellinese 2012).

One traditional way to sort and identify collection material involves loaning of relevant specimens to an expert, usually upon the expert request and related to a systematic revision, and restoring the specimens to the collection once they have been studied. Although

convenient for the expert, there are several disadvantages to consider: (i) it takes time, effort and costs of personnel to sort the material to loan, prepare the parcels and carry out the administrative procedures, including loan forms and registries documenting the loan and subsequent follow-up; (ii) shipping specimens incurs the risk of losing parcels, damaging or even destruction of often irreplaceable and valuable specimens; and (iii) the shipped material might not all be relevant for the expert and, in any case, any of the specimens on loan remain unavailable for other experts. Alternatively, the experts can visit the institute, but it is generally a less cost-effective option since one needs to consider expenses related to accommodation and travel. Although these traditional approaches have advantages for taxonomic research, including the possibility to study the specimens up close for good taxonomic practice, screening of specimens for collection sorting via a photographic inventory can avoid shipment of specimens and avoid unnecessary research visits.

Even though several articles have been published about the advantages and approaches to specimen digitization (Blagoderov et al. 2012; Smith and Blagoderov 2012), few focus on examples where digitization has led to a practical outcome by cooperation with an end user (Barber et al. 2013). In this article, we show the results of implementing crowd sourcing in an efficient manner to help the digitization of entomological collections in immediate cooperation with a taxonomic expert for collection organization. A coupled digitization-identification workflow can create a mutually beneficial platform whereby the institute gains immediate feedback on species taxonomy and the researchers (including third party researchers and the public) have easy access to specimen data, while avoiding unnecessary risks to specimens for collection organization (instead of taxonomic research). We describe the results of the digitization of *Calligrapha* specimens in the form of a specimen list and dorsal photographs of the specimens, as well as an assessment of the monetary cost avoided with the use of specimen digitization and give an estimation of the time needed for each step of the process. The applicability of such a workflow is discussed for other insect collections including other taxonomic groups.

METHODS

Taxonomic choice

To assess the feasibility of a digitization-identification workflow, we specifically selected a spe-

cies-rich taxon with species that can be identified reliably based on photographic material. We therefore opted to digitize the specimens of the leaf beetle genus *Calligrapha* Chevrolat (Chrysomelidae) from the collections in the Royal Belgian Institute of Natural Sciences (RBINS), see Figure 1. The genus *Calligrapha* currently comprises some 130 species and it is distributed from Alaska to Argentina (Montelongo and Gómez-Zurita 2014). Most species in this genus display a striking character, a contrasting pattern of intricate dark and pale markings on the elytra. These markings have recently been shown to hold strong systematic value (Montelongo and Gómez-Zurita 2014). For the purposes of this project, the elytral markings are extremely useful for the identification of the majority of species, thus eliminating the need for genitalia dissection, the typical ‘gold-standard’ for beetle species identification (Richmond et al. 2016). Every specimen in the collection was identified remotely using digital photographs by one of the authors (JGZ), an expert in the taxonomy of the group.

Specimen digitization

For an overview of the followed digitization flow, see Figure 2. Every specimen was photographed from dorsal, lateral and frontal views using an Olympus TG4 digital camera with focus stacking functionality. This rugged point-and-shoot camera has an in-camera focus-stacking feature with two stacking methods: internal stacking (in which a stacked picture is constructed by an internal stacking algorithm in the camera, based on a total of 10 pictures) and focus bracketing (in which the camera can take up to 29 pictures, which have to be stacked manually afterwards by means of external software). This camera is on the market for approximately US\$400, some eightfold cheaper than a professional setup for photo-stacking used in documentation of collection specimens (for a comprehensive review of this method and a comparison with a professional Canon-Cognisys setup, see Mertens et al. 2017). Since the focus-bracketing feature allows for sharper pictures (Mertens et al., 2017), we chose to use this method over internal stacking. Pictures of the specimens were manually stacked using Helicon Focus software (HeliconSoft Ltd., Kharkiv, Ukraine), which has a one-time license fee of approximately US\$ 120.

Original specimen labels were photographed and digitized as well, although for the majority of the specimens, some important information (such as



Figure 1. Whole-drawer photograph of one of the trays with *Calligrapha* specimens as found in the Royal Belgian Institute of Natural Sciences.

locality, collecting date and collector) was missing, as is often the case for labels of historical insect voucher specimens. Despite the lack of this information, the catalogue of these specimens and their identifications are included in the results for archiving purposes. Photographs were made available to JGZ via a Google Drive folder where all specimen photographs and label data were given specific IDs by the taxonomist. After identification, the pictures and data were made publicly available online at the RBINS online database¹.

Workflow assessment

To help assessing the cost-effectiveness of the digitization-identification workflow, we quan-

tified the amount of time needed for each of the steps described above (taking photographs, manual stacking, label digitization, species identification), as well as the overall cost of the project (e.g. equipment material, transportation cost of the volunteers).

RESULTS

Workflow assessment

In all, 529 specimens of *Calligrapha* stored in the RBINS were digitized (Figure 3 shows the dorsal views of one specimen per species). As there were four photographs taken per specimen, 2,116 pictures were taken in total. This number is a conservative estimation as some specimens had to be photographed a second time (e.g., because some parts of it were out of focus). It required two volunteers (working separately) an estimated 100 working hours

¹<http://collections.naturalsciences.be/ssh-entomo/collections/be-rbins-calligrapha-chevrolat-1836>.

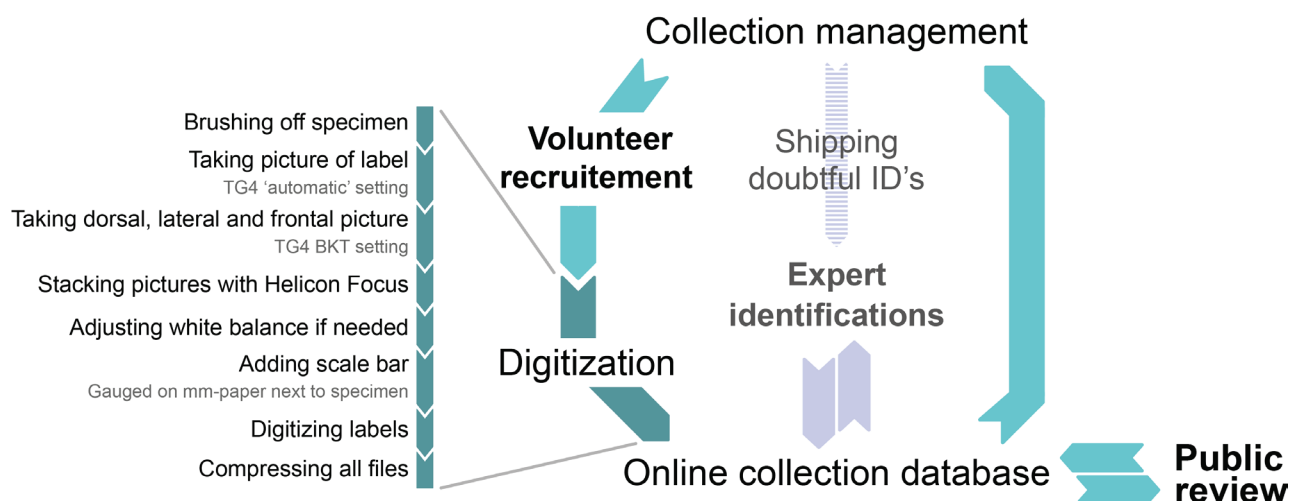


Figure 2. Scheme of the digitization-identification workflow. After an expert offers help with collection management, museum staff screens the collections for relevant material. After recruitment of volunteers, the digitization step starts with brushing off the specimens and taking pictures of the labels and all relevant angles of the specimens (here dorsal-lateral-frontal). Resulting stacked pictures get adjusted if needed and labels get digitized in a database. After the expert receives the pictures, she/he can remotely aid in identifications and collection sorting. Any more unidentifiable specimens can then be shipped to the expert if needed. Additionally, all of the data can be made available online instantly, where they can be double-checked by public review.

or 12 working days, to take all the photographs. The manual stacking using the Helicon software took eight hours, and label digitization another 14 hours. For most specimens in the collection (80%), identification only required looking at the dorsal pictures and the whole process of downloading the picture, identifying the species and writing down the identification in an Excel file took approximately 15-20 seconds per specimen. The remaining specimens required checking lateral pictures as well, to confirm identifications based on elytral spots close to the border of the elytron; in these cases, the whole process took an additional 5 seconds to finish. We estimate that the net amount of time devoted to species identification and cataloguing of the entire collection took approximately 3 hours of work.

The highest monetary costs for the project were related to the acquisition of the required equipment, namely the camera setup (US\$400) and a Helicon software license (US\$120; see Mertens et al. (2017) for a detailed cost description). However, this was a once-off investment rather than a recurring expense which should be amortized relatively easily, as the equipment may be used in subsequent projects. Additional costs were related to the transportation of volunteers to the museum (in our case, US\$170, but this is highly dependent on mode of transportation, distance traveled, age of volunteers, and other factors). For the steps of the procedure

involving specimen identification, the cost for one expert to travel to Brussels to do the identification *in situ* (avoided thanks to our digitization setup) would have not been trivial, and it is estimated as: (i) a plane return ticket Barcelona-Brussels (US\$150); and (ii) two/three days accommodation for the visiting taxonomist (US\$500-800). This cost may even have to consider the equivalent of three days salary for an expert assessment when taxonomic work has a service component. These avoided costs are very much circumstantial, but could be easily estimated in the range of several hundred dollars per day (ca. US\$300-350). Moreover, several other non-trivial costs involving curatorial work for the collection and institution that houses the specimens were avoided. These are estimated as: (i) a salary for one full day to search, select and prepare 529 specimens (ca. US\$250-300); and (ii) the cost to send the parcel by registered airmail (in our case, to Spain, this would be estimated at US\$200, but it depends on the chosen package delivery service). In summary, we estimated the avoided costs for this project to be in the range of US\$1400-1800.

Catalogue of Calligrapha at RBINS

In the original classification of *Calligrapha* at the RBINS, 39 taxa were considered. However, after the remote taxonomic reassessment of the specimens by the specialist, the new total was of 47 species and



Figure 3. Dorsal photographs of the species of *Calligrapha* in the RBINS collections. (a) *C. aeneopicta*; (b) *C. alni*; (c) *C. amelia*; (d) *C. ancoralis*; (e) *C. annulata*; (f) *C. apicalis*; (g) *C. argus*; (h) *C. bajula*; (i) *C. bidenticola*; (j) *C. californica coreopsivora*; (k) *C. confluens*; (l) *C. curvilinea*; (m) *C. dislocata*; (n) *C. diversa*; (o) *elegantula*; (p) *C. felina*; (q) *C. fulvipes*; (r) *C. geographica*; (s) *C. ignara*; (t) *C. knabi*; (u) *C. labyrinthica*; (v) *C. limbaticollis*; (w) *C. lunata*; (x) *C. lunata hybrida*; (y) *C. matronalis*; (z) *C. multiguttata*; (A) *C. multipunctata bigsbyana*; (B) *C. limbaticollis*; (C) *C. nupta*; (D) *C. pantherina*; (E) *C. percheroni*; (F) *C. philadelphia*; (G) *C. polyspila*; (H) *C. praecelsis*; (I) *C. pruni*; (J) *C. ramulifera*; (K) *C. rhoda*; (L) *C. rowena*; (M) *C. scalaris*; (N) *C. serpentina*; (O) *C. serpentina temaxensis*; (P) *C. sigmoidea*; (Q) *C. spiraea*; (R) *C. sponsa*; (S) *C. suffriani*; (T) *C. verrucosa*; (U) *C. vicina*; (V) *C. vigitimaculata*.

two subspecies (excluding five specimens which cannot as yet be identified to species level). The discrepancies between the old and new classifications were due to misidentifications (33.46%), naming of unidentified specimens (0.01%) and correction of old, invalid names (0.04%) rather than altered taxonomic status. We provide a catalogue of the specimens in the collection to the lowest taxonomical level as possible. The original labels can be found online at the RBINS online database.

***Calligrapha aeneopicta* Stål, 1859** (Fig. 3a)

CHILE: 2 specimens, Coll. Chapuis. MEXICO: 1 specimen Jalapa, Höge. 1 specimen, Genin. 1 specimen, Ghiesbrecht. UNKNOWN: 1 specimen, 1885, Restité. 3 specimens, Coll. Duvivier.

***Calligrapha alni* Schaeffer, 1928** (Fig. 3b)

CANADA: 3 specimens, Env. De Quebec, Provanchers. 2 specimens, Saguenay, V. Huart. USA: 3 specimens, Bayfield Wisconsin, Wickham. 1 specimen, D. Leconte, Coll. Chapuis. 1 specimen, Coll. Chapuis.

***Calligrapha amelia* Knab, 1909** (Fig. 3c)

USA: 1 specimen, California, 1937, F. Heylemans. 2 specimens, Massachusetts. 3 specimens, Springfield, Massachusetts, Dimmock.

***Calligrapha ancoralis* Stål, 1860** (Fig. 3d)

MEXICO: 1 specimen, Ventanas, Durango, Höge.

***Calligrapha annulata* Jacoby, 1903** (Fig. 3e)

BOLIVIA: 1 specimen, Restité, 1885.

***Calligrapha apicalis* Notman, 1919** (Fig. 3f)

UNKNOWN: 1 specimen, Coll. Duvivier.

***Calligrapha argus* Stål, 1859** (Fig. 3g)

GUATEMALA: 4 specimens, Chacoj, Vera Paz, Champion. MEXICO: 3 specimens, Coll. Chapuis. UNKNOWN: 1 specimen.

***Calligrapha bajula* Stål, 1860** (Fig. 3h)

EL SALVADOR: 1 specimen, El Boqueron (San Salvador), vii/1959, J. Béchyne.

***Calligrapha bidenticola* Brown, 1945** (Fig. 3i)

CANADA : 1 specimen, Ottawa, vi/1949, R. de Ruelle. USA: 2 specimens, Illinois. 1 specimen, Massachusetts. 1 specimen, New York, Coll. Chapuis. 1 specimen, Philadelphia, Coll. Chapuis. UNKNOWN: 1 specimen, Restité, 1885. 1 specimen, Candèze, Coll. Chapuis.

Calligrapha californica coreopsivora

(Linell, 1896) (Fig. 3j)

USA: 1 specimen, Illinois, Coll. Chapuis.

***Calligrapha confluens* Schaeffer, 1928** (Fig. 3k)

CANADA: 2 specimens, Quebec, Provanchers. 2 specimens, Saguenay, 1876, V. Huart. 2 specimens, Saguenay, 1877, V. Huart. 13 specimens, Saguenay, V. Huart. USA: 1 specimen, Massachusetts. UNKNOWN: 1 specimen, Coll. Duvivier.

***Calligrapha curvilinea* Stål, 1859** (Fig. 3l)

PERU: 3 specimens, Coll. Chapuis. UNKNOWN: 1 specimen, Coll. Duvivier.

***Calligrapha dislocata* (Rogers, 1956)** (Fig. 3m)

BRASIL: 1 specimen, A. Bau, Coll. Duvivier. MEXICO: 2 specimens, Ocoyoacac, Coll. L. Legiest. 1 specimen, Pachuca, Hidalgo, Höge. USA: 2 specimens, Texas, Coll. Chapuis. UNKNOWN: 1 specimen, Coll. Duvivier.

***Calligrapha diversa* Stål, 1859** (Fig. 3n)

COSTA RICA: 1 specimen, Coll. Chapuis. GUATEMALA: 1 specimen, Capetilla, G.C. Champion. MEXICO: 8 specimens, Guanajuato, E. Dugès. 2 specimens, Xocomanatlan Guerrero 7000ft., vii, H.H. Smith. 1 specimen, 1891, E. Dugès. UNKNOWN: 1 specimen, Van Lansberg. 3 specimens, Coll. Duvivier. 1 specimen, Coll. Chapuis. 5 specimens, Restité, 1885.

***Calligrapha elegantula* Jacoby, 1877** (Fig. 3o)

AMERICA: 1 specimen, Coll. Duvivier. BRASIL: 1 specimen, Coll. Camille Van Volxem. CENTRAL AMERICA: 2 specimens, Weyers. COSTA RICA: 1 specimen, Irazu 6-7000ft.[sic], H. Rogers. 1 specimen, Van Patten, Coll. Duvivier. 1 specimen, Van Patten. UNKNOWN: 1 specimen, Coll. Thiro. 1 specimen, Restité, 1885.

***Calligrapha felina* Stål, 1860** (Fig. 3p)

MEXICO: 4 specimens, Central States, 1891, E. Dugès. 4 specimens, Guanajuato, E. Dugès. 1 specimen, Coll. Duvivier. UNKNOWN: 3 specimens, Coll. Duvivier. 1 specimen, Restité, 1885.

***Calligrapha fulvipes* Stål, 1859** (Fig. 3q)

BELIZE: 9 specimens, Ventes, 1893, J.C. Stevens. BRASIL: 1 specimen, Coll. Camille Van Volxem. CENTRAL AMERICA: 17 specimens, Weyers. EL SALVADOR: 40 specimens, El Boqueron (San Sal-

vador), vii/1959, J. Béchyne. GUATEMALA: 1 specimen, Purula, Vera Paz, Champion. 2 specimens, 1943, J. Rodriguez. HONDURAS: 1 specimen, R. Sarstoon & B. Blancaneau. MEXICO: 1 specimen, Oaxaca, Hoega. 1 specimen, 1954, Coll. Thiro. 1 specimen, Ghiesbrecht. 5 specimens, Coll. Thiro. 2 specimens, Coll. Chapuis. UNKNOWN: 1 specimen, Coll. Thiro. 3 specimens, Coll. Duvivier. 2 specimens, Coll. Chapuis. 3 specimens, Restité, 1885.

***Calligrapha geographica* Stål, 1860** (Fig. 3r)
UNKNOWN: 1 specimen, Coll. Chapuis. 1 specimen, Coll. Duvivier.

***Calligrapha ignara* Stål, 1860** (Fig. 3s)
BOLIVIA: 1 specimen, Chuquisaca, J. Bechyne, Coll. Chapuis.

***Calligrapha knabi* Brown, 1940** (Fig. 3t)
CANADA: 1 specimen, Un. Laval, Prov. Quebec.

***Calligrapha labyrinthica* Stål, 1859** (Fig. 3u)
MEXICO: 1 specimen, Coll. Chapuis. NICARAGUA: 1 specimen, Chontales, T. Belt. UNKNOWN: 1 specimen, 1885, Restité. 2 specimens, Coll. Chapuis. 2 specimens, Coll. Duvivier. 2 specimens, Coll. Thiro. 2 specimens.

***Calligrapha limbaticollis* Stål, 1859** (Fig. 3v)
MEXICO: 2 specimens, Coll. Chapuis. 1 specimen, 2012. UNKNOWN: 1 specimen, 1885, Restité. 2 specimens, Coll. Duvivier.

***Calligrapha lunata* (Fabricius, 1787)** (Fig. 3w)
AMERICA: 1 specimen, Restité, 1. USA: 1 specimen, Massachusetts.

***Calligrapha lunata hybrida* (Fabricius, 1787)** (Fig. 3x)
UNKNOWN: 4 specimens, iv/1923, F.S. Carr, Coll. Ant. Ball.

***Calligrapha matronalis* Erichson, 1847** (Fig. 3y)
PERU: 1 specimen, Chanchamayo, 1896, Ventes J.C. Stevens. 2 specimens, Chanchamayo. 1 specimen, Duvivier. SOUTH-AMERICA: 1 specimen, Rio Santiago '29, Marquis de Wavria. UNKNOWN: 1 specimen, Coll. Duvivier. 1 specimen.

***Calligrapha multiguttata* Stål, 1859** (Fig. 3z)
MEXICO: 1 specimen, J. Bechyne, Coll. Chapuis.

***Calligrapha multipunctata bigsbyana* (Kirby, 1837)** (Fig. 3A)

CANADA: 17 specimens, Ottawa, v/1949, R. de Ruelle. 3 specimens, Ottawa, vi/1949, R. de Ruelle. 1 specimen, Ottawa, vii/1949, R. de Ruelle. 1 specimen, Env. De Quebec, Provanchers. 1 specimen, Un. Laval, Prov. Quebec. 1 specimen, Saguenay, V. Huart. 1 specimen, L. Burgeon, Coll. L. Burgeon. USA: 1 specimen, Illinois, 1954, Coll. Chapuis. 1 specimen, Springfield, Massachusetts, Dimmock. 1 specimen, Springfield, Massachusetts. 1 specimen, Massachusetts. 2 specimens, Coll. Schramm. 1 specimen, Coll. Thiro, 1. UNKNOWN: 1 specimen, mont. Roch, Coll. Chapuis. 1 specimen, Coll. Chapuis. 1 specimen, 1954, Coll. Duvivier. 3 specimens, Coll. Duvivier. 1 specimen, Ct.

***Calligrapha notatipennis* Stål, 1859** (Fig. 3B)
MEXICO: 1 specimen, Jalapa, 1954, Hoega. 1 specimen, Jalapa, Hoega. 1 specimen, Jalapa, Dr. A. Fenyés. 1 specimen, Ghiesbrecht. 2 specimens, Coll. Duvivier. 1 specimen, Coll. Chapuis. CHILE: 1 specimen. UNKNOWN: 3 specimens, 1885, Restité. 1 specimen, Roelofs. 2 specimens, Coll. Chapuis. 1 specimen, Coll. Duvivier. 2 specimens, Coll. Chapuis. 1 specimen.

***Calligrapha nupta* Stål, 1859** (Fig. 3C)
COLOMBIA: 7 specimens, Le Bas. EL SALVADOR : 1 specimen, El Boqueron, vii/1959, J. Bechyne. CENTRAL AMERICA: 1 specimen, Weyers. UNKNOWN: 1 specimen, 1885, Restité.

***Calligrapha pantherina* Stål, 1859** (Fig. 3D)
AMERICA: 1 specimen, Chevrolat. COLOMBIA: 1 specimen, 1954, Coll. Chapuis. GUATEMALA: 1 specimen, Candèze, Coll. Chapuis. 1 specimen, Rodriguez. 2 specimens, Coll. Chapuis. MEXICO: 1 specimen, Presidio, Forrer. 1 specimen, Amula, Guerrero 6000 ft., H.H. Smith. 1 specimen, Coll. Duvivier. UNKNOWN: 2 specimens, 1885, Restité. 3 specimens, Coll. Chapuis. 4 specimens, Coll. Duvivier. 1 specimen, Coll. Thomson.

***Calligrapha percheroni* (Guérin-Méneville, 1830)** (Fig. 3E)

BOLIVIA: 1 specimen, Santos Varros, 2000m. ECUADOR: 1 specimen, 1971, E. de Ville, Coll. Chapuis. 1 specimen, 1971, E. de Ville. 1 specimen, Coll. Chapuis. PERU: 1 specimen, Coll. Chapuis. UNKNOWN : 1 specimen, 1954, Coll. Duvivier. 1

specimen, 1885, Restité. 2 specimens, Coll. Duvivier. 1 specimen, Coll. Chapuis. 3 specimens.

***Calligrapha philadelphica* (Linnaeus, 1758)**

(Fig. 3F)

CANADA: 1 specimen, Ottawa, vii/1948, R. de Ruelle. 5 specimens, Ottawa, v/1949, R. de Ruelle. 1 specimen, Ottawa, vi/1949, R. de Ruelle. 3 specimens, Saguenay, V. Huart. 1 specimen, Coll. Chapuis. 1 specimen, Coll. L. Burgeon. USA: 1 specimen, Illinois, Coll. Chapuis. 1 specimen, Springfield, Massachusetts, Dimmock. UNKNOWN: 1 specimen, 1885, Restité. 2 specimens, Coll. Duvivier. 1 specimen.

***Calligrapha polyspila* (Germar, 1821)** (Fig. 3G)

ARGENTINA: 2 specimens, Buenos Aires, Palermo, Coll. J. Muller. 1 specimen, Buenos Aires Coll. Thirot. 2 specimens, Buenos Aires, Coll. Camille Van Volxem. 6 specimens, Buenos Aires. 1 specimen, East-Chavarría, Corrientes, xii/1904. 2 specimens, San Nicolas, 1928, Dr. Ch. Michel. BRASIL: 3 specimens, Rio Janeiro, C. Hygin Furey. 1 specimen, de Lacerda. 2 specimens, Santa Catarina, 1893, Ach. Geilenkeuser. 1 specimen, Bahia, de Lacerda. 1 specimen, Bahia, Coll. Chapuis. 1 specimen, The-reyspolis. 5 specimens, De Segueira. 2 specimens, Roelofs. 1 specimen, Coll. J. Muller. 7 specimens. GUYANA: 1 specimen, P. Mabile. URUGUAY: 3 specimens, Montevideo, Coll. Chapuis. USA: 1 specimen, Pennsylvania, 1920. SOUTH AMERICA: 1 specimen. UNKNOWN: 1 specimen, Dr. A. Breyer. 2 specimens, De Segueira. 3 specimens, Coll. Chapuis. 4 specimens, Coll. De Borre. 1 specimen, Coll. Duvivier. 5 specimens, Coll. J. Muller. 6 specimens, Coll. H. D'Udekem d'Acoz. 6 specimens.

***Calligrapha praecelsis* (Rogers, 1856)** (Fig. 3H)

USA: 1 specimen, Kansas, 1885, Restité. 1 specimen, Kansas, Coll. Duvivier. UNKNOWN: 2 specimens.

***Calligrapha pruni* Brown, 1945** (Fig. 3I)

USA: 1 specimen, Illinois, Duvivier.

***Calligrapha ramulifera* Stål, 1859** (Fig. 3J)

GUATEMALA: 1 specimen, Coll. Chapuis. UNKNOWN: 1 specimen, Coll. Duvivier. 1 specimen.

***Calligrapha rhoda* Knab, 1909** (Fig. 3K)

USA: 2 specimens, Illinois, Coll. Chapuis. UNKNOWN: 2 specimens, Coll. Duvivier.

***Calligrapha rowena* Knab, 1909** (Fig. 3L)

CANADA: 1 specimen, Saguenay, V. Huart. 1 specimen, Un. Laval, Prov. Quebec. USA: 3 specimens, Ithaca, New York, viii/1928, A. Ball.

***Calligrapha scalaris* (Le Conte, 1824)** (Fig. 3M)

CANADA: 1 specimen, Montreal, v/1936, Coll. J. Muller. 2 specimens, Saguenay, 1877, V. Huart. MEXICO: 1 specimen, 1994, Coll. F. Heylemans. USA: 2 specimens, Cambridge, Massachusetts. 1 specimen, Massachusetts. 1 specimen, Coll. Schram. UNKNOWN: 1 specimen, Mont. Roch, Coll. Chapuis. 1 specimen, 1885, Restité. 2 specimens, Coll. Duvivier.

***Calligrapha serpentina* (Rogers, 1856)** (Fig. 3N)

MEXICO: 14 specimens, Guanajuato, E. Dugès. 1 specimen, Mexico City, Höge. 1 specimen, North Sonora, Morrison. 1 specimen, Queretaro, Dr. Palmer. 1 specimen, Saltillo, Coahuila, Dr. Palmer. 1 specimen, Genin. 1 specimen, Reitter. 3 specimens, Coll. F. Heylemans. 2 specimens. USA: 3 specimens, Albuquerque, New Mexico. UNKNOWN: 2 specimens, Coll. Chapuis. 1 specimen.

***Calligrapha serpentina temaxensis* Bechyné, 1952**
(Fig. 3O)

MEXICO: 1 specimen, Temax, North Yucatan, Gaumer.

***Calligrapha sigmoidea* (LeConte, 1859)** (Fig. 3P)

USA: 2 specimens, California, Coll. Duvivier. UNKNOWN: 1 specimen, 1885, Restité. 2 specimens, Coll. Chapuis. 1 specimen, Coll. Duvivier.

***Calligrapha ?simillima* Stål, 1860**

UNKNOWN: 1 specimen, 1885, Restité. 1 specimen, Coll. Chapuis.

***Calligrapha spiraea* (Say, 1826)** (Fig. 3Q)

USA: 1 specimen. UNKNOWN: 1 specimen, Coll. Duvivier. 1 specimen, Coll. Wellens.

***Calligrapha sponsa* Stål, 1859** (Fig. 3R)

PANAMA: 1 specimen, Chiriqui 25-4000 ft.[sic], Champion.

***Calligrapha suffriani* Jacoby, 1882** (Fig. 3S)

MEXICO: 2 specimens, Central States, E. Dugès. 1 specimen, Ventanas, Durango, Höge, Coll. Duvivier.

***Calligrapha verrucosa* (Suffrian, 1858)** (Fig. 3T)
UNKNOWN: 1 specimen, Coll. Chapuis.

***Calligrapha vicina* Schaeffer, 1933** (Fig. 3U)
CANADA: 2 specimens, Ottawa, v/1949, R. de Ruelle. 1 specimen, Env. De Quebec, Provanchers.

***Calligrapha vigintimaculata* (Chevrolat, 1833)**
(Fig. 3V)
GUATEMALA: 3 specimens, Capetillo, G.C. Champion. 1 specimen, Coll. Chapuis. MEXICO: 1 specimen, Caracas, Bihimit, Coll. Duvivier. 1 specimen, Roelofs, Ghiesbrecht. UNKNOWN: 1 specimen, Restité, 1885. 1 specimen, Coll. Chapuis. 1 specimen.

DISCUSSION

This project allowed for the digitization and taxonomic reassessment of 529 specimens of *Calligrapha* present in the RBINS collection. This allowed all species names to be updated and established that the collection contains 47 species and two subspecies of *Calligrapha*, although initially only 39 species were listed, with 33.5% of specimens bearing incorrect names. Despite of the genus *Calligrapha* not being taxonomically challenging in general, this high proportion of misidentifications follows a consistent trend which has emerged after working on the collections of 17 museums in Europe and North America visited for the systematic revision of this genus (Gomez-Zurita 2015, 2016). The results of this work now give access to a complete and reassessed catalogue with pictures of all the specimens and their labels. The digital interface produced by this project will allow taxonomists to easily consult the database and study specimens for more than one third of the known species of *Calligrapha*.

Based on the experience gained in this project, we note some necessary prerequisites for successful volunteer-based digitization projects. (i) The first one would be engaging committed volunteers to digitize the specimens in a standardized way as a key aspect to ensure that the delicate and repetitive work required can be done efficiently and effectively. (ii) Also, the availability of an expert in the taxonomy of the taxon of interest is essential to the correct identification and classification of the digitized specimens. (iii) The taxon targeted by the digitization initiative must be amenable to identification based on visible external structures. Finally, (iv) a cost-effective online interface is needed to archive digitized pictures and facil-

itate remote consultation of the specimens (Hill et al. 2012).

The most crucial point in our workflow was recruiting capable volunteers. This task can be fairly challenging, but using institutional websites as platforms to promote the importance of digitization and its associated positive implications for biodiversity documentation can encourage recruitment. The importance of direct promotion through professional and amateur Entomological meetings and nature enthusiast forums cannot be overstated in their potential to recruit volunteers. There is also the potential for projects to be launched directly by entomological societies such as the Royal Belgian Entomological Society².

Increased time spent on a project translates into the perception of increased effort and cost, which are factors to take into account when recruiting volunteers or choosing to volunteer for a task (e.g. Andow et al. 2016³). During our work, two working volunteers processed all the specimens. With more cameras available (e.g. by renting or sponsorship), this procedure could be accelerated to accommodate multiple volunteers working simultaneously. A whole collection could be digitized in a relatively short amount of time.

For the vast majority of animal groups, the simple approach adopted in this project is not feasible, since species identification may require dissection of specimens when no obvious external diagnostic characters are visible. In our work, this affected, for instance, the group of cryptic species ranked under *C. scalaris*, which includes several North American taxa that cannot be confidently identified by external characteristics without knowledge about their host plant (Brown 1945; Gómez-Zurita 2015). As information on the plants where these beetles were collected was not recorded, the identification of these RBINS specimens is compromised. Although these specimens could not be identified to species level, they could be reliably classified as members of a species complex, an improvement on the original collection catalogue. As such, taxa that are difficult to classify or require dissection are not excluded from approaches like the one developed here, they only require additional volunteer power to prepare and photograph serial mounted slides of the structures of interest such as genitalia of Lepidoptera or other insect groups like

²<http://www.srbe-kbve.be>.

³<http://www.serviceleader.org/virtual>.

Boopidae⁴. In these cases, however, it might be more practical to send the specimens to an expert taxonomist.

By using this digitization-identification approach to museum specimen identification, the transportation and accommodation costs associated with enlisting a taxonomist can be avoided. The cost of the photographic setup is a once-off expense that is amortized easily with the use of the equipment in subsequent projects. In terms of time spent, finishing the project took approximately 125 hours or 18 working days. In reality, the project took several months (due to the time schedule of the volunteer, corrections of mistakes in photographs, etc.) during which time the authors were pursuing other research endeavors. If time is a constraint, the digitization time as described in the methods section can be considered the only drawback of the digitization approach. However, the digitization approach not only allows for the same kind of taxonomic assessment that could be achieved working directly with the collection, but also provides with an online photographic inventory of *Calligrapha* species for researchers and the public not able to visit the museum. Democratizing the collections through digital archives is one of the most important goals of initiatives like ours, offering a solution to one serious conundrum traditionally faced by museums, i.e. that their collections, patrimony of the society, have to be secluded in order to protect and conserve them (e.g. Milroy and Rozeffelds (2015)). This democratization is intrinsically associated to an opportunity for discussion and also puts in place a control mechanism for the inflexibility of the principle of authority, so strongly linked to taxonomic practice. Lastly, the workflow proposed here avoids the risks of specimen loss or damage associated with shipping them to a taxonomist. In addition, the risk of infection by fungi, *Anthrenus* spp. and other pest species is avoided as the specimens do not leave the conservation room where they are stored at ideal climatic conditions and under IPM Integrated Pest Management protocol.

This study highlights the importance of museum specimen digitization and demonstrates that very basic tasks like organizing a collection can be done remotely. Good communication between the institute, digitizing volunteers and taxonomists results in more profitable research visits and avoids the hazards associated with specimen loans thus making

specimen digitization a valuable tool in facilitating museum collection management.

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⁴<https://digivol.ala.org.au/project/index/21451805>.

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