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Teaching Old Collections New Tricks: Initial Findings of the ISTF Herbarium Digitization Project*

Eski Koleksiyonlara Yeni Yollar Açmak: ISTF Herbaryumunun Dijitalleşmesinin İlk Çıktıları

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ABSTRACT

The digitization of herbaria and other scientific collections has been championed by many researchers, especially taxonomists, who are acutely aware of their importance for the future. Both technological developments and the progression of globalization have accelerated digitization efforts worldwide in recent years. The digitization of the Istanbul University Faculty of Science Herbarium (ISTF) is one example of such a project, which has spanned many years, through various challenges, constantly changing conditions, and technological advancements. This article aims to briefly document the history of efforts made to this end, from the very first spark of an idea to the eventual procurement of institutional support and the start of digitization in October 2022. As of February 2023, data entries for 25,584 specimens (53% of the collection), 3,442 (8% of the collection) of which include high-quality photos, can be accessed through the ISTF virtual herbarium website. We also aim to outline the methods used at ISTF, which we hope will serve as a reference for virtual herbaria yet to be established. We discuss the place of undergraduate and graduate students in digitization alongside best practices to manage these volunteer students so that they may effectively contribute to herbarium work for the long-term benefit of themselves and the collections.

Keywords: Herbarium management, digitization, natural history collections, imaging

ÖZ

Herbaryumlar ve diğer bilimsel koleksiyonların dijitalleşmesinin önemi, başta taksonomistler olmak üzere çok sayıda bilim insanının uzun zamandır farkında olduğu bir konudur. Son yıllarda hem teknolojik gelişmeler hem de küreselleşme, dijitalizasyona dünya çapında hız kazandırmıştır. İstanbul Üniversitesi Fen Fakültesi Herbaryumunun (ISTF) dijitalleşme süreci, çeşitli zorluklardan, değişen koşullardan ve teknolojik ilerlemelerden geçen, uzun yıllara yayılmış bir çabanın ürünüdür. Makalede bu çabanın ilk hayal edilen fikirden, nihayet kurumsal destek sağlanmasına ve dijitalleşme sürecinin başlangıncına kadar kısa bir tarihini anlatmak amaçlanmıştır. Ekim 2022'den Şubat 2023'e kadar toplam 25,584 örneğin (koleksiyonun %53'ü) veri girişi yapılmış ve bu örneklerden 3,442'si (koleksiyonun %8'i) fotoğraflanmış olarak ISTF sanal herbaryum web sitesinden erişilebilir. Ayrıca, ISTF herbaryumunun sayısallaşması konusunda hangi yolun izlendiğini anlatmak ve daha sonra kurulacak diğer sanal herbaryumlar için bir referans olmak amaçlanmıştır. Lisans ve lisansüstü öğrencilerin sayısallaşmadaki yeri tartışılırken, öğrenciler ve herbaryum için faydalı olacak şekilde, hangi şartlarda çalışmada yer almalarının ve nasıl yönetilmelerinin sağlıklı olduğuna da değinilmiştir.

Anahtar Kelimeler: Herbaryum yönetimi, sayısallaşma, doğa tarihi koleksiyonları, görüntüleme

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INTRODUCTION

With 3,100 registered herbaria globally, and the 390 million plant, algae, and fungus specimens they house (Thiers, 2017), herbaria constitute a vast and extremely valuable databank of the world's biodiversity. However, the majority of these collections remain "inaccessible" to the worldwide scientific community, which prevents them for being used to their full potential (Thiers, 2017). The movement toward digitization and online mobilization of herbarium specimens has helped overcome this impasse and stands to revolutionize the biological sciences. At the time of his writing, Seregin (2016) reported that more than 17 million specimens had been recorded in digital herbaria worldwide. Although this is but a small fraction of the total number of specimens found around the world, these efforts have had an outsized effect in terms of contributions to science. Before the digitization movement began, herbarium collections were a database used almost exclusively by taxonomists. Today, their reach has expanded to include all plant-related scientific studies, from studies on biodiversity to global ecological changes (Heberling et al., 2019). In particular, massive and diverse collections such as the US National Herbarium housed at the Smithsonian Museum of Natural History, whose 3.8 million herbarium sheets were digitized over seven years in 2015-2022, have ensured that their data is useable by researchers around the world (Tamisiea, 2022). Today, it is becoming increasingly feasible for smaller herbaria to digitize their collections.

Although digitization efforts are ongoing at several herbaria in Turkey, there are very few resources documenting their methods and processes (Yılmaz et al., 2012; Öztürk & Ege, 2018; Budak et al., 2021; Demirkuş et al., 2021). The first virtual herbarium established in Turkey was at the Izmir Ege University Faculty of Pharmacy Herbarium (IZEF) (Öztürk & Ege, 2018). While many herbaria in Turkey would soon follow IZEF's lead, many of these virtual collections remained inaccessible to third parties at the time this article was written. This indicates that maintenance and continuity is an often-overlooked issue that should be given the same consideration and planning as the initial establishment phase.

Prof. Dr. Hüsnü Demiriz took what may be considered the first steps towards digitizing the Istanbul University Faculty of Science Herbarium (ISTF) long before digitization works had been discussed. Demiriz devised a coding system in which he assigned numerical codes to all plant families, provinces, and districts. Although he never completed this work, the system he created represents a first step toward digitization. The current ISTF curator, Prof. Dr. Osman Erol, has led three digitization attempts. The first began in 2006, when the collection data of 1,775 specimens were entered into a simple offline software. The second started in 2009 after publication of the digitization plan and outline (Şimşek et al., 2008). This attempt called on the support of postgraduate students in the bioinformatics department and culminated in migration to an online system, as well as the entry of approximately 20,000 more specimens. Securing support was a major challenge throughout these earlier efforts, and lack of funds prevented the start of an imaging phase. At this point, the only specimens photographed and uploaded were the *Plantago* specimens featured in Çiftçi's thesis (2012); however, these did not make it into the present system. Meanwhile, all maintenance and digitization efforts were suspended with the closure of the herbarium due to it being moved three times from the middle of 2018 to 2022. The process picked up again only after ISTF settled into its permanent home at the beginning of 2022. The collections were opened to visiting researchers once again by early summer and digitization efforts took off in earnest in the fall of 2022, after procuring the necessary funding to establish a full imaging system.

The 3rd National Botanical Garden Symposium (2022) brought to the fore a plan to create a common, online National Herbarium Network comprising all of the herbaria of Turkey. The success of such an ambitious project will depend on the swift and successful digitization of each individual collection. This time-consuming and labor-intensive process will be facilitated by the establishment of best practices for digitization, especially in the realm of software, where a standard, effective and efficient program will ensure the creation of a common database and ultimately the success of this project on a national scale.

In this context, this article aims to outline a practical method for the digitization of medium- to large-scale herbaria, while summarizing the work done so far at ISTF. We share our experience in the face of challenges encountered over the last 15 years and provide tips and advice to herbarium workers who intend to follow a similar path toward collection digitization. At the same time, we hope that the opening up of the treasure trove of data in the form of specimens, plus their collection data and histories, on a platform to be used by all will benefit researchers around the world.

MATERIALS AND METHODS

Mounting of Specimens

Materials in use at ISTF include: 260-gram acid-free white cardboard and water-activated paper tape for mounting, graphite pencil to write specimen numbers, solvent-free solid adhesive for adhering labels to herbarium sheets, and scissors to cut tape to the desired size. For plant parts too small to be mounted, envelopes made of tissue paper are prepared and glued to cardboard using solid adhesive or paperclips (Çiftçi, 2012). We use the herbarium techniques specified in Forman & Bridson (1998) for mounting (Figure 1).

Data Entry and Printing of Labels

Collection information from each specimen is entered via an online digital herbarium software developed for easy data entry by Argenit, a company based in Turkey. The biggest advantage of an online system is that newly added data are instantly available to third-party users (Figure 1). Upon entry of collection data, the user may download a fully formatted A6-sized label directly from the website. Collection data includes standard headings used in herbaria worldwide, including accession number, taxonomic categories (plant family, genus,

species, subspecies, variety, and their respective authors), location data (country, province, location description, and coordinates), habitat, altitude, collector names, date of collection, identification information (researcher name and date), as well as endemism and type and a section for notes. These are printed and immediately fixed to the specimens.

Preparing Mounted Specimens for Imaging

The ISTF herbarium being moved three times in the past three years has led to extra wear and tear on previously mounted specimens. The damage most often seen includes loss of tape adhesion due to fluctuations in temperature and humidity, and breakage of plant material. As a result, specimens must be carefully checked, fixed, and cleaned of dust and debris using a brush or small bursts of air (a pipette bulb is useful for this purpose), and any missing or erroneous information is corrected on the labels (Figure 1).

Specimen Imaging and Uploading

Based on the specifications outlined in Davis et al. (2021), a small, single-user photo station was selected to suit the limited available space and to save labor while imaging specimens as quickly as possible. One addition we made to the system came

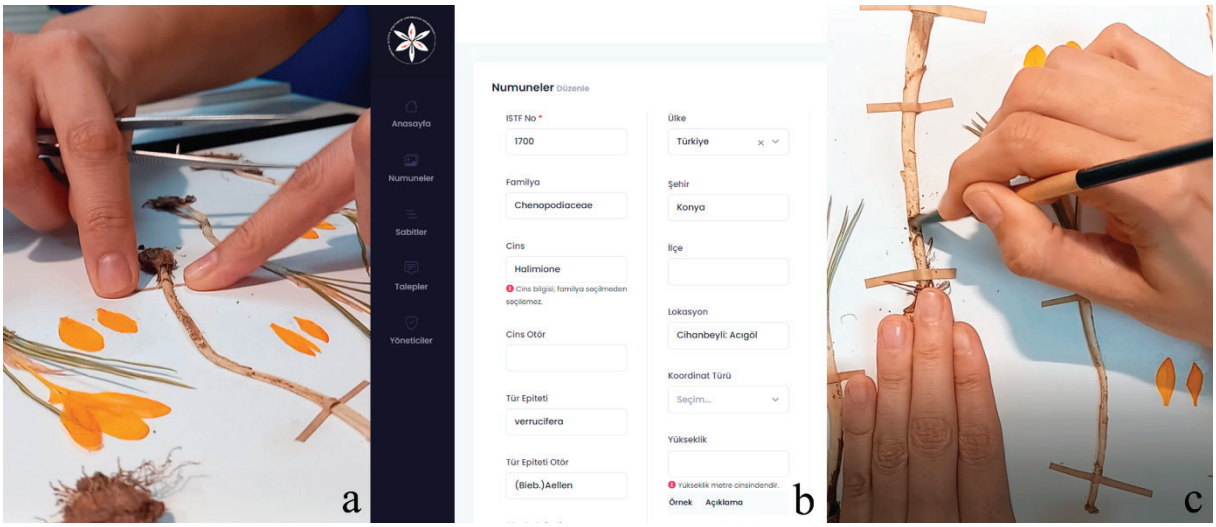

Figure 1. The stages of preparation undergone by specimens before photographing at ISTF: a. Mounting plant material to herbarium sheets, b. Entering label data into the virtual herbarium, c. Maintenance, repair, and cleaning of specimens to be photographed.

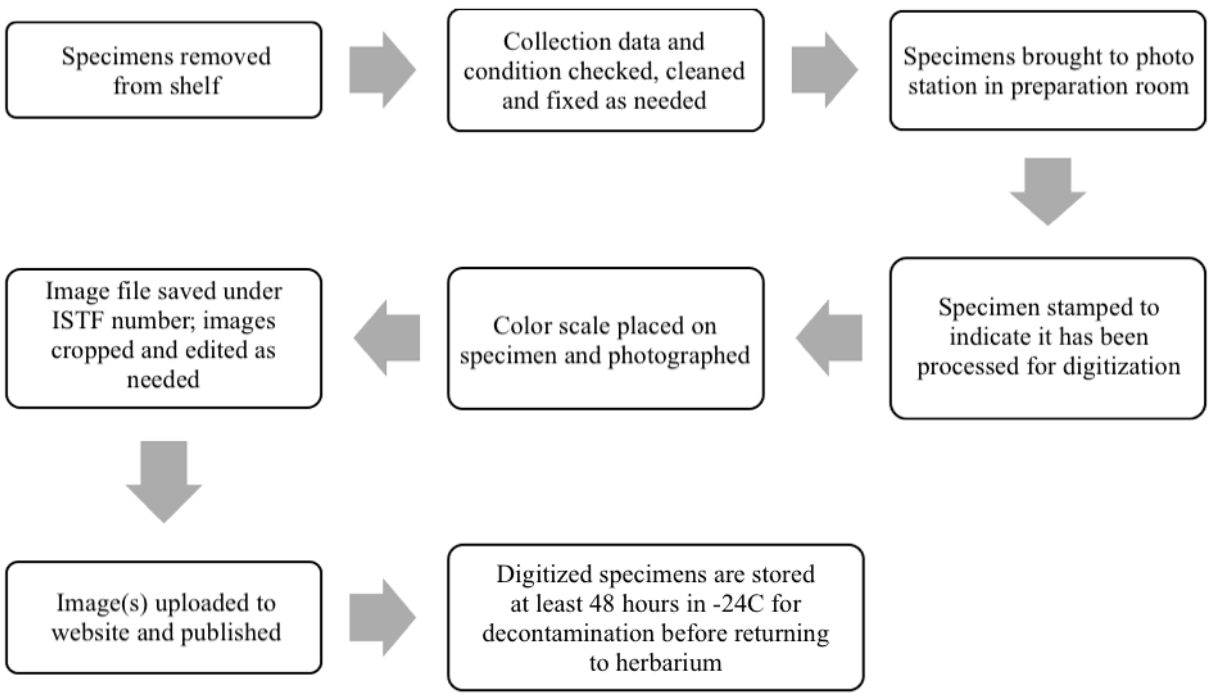

Figure 2. Work flow chart showing the process from removing and photographing the specimens to returning them to their original place in the collection.

in the form of thick rubber mats placed under the table, which was also modified to stand on four legs for added stability. These were necessary adaptations to minimize vibrations from the building. The system features a Sony brand ILCE-7RM4A model camera used with remote controller to avoid bumping or jarring the table during photography. Images are taken in both JPG format for uploading and high-quality raw format .ARW at 6336 × 9504 pixels for standard herbarium sheets. Camera settings are as follows: f value f/6.3, exposure: 1/100. An X-rite ColorChecker Classic color and millimetric scale is placed on each sheet and the sheet is stamped with the ISTF logo before imaging. The workflow for photographing specimens and uploading them to the online system via web browser is outlined in Figure 2.

Software specifications

The herbarium server is located at the Istanbul University computer center and operates using the Linux operating system. My Structural Query Language (MySQL) is the database management system application housing the herbarium data. The Laravel Framework, which was developed in the PHP programming language, was used to prepare the back end in accordance with the MVC structure. High-quality specimen photos are uploaded to the server using the "Dropzone.js" plugin and previews are produced using the PHP-Imagick module. To see high-resolution photos client-side, we use the "OpenSeadragon" JavaScript package. Photos are transformed into the multi-resolution DeepZoom (dzi) format so that OpenSeadragon viewer clients can access them. The PHP-Imagick library is employed to allow automatic label printing. Label typefaces and designs were the subject of a specific study and picture size of the printed label is a standard A6 sheet. The HTML5, CSS, Bootstrap, JavaScript and jQuery languages were used to construct the front-end. Any client device, whether a PC, notebook, tablet, or smart phone, can browse the website in any screen resolution. The Laravel Framework's localization capability is used to support several languages. Specimen locations are shown on the map using the mapbox code library. A sample specimen page from the ISTF virtual herbarium website is shown in Figure 3.

RESULTS

The population of the ISTF Virtual Herbarium is an ongoing process. Although it has been just a few short months since support was received, the entry of data for more than 20,000 specimens during the previous digitization efforts allowed for a quick start. Using the workflow and system outlined in this paper, approximately 30-100 specimens, or more, can be imaged and uploaded per day by one person, depending on their condition and the number of herbarium sheets per specimen.

As of February 2023, collection data for 25,584 specimens are available on the ISTF virtual herbarium website, and images have been uploaded for 3,442 of them. In all, this constitutes collection data for 53% and images for 8% of the ISTF herbarium now available to the public (Figure 4).

Data concerning the families with the largest presence in terms of data entry and photographic digitization at the ISTF Digital Herbarium (https://istf.istanbul.edu.tr) as of February 2023 can be found in Table 1.

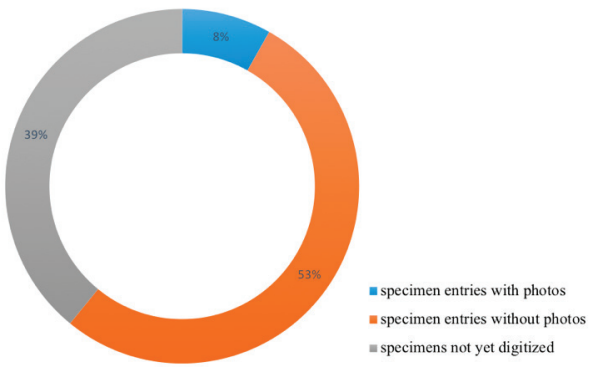

Figure 4. Graphic summarizing digitization work completed at ISTF as of February 2023. All specimen entries include collection data.

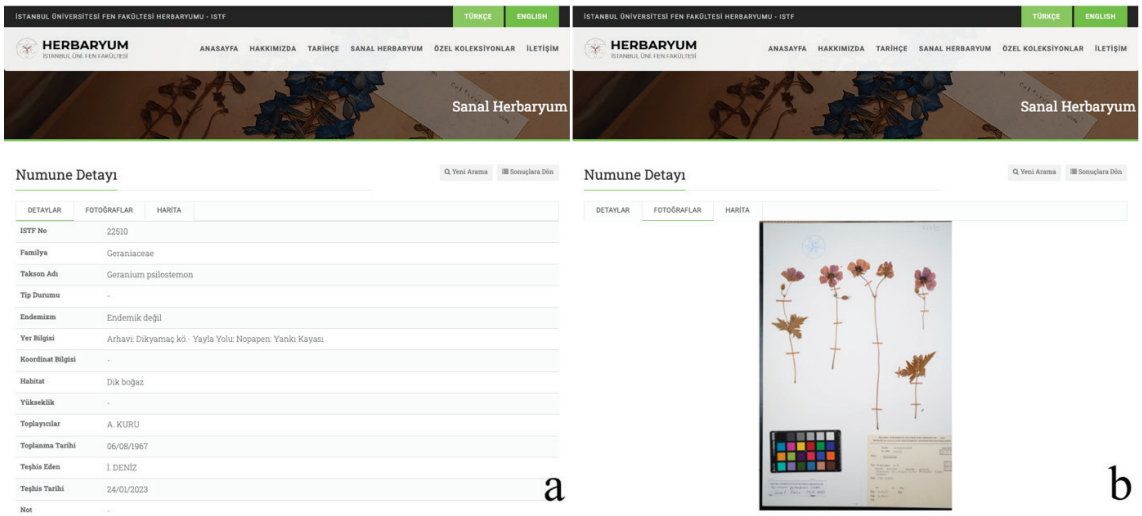

Figure 3. Example specimen page on ISTF Virtual Herbarium website: a. Specimen data tab and b. Specimen images tab.

Table 1. The 20 plant families with highest specimen data and image counts in the ISTF Digital Herbarium as of February 2023

Family	Specimen data entered	Specimens imaged	Family	Specimen data entered	Specimens imaged
Acanthaceae	32	32	Caryophyllaceae	2,350	274
Aceraceae	48	48	Crassulaceae	1,024	0
Amaranthaceae	33	33	Euphorbiaceae	605	0
Amaryllidaceae	74	42	Fabaceae	2,947	0
Asteraceae	3,713	58	Fagaceae	250	210
Boraginaceae	1,373	48	Geraniaceae	512	379
Brassicaceae	1,684	1,363	Iridaceae	474	270
Campanulaceae	510	493	Lamiaceae	1,589	0
Capparaceae	33	33	Plantaginaceae	544	0
Caprifoliaceae	88	88	Poaceae	1,484	0

Ideally, digitization would proceed in a more or less linear fashion to avoid skipping over specimens; however, practical concerns, such as the state of the collections and ongoing work, including that of visiting researchers, must be taken into account. For instance, mounting of the entire collection was never completed at ISTF, while many more specimens were mounted using outdated methods or otherwise need maintenance prior to imaging. The initial phase of digitization started from families such as Aceraceae, Brassicaceae, Campanulaceae, and Caryophyllaceae, which were ready to be imaged immediately, while other groups, including Iridaceae and Lamiaceae, entered into the mounting phase. Families that were previously mounted but for various reasons require work before imaging, such as Apiaceae and Amaryllidaceae, have entered into a maintenance phase that includes cleaning of the specimens, updating of mounting material, and entry of collection data into the system, as needed.

We have also prioritized the entry of specimens whose identifications have been updated by visiting researchers since the reopening of ISTF, including some groups of Boraginaceae and Geraniaceae. Entry of many specimens not identified to the species level has also been postponed in order to cut down on the labor-intensive task of updating their entries later. These will be entered either upon identification or after all identified specimens have been entered.

DISCUSSION AND CONCLUSION

Natural sciences and natural history collections around the world receive comparatively much less funding than other fields. Many herbaria struggle with a lack of permanent staff and financial support, as well as relocations (Personal communication, JE curator 2018, OSU curator 2021). Beyond digitization, the very existence and maintenance of herbaria is usually dependent on the personal efforts and dedication of their workers. In this context, the inclusion of undergraduate and graduate students in digitization efforts, at least in university herbaria, is a critical issue both for the development of students and for the longevity of the herbarium. The staff of the ISTF herbarium has long worked to involve students in many herbarium tasks, including mounting, maintenance, and digitization, as well as packing of specimens for relocations. While this has brought about a number of challenges, with proper management, working with student volunteers can make for a success story.

The most important aspect of working with students is ensuring they are properly trained and supervised for at least the first few months. While biology students in many institutions may learn about herbarium collection management in theory-based courses, each herbarium has its own system and the best way to learn is through actively working with the collection. It is helpful to break down work into clear tasks that are easily taught and learned in a modular fashion. At ISTF these include mounting, maintenance, data entry, and imaging. It is also desirable to instill in students a sense of responsibility and curiosity by teaching them about the collections and their importance, as well as encouraging them to take ownership and learn from mistakes to prevent ongoing or irreversible damage. Errors in data entry are unavoidable, especially when working with students, and are much more easily reversed than errors in management of physical collections. Checking of data entered on a regular basis by senior herbarium workers helps fix problems before they get out of hand. As long as these major issues are taken into consideration, including students in this process benefits both the students and the herbaria where they volunteer.

Alongside digitization, mounting of specimens is ongoing at ISTF. Some of the specimens deposited remain housed in newspapers with their collection information, while other specimens and collections were added to ISTF from other herbaria and private collections. These specimens are in various states of maintenance and many need updating to archival-quality mounting materials and methods, as well as cleaning and proper labels. While this process began before the relocations, transportation and storage in less-than-ideal conditions has made it even more critical. While imaging is ongoing at the photo-station in the preparation room for plant families in good condition, families that have yet to be mounted or need maintenance are worked on in the main herbarium, and these two processes are largely independent of one another. ISTF is arranged alphabetically by family and genus, and while the majority of work proceeds accordingly, recently updated groups are prioritized for imaging, while groups to be

used by visiting researchers, who are often working on revisions and taxonomic treatments for the ongoing Illustrated Flora of Turkiye (Güner et al., 2014) and constitute an important source of taxonomic updates for the collection, may be prioritized for mounting.

The software created by Argenit is especially useful to this end because it allows the user to create and print a standard label immediately upon creation of an herbarium entry. As previously noted, long-term maintenance of these systems seems to be a challenge in virtual herbaria in Turkey. Software and website selection should include planning for ongoing maintenance and bug fixing, which in the case of ISTF is handled through direct communication with Argenit, who then makes the necessary changes to the code. While larger institutions may be able to handle all technical aspects in-house, such an agreement may be appropriate for many smaller herbaria. Another option is to use commercially available or other ready-built programs, which have the benefit of previous testing and bug fixing, as well as good prospects for maintenance.

As far as management of data and images are concerned, we have found it helpful for the software to check the file name of the specimen image, which is labelled with its ISTF number, with the number of the entry in the system, and give an error if they do not match. This helps prevent errors uploading the image under the wrong specimen. We have found that a download to Excel feature that was built into the website for the benefit of researchers is also useful for checking other types of errors, including typos. Once the data is downloaded, it can be quickly checked with basic data-cleaning methods in Excel and the appropriate errors fixed on the system manually.

Another important outcome of the ongoing digitization at ISTF is the overhaul of old collections, updated identification of specimens and, ultimately, the rediscovery of the herbarium's richness. İsmail Deniz visited ISTF in January 2023 to work on the treatment of the genus *Geranium* in the Illustrated Flora of Turkey, and through his diligent work on the considerable number of unidentified *Geranium* specimens, revealed several rare specimens, including *G. lanuginosum* Lam., *G. macrorrhizum* L., and *G. gymnocaulon* DC, for which only one other known specimen is housed in Turkey, and that is incomplete. When conducted properly, such visits result in the updating of taxon data and identification of previously unidentified specimens, which may sometimes wait years waiting for specialist care. Other collections have come to ISTF from other herbaria or the personal collections of various researchers, such as Turhan Baytop's extensive geophyte collections and Ali Çırpıcı's specimens from Murat Mountain between Uşak and Kütahya, as well as plants of Uludağ Mountain in Bursa collected by ISTF founder Alfred Heilbronn and Mehpare Heilbronn. Some of these collections have been entered into the herbarium registry, while others contribute to a backlog of specimens to be entered. That some of these collections, and even the various curators of ISTF themselves, used very different systems for managing their collection information can make location and entry of data time consuming. While the official herbarium registry currently goes up to nearly 41,500 specimens, missing or mixed-up entries and lost specimens, as well as the backlog of unentered collections and problematic specimens, mean this number may change dramatically by the end of the project. The eventual registration and entry of the entire herbarium into the standardized, online data management system will bring all of these collections to the light of day to the benefit of herbarium staff and outside researchers alike.

Meanwhile, some important collections stored in improperly labeled boxes and forgotten were rediscovered while organizing the herbarium before and during its relocations. Among them are Bilgin Tözün's macroalgae collection from Florida (USA), a collection of fungi that cause diseases in forest trees from Germany from 1917, an algae and diatom collection from 1887, specimens collected from around the Dead Sea for Sultan Abdulhamid II at the turn of the 20th century and, perhaps most importantly, a number of specimens used in Boissier's Flora Orientalis. Parallel to digitization, our graduate students are conducting a survey of the Herbarium Boissier collection at ISTF to be prepared for publication. Once fully integrated into the registry, these collections will join the other herbaria and collections now housed and entered into the ISTF registry, including the 1,400 specimens of M. J. E. Coode and B. M. G. Jones from 1965, as well as collections by P.H. Davis and Arthur Huber-Morath, among others (Demiriz, 1969). These will all be fully accounted for and accessible online by the end of the project.

One source of difficulty in herbarium management is the confusion surrounding their museum status. Evaluating and managing herbarium collections within the same framework as, say, objects in an archeology museum ignores the dynamic nature of organic specimens and can lead to management practices that are impractical at best but more often outright harmful. While they still require a degree of care and upkeep, most museum objects are usually not small organic items in use as active research material that puts them in a constant state of change. Placing these very different types of objects in the same regulatory category results in mismanagement of collections. Institutions in some countries, including Turkey, dictate that each specimen be registered as an accession with monetary value attached, in addition to and independent of a standard international herbarium accession system. Aside from being poor use of already inadequate labor, this runs contrary to the dynamic nature of the material itself, to which no monetary value can be meaningfully assigned. Although herbarium material is ideally meant for long-term storage and use, it can hardly be classed as a permanent object any more than it can be understood as consumable inventory. Understanding this, herbarium curators are put in a difficult position, because placing high values on specimens constitutes risk, while underselling them sends the false message that herbaria collections lack value. In reality, herbarium collections constitute a priceless source of data whose uses are constantly changing and whose management must reflect the reality of the material they house. Transfer of the herbarium to a digital environment will help prevent damage to the specimens and benefit their long-term preservation through reduction of contact with specimens.

The relocations that have afflicted so many herbaria in Turkey seem to have hit ISTF the hardest. Having moved once within the same building and three times between buildings since its establishment in 1933, ISTF may hold the record in this regard. The collection was housed in temporary venues during its past three relocations due to improper planning and delays in the construction of its permanent location. Specimens were sealed in plastic bags and packed in cardboard boxes during this period. Due to the uncertain length of stay, the material was not unpacked or made accessible at these temporary venues, which lacked conditions conducive to the long-term health and safety of the specimens. This ensured that the collections were least affected by external factors. While there were concerns that long-term storage in plastic bags may lead to further damage in the form of mold and humidity, the result was overall very positive. The vast majority of the specimens arrived at their final destination intact, without mold or decay. We must conclude that this was the best decision for these collections. Open air storage in these temporary venues, which were older buildings that lack sterile, dry environments, would likely have resulted in severe mold damage and insect infestation. The critical factor here is that the specimens were very dry when packed, largely because ISTF is primarily made up of old, well-dried specimens. Improperly dried specimens should never be stored in airtight conditions. Ideally, digitization would have taken place before moving in order to mitigate the risk of damage to the specimens before imaging, as well as to keep the collections accessible for the duration of the herbarium's closure. However, adherence to these practices has brought the collection to its current location with minimal damage.

The staff of ISTF is fully aware that our work has only just begun. As this process continues, high-resolution image and collection data of more than 40,000 specimens will be processed. We believe that this data will inspire many scientific studies to come and serve as a database for future generations of researchers. We are also aware that herbaria are not just about macro-sized material. After the successful digitization of all the higher plant material in the herbarium we plan to take the necessary steps to digitize the various micro collections at ISTF, such as diatoms and algae.

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