METHODS AND TECHNIQUES

World Flora Online: Placing taxonomists at the heart of a definitive and comprehensive global resource on the world's plants

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Abstract It is time to synthesize the knowledge that has been generated through more than 260 years of botanical exploration, taxonomic and, more recently, phylogenetic research throughout the world. The adoption of an updated Global Strategy for Plant Conservation (GSPC) in 2011 provided the essential impetus for the development of the World Flora Online (WFO) project. The project represents an international, coordinated effort by the botanical community to achieve GSPC Target 1, an electronic Flora of all plants. It will be a first-ever unique and authoritative global source of information on the world's plant diversity, compiled, curated, moderated and updated by an expert and specialist-based community (Taxonomic Expert Networks – "TENs" – covering a taxonomic group such as family or order) and actively managed by those who have compiled and contributed the data it includes. Full credit and acknowledgement will be given to the original sources, allowing users to refer back to the primary data. A strength of the project is that it is led and endorsed by a global consortium of more than 40 leading botanical institutions worldwide. A first milestone for producing the World Flora Online is to be accomplished by the end of 2020, but the WFO Consortium is committed to continuing the WFO programme beyond 2020 when it will develop its full impact as the authoritative source of information on the world's plant biodiversity.

Keywords biodiversity assessment; global species list; Global Strategy for Plant Conservation; science policy; taxonomy; vascular plants

■ INTRODUCTION

There are an estimated 400,000 species of vascular plants and bryophytes on Earth, with perhaps an additional 10% yet to be discovered. The majority are flowering plants (calculations centre around 352,000 to 370,000 accepted species; Paton & al., 2008; Nic Lughadha & al., 2016), whereas gymnosperms amount to 1090 species (WCSP, 2016), and there are roughly 13,300 species of ferns and fern allies (Hassler, 2020), 12,800 mosses (Crosby & al., 2000), and 7500 hornworts and liverworts (Söderström & al., 2016). These plants constitute the basis of most terrestrial ecosystems and hold answers to many of the world's health, social, environmental and economic problems. The completion of a full inventory of plant life is vital for protecting threatened species of all kinds of organisms and realizing their full potential to support human needs before many of them become extinct.

The WFO portal is a freely available online source of rigorously assembled scientific verified biodiversity data on bryophytes, pteridophytes, gymnosperms and angiosperms. Backed by the international taxonomic community, the WFO provides two fundamental data resources critical for underpinning botanical research, plant conservation and the sustainable use of plant resources. The first resource is a curated and updatable synonymized checklist of all plant species as well as other taxon categories (families, genera, subspecies, etc.) – the Taxonomic Backbone of the WFO. The Taxonomic Backbone aims to provide the most up to date source of scientific plant names and their synonyms: a consensus classification of the world's plants. Comprehensiveness (including all effectively published names), and particularly the active curation by taxonomic experts (*TENs – Taxonomic Expert Networks*) will turn this into a unique, dynamic, living resource. Content, the second essential resource, is a managed aggregation of published floristic and monographic data with descriptions, distributions, images, etc. linked to names in the Taxonomic Backbone. *Content Providers* contribute data from their publications (print or electronic), which are displayed in taxon pages alongside other contributions, with credits linking to sources of these data. Aimed primarily at the conservation community and applied users of biodiversity data, the WFO online portal will be the first comprehensive global resource for the discovery of information on plant species, their names, descriptions, distributions and conservation status.

A globally consistent and reliable architecture for plant taxonomy is a fundamental requirement for many applications, amongst which conservation is foremost. Biodiversity monitoring and conservation status assessments are based on a consensus classification and accurate information on geographic ranges, often in the form of maps that present the complete range of species occurrence across countries. International collaborative approaches such as the Global Biodiversity Information Facility (GBIF, https://www.gbif.org) are increasingly facilitating access to specimen and observational data. These enable broad-scale biodiversity analyses and as such depend on the linkage of these data to an authoritative taxonomic and floristic source of information on all known plant taxa. At present the IUCN Global Red List (IUCN, 2019), complemented by the ThreatSearch database (BGCI, 2019), contains over 300,000 conservation assessments representing more than 180,000 plant taxa, and merely uses the names as published in the original assessments, whether accepted or synonyms. Such assessments will therefore benefit greatly from a globally consistent taxonomic source that links synonyms to currently accepted names. The need for a globally consistent name architecture to correctly link other plant-related data (e.g., DNA sequence data, secondary compounds, medicinal and nutritional uses, common names, invasive potential, occurrence in *ex situ* collections, etc.) that are becoming increasingly abundant and available through databases such as GenBank/ENA, iBOL, Plant Trait Database TRY, and the Catalogue of Life (CoL) is obvious. The same applies to policy documents, legislation and conservation, as highlighted in a number of recent papers (Patterson & al., 2010, 2016; Garnett & Christidis, 2017; Jackson & al, 2017; Thomson & al., 2018). The need for a unique global list of all accepted species as a basis for managing biodiversity in an era of accelerating global change was further advocated recently (Garnett & al., 2020). The authors thereby envision a transparent science-based and content-driven governance framework, with different

groups of organisms being managed by the respective scientific communities as most promising to become universally adopted. The World Flora Online provides this for land plants.

The WFO Consortium also recognizes that the WFO portal has a wider application and that the inclusion of distribution maps and conservation status of species in WFO will directly contribute to the achievement of the Aichi Targets (Convention on Biological Diversity, 2018). For example, Target 12: to prevent the extinction of known threatened species, particularly of those most in decline, by 2020; and Target 9: to identify and prioritize invasive alien species with the goal of controlling or eradicating them are directly related to accurate knowledge about distribution. The importance of plants to support and sustain humanity is also recognized in Target 15 (Life on Land) and Target 14 (Life below Water) of the U.N.'s Sustainable Development Goals (Sharrock & Wyse Jackson, 2017).

Responding to the many uses envisaged for the WFO requires an up-to-date taxonomic backbone that must be managed as a dynamic information source to mirror the best available knowledge. The classification of plants is currently in transition from a classification based mainly on comparative morphology (morpho-species) to the implementation of the results of phylogenetic analyses and evolution-based taxon circumscriptions (Borsch & al., 2015). While a more-or-less stable classification has been achieved at the level of orders and families (e.g., APG IV, 2016), advances in knowledge have led to significant changes in generic and suprageneric classifications (e.g., Caryophyllales, Hernández-Ledesma & al., 2015 + online and updated by Caryophyllales Network 2015−; LPWG, 2017). Changes at the generic level affect the naming of organisms following the rules of nomenclature (Turland & al., 2018), and thus directly influence the linking of distribution, molecular or morphological data to scientific names. This is also true for ongoing changes in species circumscriptions (hence a change in a taxon concept) that occur as a consequence of new collections, new information sources and the application of new analytical methods in systematics.

In addition, significant numbers of species are still being discovered and described as new to science every year (on average 2000 species of vascular plants per year in the last two decades; Christenhusz & Byng, 2016), so there is a constant need for the incorporation of taxa into the Taxonomic Backbone. Verification of names and identities of species by taxonomic experts has been shown to have a significant effect on the estimation of biodiversity overall (Cardoso & al., 2017), making it imperative that the global taxonomic community is involved in such efforts. To that end, WFO foments the establishment of Taxonomic Expert Networks. WFO is developing workflows to bring in to the Taxonomic Backbone newly published names from nomenclators (e.g., International Plant Names Index; IPNI, 2020), and alerting TENs to their inclusion. Conversely, new names brought into the Taxonomic Backbone from TEN datasets will be passed on to nomenclators (see later discussion on Nepenthaceae).

The WFO is not a research project as such but represents a collaborative fresh start by the phytotaxonomic community. It will provide a platform and workflows (including software tools) that allow the assembly of information about the world's plants within a single global resource. Therefore, it is important to build upon existing sources and engage the scientific community, taking great care to ensure proper recognition of authors and contributors. It is also important to note that this engagement is now greatly facilitated by digital resources such as JSTOR Global Plants (http://plants.jstor.org), which, although not yet complete, provides access to a large number of nomenclatural types and type-related material (as of July 2019 over 2 million digitized historical specimens of vascular plants and bryophytes are included in JSTOR Global Plants, relating to roughly 1 million names and 350,000 accepted species). Other examples are the Biodiversity Heritage Library (Gwinn & Rinaldo, 2009) and the Global Biodiversity Information Facility (GBIF, 2018), which provide free and open access to enormous digital resources in taxonomic literature, and specimen and observation records, respectively.

As a collaborative enterprise of many institutions and individuals, the WFO can, however, foster the implementation and achievement of data standards and other mechanisms that support interoperability and reusability of research data (Hobern & al., 2019) following the FAIR principles (Wilkinson & al., 2016). With respect to legal restrictions, the core taxonomic data (names and their classification, i.e., the Taxonomic Backbone) are made available under a Creative Commons CC Zero Waiver ("No Rights Reserved") to be reusable without restrictions. For content data (taxon descriptions, etc.), the contributor can determine what Creative Commons license applies to the data they contribute. WFO recommends use of CC-0 or the CC-BY Attribution license (see Hagedorn & al., 2011 for a discussion of Creative Commons licensing).

The purpose of this paper is to explain the approach taken by the WFO programme and to show where it stands, as well as to discuss its content. Building upon a wealth of already available taxonomic sources and Taxonomic Expert Networks that adopt the curation of the consensus classification for entire families or orders, WFO will present the most up-to-date taxonomic knowledge ensuring global coverage. We therefore envisage the WFO programme as a great opportunity for the global taxonomic community to align, to get involved and to become more visible as a player in joint efforts towards solving future challenges of biodiversity conservation and sustainable development.

■ HISTORY OF THE WORLD FLORA ONLINE

In 2002, the Global Strategy for Plant Conservation (GSPC) of the United Nations' Convention on Biological Diversity (CBD) included as its first target the need for "a widely accessible working list of all known plant species". The publication of The Plant List, version 1.0 (www.theplantlist.org) in 2010 was a major step towards achieving this goal. In the

2011–2020 framework of the GSPC (Convention on Biological Diversity, 2012) all targets were updated, and Target 1 was extended to "An online flora of all known plants", a comprehensive compendium of the world's plant species freely available on the Internet by 2020. With this background in mind, in 2012, representatives of members of the Global Partnership for Plant Conservation (GPPC) took the initiative to meet and discuss how to achieve this highly ambitious goal (Wyse Jackson, 2013). The meeting resulted in a proposed outline of the scope and content of a World Flora Online as well as a decision to constitute an international consortium of institutions and organizations to collaborate on delivering the platform and building the content. The WFO project was welcomed by the CBD's Conference of the Parties at its 11th meeting in 2012 (Convention on Biological Diversity, 2014: 245) as a collaborative response to GSPC Target 1 (Wyse Jackson & Miller, 2015). The WFO Consortium, as of July 2020, comprises 43 partner institutions and organizations in 26 countries (www.worldfloraonline.org) and welcomes the participation of others.

Building upon the GSPC 2010 goal, WFO has constantly been working on updating and maintaining the Taxonomic Backbone. With respect to Content, large numbers of descriptions are already available in Floras and monographs published in different languages, and considerable progress is being made in digitizing these resources. Nevertheless, a major challenge both from a technical and a taxonomic point of view is to bring these data together in a single portal, whilst recognizing and acknowledging that the taxon concepts may differ between sources even when using the same scientific name. Since October 2016, descriptions, species distribution data and other Content is added to the Taxonomic Backbone to create the online Flora of the world's plants.

The WFO Consortium has established different working groups to develop a strategy and editorial workflow building upon a variety of information sources to deliver the best-quality taxonomic backbone possible at a global level. Among these, the Taxonomic Working Group (TaxWG) and the Technical Working Group (TechWG) are essential to delivering this strategy. Workshops of these Working Groups held during the St. Louis (2012), Edinburgh (2013), St. Petersburg (2014), Geneva (2015), Rio de Janeiro (2015), New York (2016), Pretoria (2016), Berlin (2017), Paris (2017), Bogotá (2018), Dublin (2018), Istanbul (2019) and St. Louis (2019) meetings of WFO, as well as numerous teleconferences and special purpose meetings, developed the strategic and practical aspects of the project. Our objective in this article is to summarize the results obtained so far.

■ ORGANIZATION AND SCOPE OF THE WORLD FLORA ONLINE

The WFO is a consortium of partner institutions from countries around the world (www.worldfloraonline.org). It is open to partner institutions as members who actively carry out scientific work such as research institutes focusing on the assessment of plant diversity and taxonomy but also consortia developing major Flora and checklist projects as well as organisations aggregating and disseminating biodiversity data (e.g., GBIF or CoL). The WFO is managed through its *Council*, which consists of representatives of all member institutions and usually meets twice a year, hosted by one of the member institutions in an alternating way. The Council acts as the main decision-making body by adopting not only the general strategy and policy for the WFO but also technical documents regarding, for example, the workflow to manage the dynamic WFO Taxonomic Backbone and Content, data ingestion standards, editorial standards and major taxonomic decisions. A further role of the Council is to adopt and promote *Taxonomic Expert Networks*, who manage the Taxonomic Backbone and Content of a group of plants in their expertise, thereby integrating knowledge and furthering participation and collaboration of taxonomists internationally. The botanists who get organized in a Taxonomic Expert Network should do active research on taxonomy and evolution of their respective plant group with a significant publication record (taxonomic treatments and peer-reviewed journal papers). A Taxonomic Expert Network should broadly represent the colleagues working on a plant group internationally, should have an institutional backup at least for the coordination and technical support, and be prepared to develop and curate the taxonomic backbone of this plant group. Documents for discussion and decision in the council are prepared by three working groups and are documented in the minutes of the council meetings. The WFO's participatory and transparent management aims to include as directly as possible the needs of research institutions producing taxonomic and floristic data as well as closely liaising with global biodiversity data infrastructures that require reliable taxonomic information. The Technical Working Group is in charge of the management of the data and the web portal, the Taxonomic Working Group emphasizes on the taxonomic concepts and content, and the Communications Working Group manages the dissemination of the consortium's activities. Working groups are open to members of the consortium, who delegate staff members depending on their expertise. The council and the working groups are co-chaired by two representatives that are elected at each meeting for the coming period.

The taxonomic coverage of the WFO is land plants (i.e., angiosperms, gymnosperms, ferns and fern allies, mosses, hornworts and liverworts). As of July 2020, the World Flora Online Portal presents 350,510 accepted species and includes 1,325,205 names with currently over 120,000 descriptions. More than 1.1 million literature references document the nomenclature and the sources of the information and are presented in the portal. The portal also depicts the data from the IUCN red list, which were imported into WFO as Content datasets.

To function as a comprehensive global source, WFO strives to include all effectively published plant names (as defined in the *International Code of Nomenclature for algae, fungi, and plants*)

including invalid "designations" in its Taxonomic Backbone (currently excluding algae). This information resource is made available under a Creative Commons CC Zero Waiver ("No Rights Reserved") to be reusable without restrictions. As a prerequisite for efficient data management, WFO has introduced a WFO-ID, which is a unique, immutable identifier for each name in the Backbone, regardless of its taxonomic and nomenclatural status. For machine readability, Representational State Transfer (REST) services are available. This was a necessary step since other IDs are not unique or don't fully cover WFO's scope (e.g., IPNI, in part, contains identical names coming from the original sources Index Kewensis, Gray Index and Australian Plant Names Index with different IDs; it does not cover hornworts, liverworts and mosses; and it has gaps in particular with respect to infraspecific taxa). Building on this nomenclatural resource, a single classification of taxon names and their synonyms is built to which Content data (such as descriptions, images, and geographic distributions) supplied by Content Providers can be attached. In addition, a list of names is maintained that have been excluded by the Taxonomic Expert Networks for various reasons, e.g., outdated orthographic variants, names not validly published, names that were not included as synonyms, or names from old publications that – although validly published – could not be assigned a place in the classification. Because these names may still come up in the process of matching names coming from Content Providers, they are considered in the name matching process (see below).

Currently, the WFO gives priority to achieving and dynamically managing a comprehensive Taxonomic Backbone and to linking as much Content as possible to facilitate access (see also "workflow" below). Therefore, the different taxonomic concepts that may be behind a name are not directly tracked by WFO, nor are concept relationships depicted (for example, between "sensu lato" and "sensu stricto" taxa). This currently also refers to misapplied names (i.e., a taxon concept that does not include the type of the name assigned to it). This may presently, in some cases, lead to incorrect assignment of content data that has to be resolved in the future. For the same reason, at the moment no taxon IDs are assigned although this may be added in the future. In this context, it may be noted that WFO does not create new content for regions of the world that currently lack a modern Flora, or families and genera without a recent revision or monograph. Nevertheless, WFO does facilitate floristic and taxonomic research by integrating the available sources and making them available electronically in a highly structured way. For all applications that need a globally consistent taxonomic backbone with distribution information, WFO aims at being the most reliable and up-to-date information source. WFO will manage the core taxonomic content (descriptive data, images and keys facilitating plant identification) and provide a one-stop-shop for external users with respect to the backbone, whereas these external users provide applied taxon-linked data (plant trait databases, conservation status, etc.). In the case of nucleotide archives, data are taxon-linked but are increasingly going to be specimen-linked in addition (Dröge & al., 2013). These linkages have to be established by mutual agreements, which the WFO Council is forging with the organisations maintaining such resources, either directly or via aggregators, such as GBIF or the CoL.

■ THE WORKFLOW TO MANAGE THE WFO TAXONOMIC BACKBONE AND CONTENT

The challenge of integrating the available information into a single global resource on the world's plants was to develop a workflow that can handle a broad spectrum of published information. Such a workflow, therefore, had to consider that taxonomic treatments will vary with respect to geographical scope (global monographic vs. local Floras), age and scientific methodology (in particular whether treatments include the results of phylogenetic studies or not). In the case of accounts in Floras, these may be written by authors who may or may not be specialists for that particular taxonomic group, potentially leading to differences in quality in the sense that they may or may not reflect the current state of knowledge. In Floras, the descriptions may refer specifically to the morphological features of the taxon within the geographical scope of the Flora. Such descriptive Content is further heavily influenced by the format of a Flora or monographic series, and ontologies/descriptive terminologies are frequently not standardized. Also, the way descriptions have been generated by the authors can vary considerably: either using a more or less intuitive selection of characters based on the experience of the author with variable degrees of consistency across taxa, or being based on consistent comparative analyses of a documented set of specimens assigned to a taxon. The ideal would be to generate descriptions from structured data in an additive taxonomic workflow (Kilian & al., 2015; Henning & al., 2018) that integrates specimen-based evolutionary research with the generation of treatments, facilitated by electronic tools. This would also allow to map taxon concepts accurately. However, only a small fraction of descriptions available to date are derived from structured data.

To account for the differing data qualities of the available information sources, WFO strictly distinguishes between generating and curating the WFO Taxonomic Backbone and incorporating Content data. The classification used by a source treatment (checklist, Flora or monograph) is the taxonomically consistent treatment of all incorporated names, i.e., their treatment as accepted taxon names, synonyms, or excluded names. Since floristic and monographic treatments represent the information at a certain point in time, and also due to differences in taxon circumscription in regional versus global accounts, there will be discrepancies between the taxonomic backbone in the sources of information and the Taxonomic Backbone. Incorporating content from such treatments into the WFO currently takes a rather mechanical approach, by linking descriptions pertaining to a taxon name in the source to the respective name in the Taxonomic Backbone. The Content thus becomes

accessible in the portal via a WFO Taxonomic Backbone taxon name or one of its synonyms. The source of the Content is cited, as well as the accepted name according to the Taxonomic Backbone, if Content was submitted under a synonym.

In this way, all the names that were used to annotate a description, regardless of whether they are still accepted or now treated as a synonym, will be linked to the currently accepted name. In the case of merging taxa that were in some sources previously treated separately, the WFO will therefore indirectly indicate this concept change. But two or more descriptions are needed to cover the features of the more widely circumscribed taxon completely. The situation is more difficult when specimens previously included in a wider taxon concept become assigned to a new taxon (e.g., a new species). In this case, there will be a published new description resembling the narrower taxon concept but no formal name relation directly evident in the Taxonomic Backbone. As a consequence, the description of the older, wider taxon concept that was perhaps used in a Flora will be misleading. But new species should nowadays be based on a thorough analysis of characters and specimens with information on their area of distribution (incl. countries, etc.). If the information has been provided to WFO, a query would still provide up-to-date information and facilitate the re-identification of specimens. Also, it has to be noted that changes in the assignment of species to a genus, which are name changes and not taxon concept changes, are well handled by the WFO. This is important because these are perhaps the most frequent name changes. The still correct species descriptions are linked individually to the currently accepted species name and are thus found in their right place. However, at the genus level, the taxon concept changes in these cases.

Mapping taxon concepts as they have been used in different treatments and their shifts would be ideal for getting accurate retrieval of derived information (e.g., trait or conservation status information of a taxon) that is usually connected to identifications made by using a certain treatment (e.g., from a Flora or monograph). This is currently not achievable for all taxa on a global scale. Nevertheless, we believe that our largely name-based approach to link Content to an up-to-date globally consistent Taxonomic Backbone is already a big advance for many user needs.

The construction of the Taxonomic Backbone is therefore central to the entire WFO enterprise. The Taxonomic Backbone determines the accessibility of the Content data and at the same time represents a taxonomic opinion on the circumscription of taxa. The WFO strives, therefore, to present a consensus on current classification. This represents a challenge for the taxonomic community, but experience, e.g., in Brazil (BFG, 2018), shows that with a certain amount of pragmatism, this can be achieved. For WFO, the initial pragmatic decision was to use The Plant List v.1.1. (TPL, 2013) as the starting point for the backbone, as this was the most comprehensive single information resource covering all plants. The Plant List is not perfect – ca. 25% of the names are unresolved, and not all the taxonomic decisions within it are derived from peer-reviewed, curated authoritative sources. Also, many infraspecific taxa are not included, and the nomenclatural status of the names is not always correct.

In the process of building and updating the Taxonomic Backbone, and adding Content, there will be a distinction of data involving names and synonymy depending on the following categories:

- The 1st level is data being actively managed as a (modern) global taxonomic treatment. Ideally, this has been or is being achieved through Taxonomic Expert Networks, specialist networks of colleagues who are currently doing research on a group of plants and collaboratively synthesize the knowledge at a global scale (consistent taxonomic backbone) and continuously update this using a dynamic information system (see Tables 1A, 1B). The WFO Taxonomic Backbone is updated at regular intervals by replacing it by output from that information system, which must include all names and their WFO-IDs that were previously used in the Taxonomic Backbone for that taxonomic group. This way, the number of unresolved names is constantly reduced.
- The 2nd level is data from large-scale (continental) syntheses where globally consistent treatments are not available. The idea is to employ a consistent taxonomic backbone for large parts of the world and to bring together a larger number of country or local Floras into a regional synthesis to realize large-scale continental consistency of the taxonomic backbone. This may also be more in-line with the priorities of individual researchers and institutions, which often have a regional approach (in their own or a foreign geographic location) for their taxonomic work. A consensus taxonomy for the backbone may be easier to achieve on a continental level as compared to globally because species on continents are more likely to correspond to single clades. However, in the process of incorporating the data into WFO, the same problems arise as in the case of individual Flora treatments (option three below): The existence of differences in the backbone between the continental backbones and the existing global WFO Taxonomic Backbone will generate concept problems that can only be resolved by specialists. To some extent, these can be detected automatically in the ingestion process and marked with appropriate caveats, but this is not always the case. A first step in the WFO workflow is thus to ensure that all names in these second-choice treatments are present in the Taxonomic Backbone and, where possible, to provide feedback any omissions to the Taxonomic Expert Networks.
- The 3rd level refers to parts of the Taxonomic Backbone that are not covered by specialist networks on a global scale nor being partially resolved by large-scale (continental) efforts. Such existing resources will have to be linked to the existing Taxonomic Backbone. Names that have not been treated previously need to be resolved in some way, at least concerning their systematic position.

The workflow for ingesting Content will then proceed by matching this content with the Taxonomic Backbone. In effect, all descriptions, distribution data, etc. coming in from Flora datasets and also monographs thus become assigned to an accepted name (i.e., a taxon), either directly or through a synonym of the respective accepted name. In the case that a name

Table 1A. Taxonomic Expert Networks (TENs) established within World Flora Online.

Taxon	Website and contact	Notes
Aquifoliaceae 480 spp.	http://www.ville-ge.ch/cjb/bd/aqf/ P.-A. Loizeau (G), pierre-andre.loizeau@ville-ge.ch	Name matching through Botalista Nom module for updating the Taxonomic Backbone done.
Arecaceae 2,400 spp.	http://www.palmweb.org B. Baker (K)	Authoritative source about palms. Work underway based on data in DwC-A.
Begoniaceae 1,900 spp.	https://padme.rbge.org.uk/Begonia/home M. Hughes (E)	Name matching done.
Caryophyllales 12,000 spp.	http://www.Caryophyllales.org BGBM (B) & partners IBUNAM (MEXU) and Darwinion (SI)	Taxonomic backbone revised for genera (complete) and species for Nepenthaceae, Cactaceae, Plumbaginacae and many smaller families are complete in TEN's database; ingestion successfully tested (see text).
Ericaceae 5,400 spp.	Ericaceae Resource Centre	Ericoideae well underway, other subfamilies in progress incl. WFO-ID assignment.
Gesneriaceae 3,540 spp.	H. Atkins (E)	TEN dataset being updated.
Hypericum	S. Crickett (Graz), N. Nürk (Bayreuth)	Incorporation of data from BM underway.
Irvingiaceae 10 spp.	D. Harris (E)	Curation completed.
Musaceae 80 spp.	T. Haevermans (P)	WFO to WCVP name match completed.
Styracaceae 160 spp.	P. Fritsch (BRIT)	Final correction in Botalista.
Zingiberaceae 2,100 spp.	M. Newman (E)	Initial name matching corrections are underway
Pinophyta (incl. Ginkgoaceae) 620 spp.	P. Thomas (E)	TEN dataset being updated.
Bryophytes 20,000 spp.	https://www.tropicos.org J. Brinda (MO)	Authorised. Currently updating higher classification of Bryophytes in WFO Taxonomic Backbone.

coming in from a Content source does not yet exist in the Taxonomic Backbone, it is forwarded to a Taxonomic Expert Network (for those groups for which a Taxonomic Expert Network exists; level 1) to resolve it and correctly place it in the Taxonomic Backbone. If a taxon is not covered by a Taxonomic Expert Network, the name is given to the editors of a large-scale checklist (level 2), who will resolve it and provide this information to WFO. In the case that this name comes from a source that is not covered through levels 1 and 2, the Taxonomic Working Group will handle it.

Although in the current WFO system, Content data are not managed by a Taxonomic Expert Network, this may change in the future. In fact, there are already some taxon portals (see Tables 1A, 1B) that provide content data curated in a more detailed way, matching not only the accepted names but also the accepted taxon concepts. Currently, these content data will be simply ingested and made accessible similarly to data from all other sources. This priority was set as it can be fulfilled by a largely automated technical workflow and will accelerate the increase in WFO's coverage.

We are aware that concept problems will also arise in the WFO System as a consequence of changes in the Taxonomic Backbone. As a future first step, an automated procedure may deduce potential issues, such as splitting or lumping of taxa from changes in synonymy, when an update of the taxonomic backbone takes place. These automated procedures will identify areas where taxonomic concepts may be in conflict, indicating problematic taxon names and potential mismatches. Taxa identified this way should ideally bear a caveat statement, at least warning users that attached descriptive information may not be aligned with the latest state of the taxonomic backbone. Widespread species will have treatments in many Floras, but still, the species concepts may differ.

■ TAXONOMIC EXPERT NETWORKS IN THE WFO SYSTEM

From the discussion above, it becomes clear that successful Taxonomic Expert Networks are a prerequisite for a successful and sustained WFO process. We define a Taxonomic Expert Network as a group of specialists that can count on a continuous organizational structure and a jointly used taxonomic information system. Pioneering initiatives in this sense were,

Table 1B. Other available electronic taxon portals with global taxonomic slicing.

Taxon	Website and contact	Notes
Asteraceae 23,600 spp.	Global Compositae Database (GCD) http://compositae.org Y.C. Flann, M. Bonifacino de León (UDELAR)	Evolution and development of the Global Compositae Checklist currently underway.
Boraginales 2,700 spp.	Boraginales Working Group http://boraginales.myspecies.info/	Curated consensus. Taxonomic family-level backbone.
Brassicaceae 4,100 spp.	BrassiBase https://brassibase.cos.uni-heidelberg.de M. Koch (HEID)	Comprehensive website including species-level checklist, phylogenetics tools, etc.
Campanuloideae 800 spp.	http://Campanula.e-taxonomy.net BGBM (B)	Species-level taxonomic backbone, and structured morphological and molecular data.
Cichorieae 2,400 spp.	Cichorieae Systematics Portal http://cichorieae.e-taxonomy.net/portal BGBM (B), N. Kilian, R. Hand, E. von Raab-Straube	Species-level taxonomic backbone and descriptions, continuously updated, to participate in Asteraceae TEN.
Cycadaceae 270 spp.	http://www.cycadgroup.org/ M. Calonje	Centered around IUCN cycad specialist group.
Dioscoreaceae 870 spp.	L. Raz (COL)	Update of taxonomic backbone underway.
Dipterocarpaceae 720 spp.	https://rbg-web2.rbge.org.uk/diptero/ M. Newman (E)	TEN ready to begin.
Poaceae 12,000 spp.	https://www.kew.org/data/grasses-db/index.htm M. Vorontsova (K)	Interactive database with descriptions, synonyms and keys in DELTA.
Lecythidaceae 311 spp.	Lecythidaceae—the Brazil nut family http://sweetgum.nybg.org/science/projects/lp/ S.A. Mori, N.P. Smith, X. Cornejo & G.T. Prance	Species-level taxonomic backbone and descriptions. Regularly updated.
Legumes 16,400 spp.	International Legume Database & Information Service https://www.ildis.org/ Y.R. Roskov, F.A. Bisby, J.L. Zarucchi, B.D. Schrire & R.J. White	Version 10.01 of the ILDIS Taxonomic Backbone is available via their portal. The data was last edited in June 2018. There is a drive to reinvigorate the taxonomic community in this collaboration.
Melastomataceae 5,150 spp.	http://www.melastomataceae.net F. Michelangeli (NY)	Data incorporation still underway.
Quiinaceae 50 spp.	G. Zizka (FR)	Unpublished website with content.
Sapotaceae 1,800 spp.	https://padme.rbge.org.uk/sapotaceae/ P. Wilkie (E)	Update of taxonomic backbone underway.

for example, ILDIS for legumes (Bisby, 1993), Solanaceae Source (2004–). Also the eMonocot project developed by Wilkin and colleagues at Kew aimed at creating a virtual environment to enhance collaboration of those working on monocots (Santarsiero, 2013), but a continuation as an independent project with the described informatics tools was not followed up. The idea of specialists in a larger taxonomic group coming together and cooperating to advance the knowledge about that group is definitely not a new one, as demonstrated by many taxon-specific conferences, in some cases with resulting publications. Interest in cooperation is thus clearly a feature of the plant taxonomic community. A somewhat firmer organizational structure and support from information technology geared at research cooperation, dissemination of results and data, and their use in applied fields such as conservation, as well as joint publications, may lead to further progress. This has the potential to bring about the much-needed speeding-up of progress in correctly delineating species boundaries, describing these entities in a timely manner and also making this information available (see Dayrat, 2005). Institutions may gain visibility by providing coordinating roles and/or the necessary IT-support. Individual taxonomists gain a forum to prioritize their research and, e.g., publish partial results. Individuals and institutions in taxonomy live in a competitive scientific world, so participation in a Taxonomic Expert Network must have advantages beyond a single product such as a WFO treatment. The WFO, however, may be able to play a role in instigating the formation of Taxonomic Expert Networks.

One issue in the formation of a Taxonomic Expert Network is the size of the taxonomic group covered. A large

enough monophyletic group should be selected to avoid falling back to the individual specialist level, but no restrictions with regard to the taxonomic rank should be imposed. For example, some large genera such as *Carex* or *Euphorbia* may well merit coverage by an individual Taxonomic Expert Network, while the multitude of families in Caryophyllales merit inclusion in an order-level Taxonomic Expert Network.

In the context of WFO, the main responsibility of a Taxonomic Expert Network will be the maintenance of the Taxonomic Backbone in their respective group. However, as stated above, management of descriptive content would also best be handled by a Taxonomic Expert Network, although this may be a long-term perspective for many taxonomic groups. A necessary medium-term aim would be the curation of geographic distribution data, such as in GBIF, because this would directly affect the usability of WFO in local, national and regional contexts, for example in the management of natural resources and conservation.

WFO standards developed for the ingestion of information have the potential to have a structuring influence on the phytotaxonomic community. However, channeling all information through Taxonomic Expert Networks or other networks will need rather sophisticated data handling capabilities and substantial editorial resources at the networks' side, which will often not be available. Language issues may further aggravate this. In view of the immediate short-term deadline of 2020, this results in a certain dilemma: the currently applied method of ingesting all datasets into the WFO database and managing them only via names in the Taxonomic Backbone will not incorporate information on concept relations generated by the specialist networks. We realize that a high-quality product will only be achievable for certain groups of angiosperms by the end of 2020. Thus, we need to make sure that WFO becomes truly dynamic and sustainable and that it can be improved as better information becomes available. We hope that conceptual discussions surrounding this endeavour will ultimately result in the establishment of organized and institutionally supported specialist networks, and that the increasing activity of such Taxonomic Expert Networks will gradually transform the taxonomic landscape. Therefore, prospective Taxonomic Expert Networks are welcome to make a proposal to the WFO council, and the council is also actively working to support the formation of new Taxonomic Expert Networks.

■ DATA SOURCES FOR THE WORLD FLORA ONLINE

There are two main kinds of data sources that both yield a wealth of information. This information is either on specific taxa (through online taxon pages managed by Taxonomic Expert Networks, published monographs and revisions) or on the plants in a specific geographical area (through Floras and checklists). However, the current state of knowledge varies considerably with respect to different plant groups and geographical regions. Active research networks exist for some taxa but not for others, and more recent revisions and monographs are available for individual genera and sometimes families in a mosaic-like pattern. Such monographic treatments cover the entire distributional range of the respective taxa, whereas Floras have limited geographic coverage. There are many completed and active modern Flora projects around the world. In the following, we provide an overview on the major existing resources for content data, with an attempt to look at what is in principle already available in a digital format, and show what has been so far ingested into the WFO (see Appendix 1).

As a principle, the taxonomic portals, which are managed by the respective specialist networks or individual researchers, are born digital. Provided that there is an agreement with the respective authors and that the collaboration with the respective Taxonomic Expert Network was adopted by the WFO council, ingesting the Taxonomic Backbone and Content data depends on the compatibility of data formats and the implementation of a technical workflow. The necessary data standards and some experiences on the practical implementation of the workflow are thus reported below. Table 1 presents a list of electronic taxon portals. It shows that the taxonomic community is making a lot of progress towards dynamic information sources for selected families and genera. The table highlights those Taxonomic Expert Networks and portals that are already interacting with WFO (Table 1A).

Also, a wealth of printed monographic information exists. In most cases, modern monographs are dedicated to monophyletic taxonomic entities, which are treated throughout their entire range of distribution (see Kilian & al., 2017; or Pessoa & Alves, 2019 for recent examples). This information is in journals or series, and has either already been scanned or needs to be scanned and made machine-readable via a markup process. Large-scale Floras can also play a monographic role for their endemic higher taxa; for example, the *Flora Neotropica* is actually a series of monographs for Neotropical plants. A recent example is the Quiinaceae (Schneider & Zizka, 2016), a complete treatment for that exclusively Neotropical plant family. The Species Plantarum Project – Flora of the World (SPPFW; Prance, 1992; G.F. Smith, 1996, 2002) published worldwide monographs of plant groups up to the year 2005. The SPPFW treatments are available as pdfs and cover approximately 1000 species in 11 families in great detail and with a globally consistent taxonomic backbone (Brummitt & al., 2001) but without updates after their publication.

A part of the globe is covered by large-scale checklists (see above, level 2 data) with a consistent taxonomic backbone. The African Plant Database (2020) currently includes 78,076 accepted taxa and 203,587 names with their nomenclatural status for the African continent and Madagascar. It is already harmonized with the Botanical Database of Southern Africa (BODATSA; SANBI, 2016). The Euro+Med PlantBase (Euro+Med, 2006–) covers Europe, the Mediterranean region and the Caucasus, which is a biogeographically consistent region. It includes ca. 44,417 accepted species and subspecies of vascular plants plus more than 94,000

synonyms, with an extensive bibliography, mapping of misapplied names, country-level distribution data and status information. The Checklist of the Vascular Plant Species of the Americas (Ulloa Ulloa & al., 2017) is a searchable database with nearly 125,000 species (Ulloa Ulloa & al., 2018–), integrating the many country-level checklists elaborated since the 1990s. The Australian Plant Census (Australian Plant Consensus, 2005–) lists nearly 28,000 species as accepted. Advantages of such checklists are the provision of a complete taxonomic coverage at least for vascular plants, a dynamic architecture and up-to-date information (albeit with content in the sense of WFO mostly restricted to geographic distribution). The African Plant Database is maintained in the modular management system Botalista (Botalista, 2019); BODATSA is held in BRAHMS (1989–), whereas Euro+Med Plantbase uses the EDIT Platform for Cybertaxonomy (Ciardelli & al., 2009; Berendsohn, 2010; EDIT, 2019), and the Americas checklist is managed in Tropicos (2019).

Many floristic projects continue to generate treatments for vast areas of the world, but in most cases, they are far from complete. Nevertheless, Floras hold the most extensive amount of Content relevant to WFO. In most of the complete Floras, the treatments were published over decades, so that the earlier family accounts may not necessarily reflect current genus and species circumscriptions, but due to the aforementioned progress in systematics, this is often also true for Floras still in progress. Frodin (2001) provided the last comprehensive overview of Floras published or in progress.

Several more recent large Floras provide consistent treatments at (or almost at) continental scale. Recently, the *Flora of China* (Wu & al., 1994–2013) was completed; *Flora of North America* (Flora of North America Editorial Committee, 1993–) and Flora of Australia (1981–) are well underway (see Appendix 1), whereas others such as *Flora Malesiana* (Van Welzen & al., 1948–) cover just a quarter of the taxa. A look at published Floras from different regions of the world makes clear that substantial content is already available, but it also illustrates some conspicuous large gaps that need filling. To get an overview on the content that is or potentially could be available for WFO, we have therefore summarized the current state of major floristic treatments (completed and underway) within the respective continents (Appendix 1). Although a complete review would be beyond the scope of this paper, we address important datasets and their availability in electronic form, and their availability to WFO as currently agreed. Table 2 presents details of the Floras that so far have been ingested into WFO (as of July 2020).

This abridged overview clearly shows that a large number of regional Floras exist, which play a pivotal role in achieving a global coverage. Although Floras cover a significant proportion of the world, many of these are not yet in a databased format that can directly be used for WFO in the short-term. Our overview also shows that many activities overlap and are not coordinated, accentuating the need for a concerted approach by the taxonomic community, e.g., by regional initiatives cooperating with Taxonomic Expert Networks that provide the global view.

Our overview also unravels several major gaps where no Floras are available. On the African continent, this applies to the Central African region, where only *Flore du Gabon* is well advanced, and *Flore d'Afrique Centrale* is 60% complete (Sosef, 2016), but a lot is missing in Cameroon and Equatorial Guinea. The Republic of the Congo, the Central African Republic and North and South Sudan remain without any Flora to date, although an annotated checklist for Sudan exists (Darbyshire & al., 2015). In the Americas, major gaps are in the Central Andes where Bolivia has no Flora at all and Peru only an incomplete and largely outdated one (MacBride, 1936–1960), and in Colombia, just 5% of the plants have been treated in the monographic series *Flora de Colombia*. Likewise, Mexico, with its estimated 24,000–25,000 vascular plants has no Flora, although various states are covered by active Flora projects. The list by Villaseñor (2016) provides an overview of the country, although the evaluation of species in most families and genera by taxonomic experts is still pending. Large parts of tropical SE Asia (in particular Indonesia and Papua New Guinea) remain a big challenge in terms of availability of Flora accounts. These are mostly available as species descriptions in journals, or treatments of selected parts of the flora such as *Tree Flora of Sabah and Sarawak* (see Tan & al., 2009) and the *Handbooks of the Flora of Papua New Guinea* (Womersley & al., 1978–1995). However, about 60 to 70% of the known species occurring in the *Flora Malesiana* region appear to be covered in regional/local treatments and scattered publications (E. Smets, pers. comm.). The Botanical Survey of India has created the *eFlora of India* with the goal of making the published treatments of about 4500 of the country's estimated 18,000 plant species available online. However, there is no consistent taxonomic backbone that would integrate progress in research on Indian plants. There are several countries without any Flora such as Myanmar. There are still gaps in parts of eastern Europe and the Balkan Peninsula, where only older and sometimes incomplete Floras are available. More recently, some synoptic keys were elaborated (Appendix 1), whereas modern Floras are lacking, and *Flora Europaea* (Tutin & al., 1964–1980) is largely outdated. Our findings underscore the need for an up-to-date and comprehensive global review on the current state of assessment of plant diversity in all countries throughout the world. On the other hand, we also show that there is a wealth of information that could be digitized, mobilized, and would substantially advance the development of the WFO.

■ TECHNICAL IMPLEMENTATION OF THE WORKFLOW

Components developed for the eMonocot project (Santarsiero, 2013) formed the initial technical base, but are now being included in a WFO software toolset. Among this, the data management tool Botalista (2019) is being developed to manage the WFO data ingestion and quality control system (Palese & al., 2019). As mentioned above, there are two

Table 2. Descriptions included in the World Flora Online portal as of September 2020.

Source	Descriptions of taxa from original source					Matching accepted taxa in WFO Taxonomic Backbone				
	Species Group	Species	Subspecies	Variety	Form	Species Group	Species	Subspecies	Variety	Form
Flora do Brasil 2020 project	33,960	32,793	280	887	–	29,984	29,362	210	412	–
Flora Neotropica	4,043	3,987	2	53	1	3,364	3,359	–	5	–
Flora of China @ efloras.org	33,890	29,244	706	3,940	–	27,611	26,115	330	1,166	–
Flora of North America @ efloras.org	13,259	11,079	710	1,470	–	11,227	10,043	402	782	–
Flora Mesoamericana	7,424	6,992	158	273	1	6,600	6,462	70	68	–
Flora de Nicaragua	7,326	6,921	160	245	–	6,167	6,036	52	79	–
Manual de Plantas de Costa Rica	5,323	5,323	–	–	–	4,668	4,668	–	–	–
Flora de Panama	5,370	5,172	28	168	2	3,641	3,607	8	26	–
Flora of west tropical Africa - POWOP	5,308	5,308	–	–	–	3,888	3,888	–	–	–
Flora tropical East Africa - POWOP	8,041	8,041	–	–	–	6,974	6,974	–	–	–
Flora Zambesiaca - POWOP	6,578	6,578	–	–	–	5,763	5,763	–	–	–
e-Flora of South Africa	16,544	15,924	338	279	3	15,666	15,087	323	253	3
Flora de Colombia	845	799	15	31	–	681	664	6	11	–
Resimli Türkiye Florası (Illustrated Flora of Turkey)	282	280	2	–	–	282	280	2	–	–
Moss Flora of China	1,720	1,673	10	37	–	1,647	1,608	9	29	1
Moss Flora of Central America	704	693	2	9	–	673	668	2	3	–
Flora of Pakistan	4,378	4,377	–	–	1	3,683	3,626	34	23	–
Flora Helvetica – Illustrierte Flora der Schweiz	3,083	2,857	226	–	–	2,565	2,482	83	–	–
Flora of the Lucayan Archipelago	276	276	–	–	–	251	251	–	–	–
Flora d'Afrique Centrale	112	2	95	–	15	37	1	35	–	1
TOTAL and *covering taxa in WFO Taxonomic Backbone*	127,552	117,536	2,682	7,310	24	*106,493*	*102,239*	*1,478*	*2,771*	*5*

The species group is the total of ranks at species level and below. The totals given for descriptions obtained from all Floras as original source is a sum whereas the totals given for matching accepted taxa in the WFO Taxonomic Backbone at the end of the Table (in italics) correspond to the taxa covered from the Backbone, counting each taxon only once.

complementary workflows: contributions to the Taxonomic Backbone and Content contributions. The Taxonomic Backbone provides the glue for the entire information system, and it is the way of linking and discovering content contributions from different sources. Key requirements are:

(i) taxonomic consistency, i.e., there should be only one accepted name for each taxon, and taxa of the same rank should not overlap in their circumscription;

(ii) comprehensiveness, i.e., all names that (potentially) are coming with contributions of content must be covered; eventually, all effectively published names should be covered;

(iii) comprehensive status assignment, i.e., all names should either be taxon names or synonyms or be marked as unresolved or excluded; and

(iv) unique identification, i.e., every name in the Taxonomic Backbone should have a globally unique identifier that is maintained ideally forever.

After looking at several options, the WFO Council, acting on a recommendation from the WFO Technology Working Group, has established the WFO Identifier (WFO-ID) to cover the latter requirement. WFO-IDs are 10-digit numbers with a "wfo-" prefix. The aim is to establish a resolvable identifier for all existing plant names that will not only be used in the context of WFO but can be used universally to reference plant names. WFO resolves its WFO-IDs utilizing HTTP URIs (Berners-Lee, 2005), which are structured as "http://www.worldfloraonline.org/taxon/" followed by the WFO-ID of the name. Ideally, all taxonomic slices of the backbone data are managed by Taxonomic Expert Networks with the technical resources to provide standardized information that can be directly input into a staging area of the WFO data management software (Fig. 1). A data definition for tabular data that can be provided to WFO using the Darwin Core-Archive (DwC-A) file format has been prepared as Guideline for *Taxonomic Backbone Contributors* (WFO, 2019a) as an appendix to the general Guidelines for Data Contributors (WFO, 2019b). However, data contributions in other formats can be accepted, depending on the resources available. The contribution will undergo an initial technical format check with the "WFO Gatekeeper" reporting back issues with the data to the data provider. Once the data pass the initial check, they will undergo further tests in the "staging area" of the Botalista system (Palese & al., 2019). Here, things like WFO-ID consistency, possible conflicts of family assignation, etc. will be reviewed, where necessary, in consultation with the data provider. Finally, the update of the Taxonomic Backbone will be incorporated, completely replacing the previous version (this is why the WFO-Identifiers must be maintained – existing Content data will stay linked to them).

For Content contributions (WFO, 2019c), the major process is the matching of names in the content treatment with those in the Taxonomic Backbone. Ideally, this will be done by the contributor, so that the content comes in with WFO-IDs already assigned. The name matching otherwise presents several challenges, which have to be resolved in the staging area – *inter alia* the treatment of homonyms and the incorporation of new names (see Fig. 2).

Although technology can help to streamline the process and provide automatic and semi-automatic processing, all this cannot be achieved without input by taxonomists. Essentially,

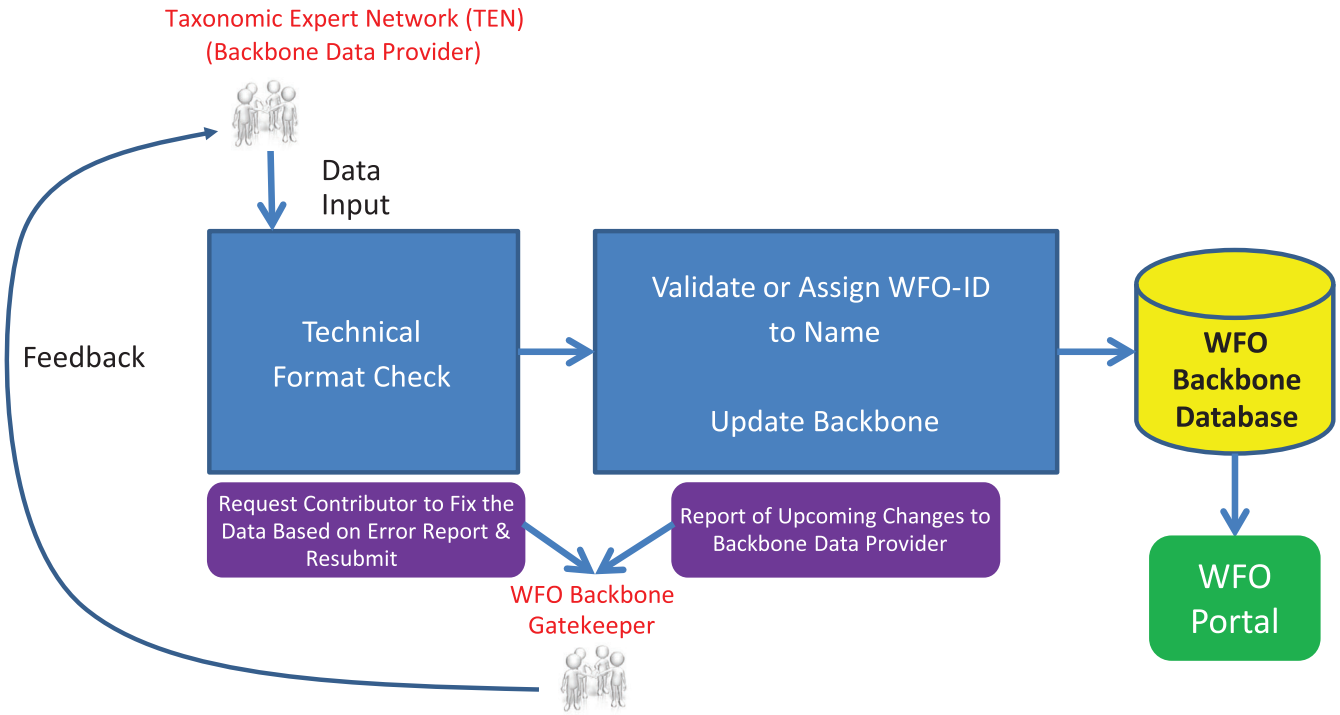

Fig. 1. Basic workflow for updates of the WFO Taxonomic Backbone.

the technical workflow for backbone contributions has to support, and be closely intertwined with, the curatorial workflow.

Data ingestion case 1: Solanaceae as a TEN. — The Solanaceae Source (2004–) aims to provide a worldwide taxonomic monograph of the nightshade family, Solanaceae. The project started with an online monograph of all species in the mega-diverse genus *Solanum* and was later extended to cover the entire family by incorporating all Solanaceae names from IPNI, with input from the worldwide Solanaceae expert community. Being a specialist-curated dataset, it was used as one of the exemplars to ingest a segment of the Taxonomic Backbone and, at the same time, descriptions and other linked Content. The initial data file from solanaceaesource.org contained 14,129 name records (including at the infraspecific level) with 1960 descriptions, 1370 images, 8950 bibliographic references and 77,178 records on types and specimens. Solanaceae Source content is managed in BRAHMS (1989–) and was converted to a ScratchPad (V.S. Smith & al., 2009) installation for community editing and public access. The data were exported as a DwC-A zip file, generated automatically through the functionality of the ScratchPads platform. On WFO's side, data checking follows a defined protocol. The taxonomy of the provided data is checked for consistency, reviewing, for example, that all accepted taxa should have a parent and all synonyms should point to an accepted name. Synonyms of synonyms and missing parent taxa are reported back to the provider in an iterative communication process. By comparison with the existing Taxonomic Backbone, new names to be added and existing names to be taken out of the Taxonomic Backbone are also reported back to the provider for confirmation before proceeding. In the process, several problems that had apparently been introduced during the migration of the Solanaceae Source data were discovered and reported back to content providers. For ingestion into WFO, the source data were corrected and modified to adhere to the requirements of the eMonocot harvester software used for WFO. Using solanacaesource.org data helped to sort out how the eMonocot software (Harvester and Portal) actually worked for Taxonomic Backbone data and ferreting out the ins and outs of the previously undocumented system. It became clear that caution must be taken when performing data conversion, even with "clean" taxonomic datasets, as the consequences of errors, omissions or misinterpretations of data will spread through the whole dataset. For example, because work on the dataset had initially focused on *Solanum*, the generic-level synonymy was not treated consistently across the entire dataset, meaning some taxa did not have the expected parent-child relationships. Feeding this back to the data provider meant such inconsistencies could be corrected, improving not only WFO but also the original dataset. Collaboration with Solanaceae

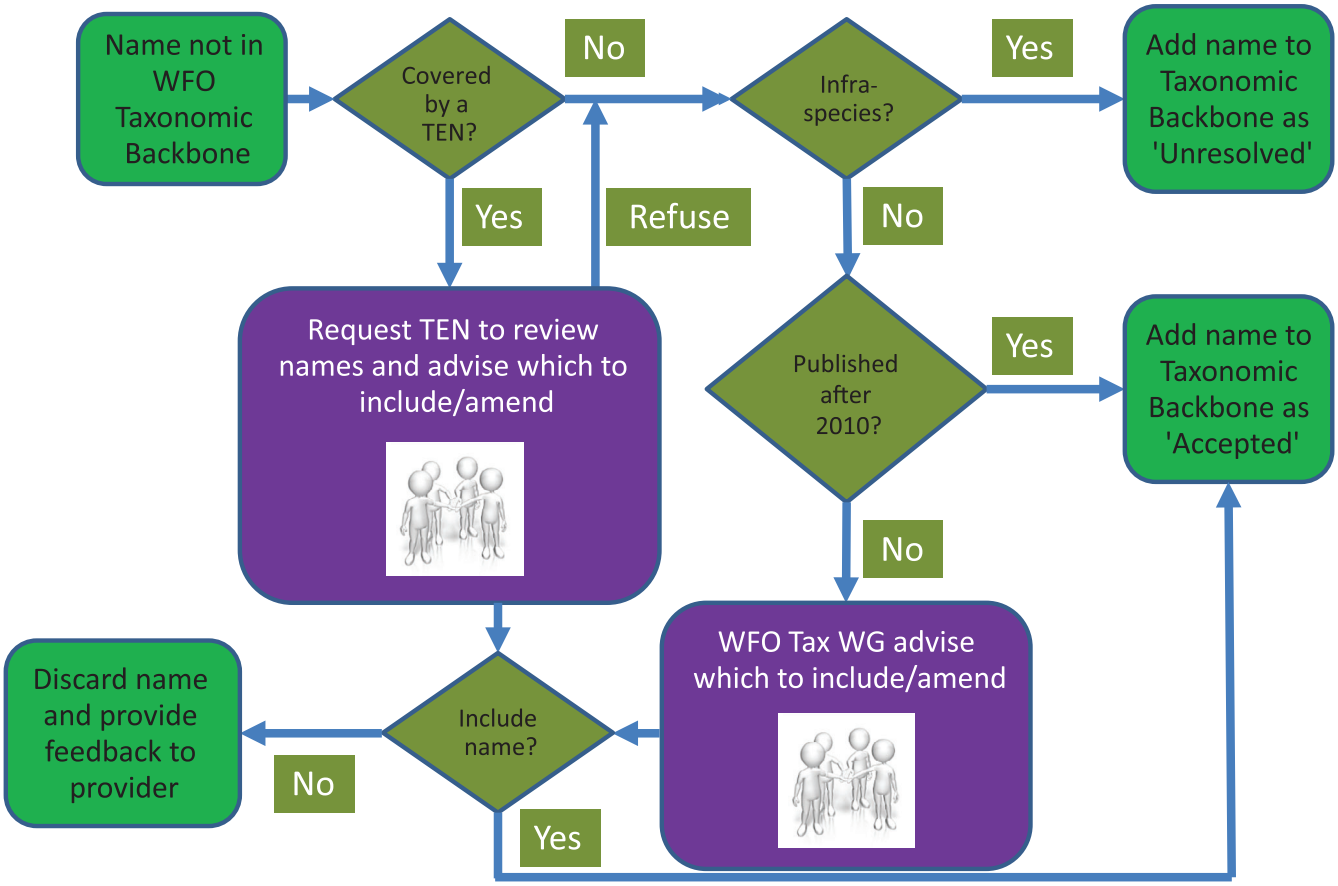

Fig. 2. Workflows for dealing with new names coming with content or backbone data for WFO. TEN, Taxonomic Expert Network.

Source also highlighted the relevance and importance of a close collaboration with the data provider to assure proper ingestion and interpretation of the data.

Solanaceae Source is continuously updated with new names, synonymies and descriptions, added on an *ad hoc* basis as they become available. Addition of new names follows their appearance in the published literature, while new synonymies and descriptions result from ongoing monographic work in the family, which proceeds at an uneven pace. The Scratchpad implementation of the dataset also includes up-to-date descriptions that are not published anywhere else (i.e., in books or journals but ideally peer-reviewed by contributors), and descriptions adhere to a standard format with the same characters treated for each taxon. Solanaceae Source is currently in revision, and in future will focus more on names and descriptions, with specimens being provided in a different format (possibly not through the Scratchpad); it is hoped that this will simplify the data exchange process with WFO. To maintain the Taxonomic Backbone for Solanaceae in WFO, updates of the Solanaceae Source dataset are shared with WFO currently on an irregular basis, but future efforts will focus on regular updates with downloads of the continuously changing dataset for ingestion into WFO.

Data ingestion case 2: Nepenthaceae from the Caryophyllales Taxonomic Expert Network. — After publishing the generic checklist for the order Caryophyllales (Hernández & al., 2015, continuously updated online: www.caryophyllales.org), the Caryophyllales Network's next task is the creation of a species-level backbone for the entire group. For the Caryophyllales Taxonomic Expert Network, this includes many authors from more than 20 countries and is carried out in parallel by working on revisions of monophyletic entities at the level of genera or groups of genera. To provide an example and develop a workflow, one of us (Berendsohn) used the semi-monographic *Flora Malesiana* treatment of the Nepenthaceae (Cheek & Jebb, 2001), which had been digitized, marked-up and imported into the EDIT Platform (Hamann & al., 2015). *Flora Malesiana* recognised 80 species and 3 naturally occurring named hybrids. The centre of diversity of this monogeneric family is in the geographic area covered by the *Flora*. Consequently, it should be a fairly simple task to expand the treatment to global coverage using the descriptions of the extra-Malesian taxa as well as those with a wider range from the "skeletal" monograph provided by Jebb & Cheek (1997) and to add a few new taxa. This was thought to be a realistic approximation for the treatment of a taxonomic group corresponding to our 1st-level Content category. To make this into an example treatment for the Caryophyllales Network, too, all names listed in IPNI and The Plant List (i.e., in the WFO backbone) were to be treated. Protologues were to be checked and (where possible) electronically linked to the name, type citations were to be added and linked, and nomenclatural citations and distribution data were to be standardized.

Due to some factors, the task turned out to be slightly more complicated than initially assumed (Berendsohn & al., 2018). IPNI includes names of several artificial hybrids, which are perhaps not relevant in the context of WFO, but which are validly published names that can (and did) block usage of those names for new taxa. More such names were found in 19th-century horticultural series. Moreover, some IPNI names could not be resolved because their original publication, as stated, could not be traced back. Also, there were 79 new species published after 2001, in addition to the 8 extra-Malesian ones already expected. Some of them had been published in books and articles not available online. The original WFO backbone contained 262 names; the finished compilation consisted of 435 names (hybrid formulas not included). As a technical process, the data was added to the EDIT Platform using the TaxEditor tool, and concept relations between different treatments were established where necessary. The existing WFO-IDs for names covered by the original Taxonomic Backbone were incorporated in the treatment as well as IPNI identifiers, where available. For all names not previously occurring in the Taxonomic Backbone, new WFO-IDs were created and provided by the WFO Gatekeeper to be added to the treatment in the EDIT Platform. The entire backbone *Nepenthes* treatment, including the WFO-IDs for all names, was subsequently exported following the procedure set out in the WFO Guide to contributors (WFO, 2019b). These data were then used by the WFO Data Manager to replace the respective "taxonomic slice" in the Taxonomic Backbone. In this case, there were no additional data from Flora datasets present in the WFO database, but if there had been, the usage of WFO-IDs would have guaranteed the correct linkage to names in the new backbone. In a second step, the additional data (descriptions, etc.) can also be exported to a DwC-A file, including the WFO-IDs of the taxa and following the respective data definition (WFO, 2019c) for Content data, and then turned over to the WFO Data Manager for ingestion into the WFO database. This two-step process can be repeated if additional data are added to the Caryophyllales database. The second step will also be used for data provision from other databases maintained using the EDIT Platform, e.g., Flora de la República de Cuba (Greuter & al. 1998–) and Euro+Med PlantBase (Euro+Med 2006–).

Data ingestion case 3: South Africa as a regional dataset. — The dataset is composed of the South African National Plant Checklist (SANPC), which currently includes 23,170 taxa (SANPC, 2019), and the Botanical Database of Southern Africa (BODATSA; SANBI, 2016), which contains data related to collections in southern Africa, published floristic data and related bibliographic references and is commonly known as the e-Flora of South Africa (Le Roux & al., 2017). The floristic information was ingested into WFO following a restructuring step (Ranwashe & Le Roux, 2019) to meet the DwC-A standard through the Integrated Publishing Toolkit of GBIF (Robertson & al., 2014).

The first step was the matching of validly published names (name identifiers) from the South African National Plant Checklist to the WFO Taxonomic Backbone. This was implemented by connecting the WFO identifiers to the names included in the e-Flora of South Africa. Initially, around 85%

of taxa provided were matched with names in the Taxonomic Backbone. Two sources of incompatibility were identified: (a) incorrect author citations/non-standard author forms or spelling irregularities in BODATSA, which could easily be rectified, leading to an improvement of the database and raising the matched-names ratio to 88% of the names provided; (b) the remaining names were not available in the Taxonomic Backbone. In many cases, these were names of narrow endemics, infraspecific taxa but also species described after 2013 (when The Plant List was last updated). These names were added to the Taxonomic Backbone through a process of registering the SANPC as a taxonomic backbone contributor. These names were then ingested into the Taxonomic Backbone as unchecked names, which allowed the assignment of a WFO-ID. In a further step, they can be verified by the provider and the respective Taxonomic Expert Network (if there is a TEN covering this taxon) and a decision is made to incorporate each name as accepted name or a synonym to a then wider taxon concept of the respective species with a different heterotypic accepted name. In either case, the description and other content remained unchanged as provided by BODATSA and is also connected in WFO to its original name, either being an accepted name or a synonym.

Once the WFO-IDs were assigned, in the second step, the content was extracted from BODATSA in three tables, matching records among the different tables: (1) the taxa table, with WFO-IDs; (2) the references table, with bibliographic citations of publications pointing to the source of the descriptions, which contains the reference identifiers along with the corresponding WFO-IDs and the bibliographic citations texts; and (3) the descriptions table, containing the WFO-IDs, the different types of descriptions, the field defining the types of descriptions (e.g., morphology, diagnostic, distribution, habitat) and the bibliographic reference identifiers that link the bibliographic source from the references table to the descriptions texts.

The third step was uploading the data into the Integrated Publishing Toolkit (IPT). This tool supports the preparation of data and prior checking of data to comply with Darwin Core (DwC) data standard and the DwC-A format. Once all precautions had been taken in terms of mapping the Darwin Core fields and assuring consistent data, there were no obstacles encountered. The workflow started with creating a resource in the IPT (e.g., e-Flora). Then the IPT was connected to the SQL server database containing the e-Flora descriptions (for the three tables mentioned above, three different connections were established). Once connected, the Darwin Core mappings were completed (and reflected in a resulting mapping configuration file called meta.xml). The Taxon Core (taxa table) was the Core used, and the descriptions table and references table were associated as extensions. The WFO-IDs were used to relate the three tables. Additionally, a unique field, the reference identifier was used to link each bibliographic reference with its corresponding description. This was declared in the mapping definition of the references table through the Dublin Core term "dcterms:identifier". Finally, the successful implementation of the upload required the mapping of descriptions (from the descriptions table) to their references through the reference identifiers (from the references table). The Dublin Core term "dcterms:source" allows the harvesting tool used by WFO to create the link between the description and its bibliographic citation.

■ ACHIEVEMENTS OF THE WFO BY 2020 AND BEYOND

The council decided during the 2016 meeting in South Africa that WFO will be an ongoing program that will operate post 2020 and not just a response to the 2020 biodiversity goals. This is more than reasonable considering the enormous efforts put in by many institutions and individuals and the momentum gained in the botanical scientific community. The development of decision making, technical and editorial workflows has already led to broad participation so that it provides a solid base for further refinements.

It is important to note that the WFO is already comprehensive, both in terms of the Taxonomic Backbone that already includes practically every plant species known and of its Content. As of July 2020, the WFO contains 350,510 accepted names of land plants (i.e., names of currently accepted species = taxa at species level), and 1,325,205 names linked to the unique and consistent WFO-IDs and the corresponding 1,154,754 references. By the end of 2020, the status of more than 85% of accepted species has at least been reviewed by specialists working on the respective families or genera, or the respective species-level treatments were made by Taxonomic Expert Networks, which is important for the species classification to reflect up-to-date research. Only the remaining less than 15% of taxa still comes from the more or less automated process used to generate The Plant List, but work is underway to replace this part by authoritative treatments. The TENs are an achievement of the WFO programme and are increasingly covering the families and genera of land plants. The WFO has therefore already accomplished the best synthesis of land plant taxonomy, with its Taxonomic Backbone meeting the requirements of modern global species lists to be science-based and community-supported (Garnett & al., 2020).

Currently, WFO includes 127,552 descriptions of taxa at the rank of species and below (see Table 2), which are assigned to 102,239 accepted species plus 4254 accepted infraspecific taxa. This means that about 25 thousand descriptions belong to synonyms, which shows that the amount of taxonomic knowledge turnover is significant and underscores the need for an up to date taxonomic synthesis as provided by WFO. There are more than 55,000 images, and many more are to come in due course. Because the WFO database is a dynamic system with constant updating, stable versions are provided periodically as citable output. A possible model for this is the CoL, where annual versions are produced from the dynamic database to provide a referenceable snapshot of the entire dataset (Roskov & al., 2019).

We aim to ensure that the WFO portal is user-friendly and provides information in an easily accessible and usable format for consumers based on a single preferred global species list. The project will be a success if the WFO becomes not only a research database for the taxonomic community but also provides data for a wide spectrum of users, which can be applied especially to plant conservation or other needs arising from science-based management of biological diversity. Also, the availability of an application programming interface (API) and the creation of tools to match plant names against the WFO Taxonomic Backbone (Kindt, 2020) will promote the incorporation of WFO information in products created for end-users.

The development of the WFO is work in progress and will require input from the entire community, not only in terms of data but also with respect to collaborative procedures and communication with user communities. Today and in the future, WFO provides an opportunity to advance standards with respect to describing decision making processes regarding the data presented and regarding the editorial workflows in a dynamic online system. Taxon-based links to the sources being maintained by Taxonomic Expert Networks will in this context not become superfluous but may provide easy access to the research data and original results supporting the hypotheses on species and genus limits adopted for classification, including alternative hypotheses. Here we envision a huge potential for the Taxonomic Expert Networks when they become increasingly active in research data management for "their" taxa.

Apart from work towards mobilizing more data from sources that are currently only represented as hard-copy-published materials, and involving more institutions and Taxonomic Expert Networks from throughout the world, we have some specific "post 2020" milestones for the WFO. One of them will be to streamline the incorporation of newly described species, where Taxonomic Expert Networks do not already pick these up. For example, in the course of the preparation of the *Manual de las Plantas de Costa Rica*, hundreds of taxa were newly described (Grayum & al., 2004). As long as name registration is not mandatory for plants (see Turland & al., 2018), these names would have to be submitted directly to WFO or one of the participating networks. A workflow involving IPNI and participating networks needs to be implemented to manage this. Another milestone concerns software development, which will not only enhance the overall functionality of the portal but will also focus to better explore the geographical data to support the utility of WFO for national and regional inventories and conservation assessments.

To further raise the quality of taxonomic information and to pave the way for the mapping of taxon concepts that are ultimately needed to accurately relate up-to-date taxonomic information to specific geographical areas, some simple indicators are currently under discussion in the WFO consortium:

- Reasons why a certain name was not accepted can be indicated by "flagging" names to specify one of the following: (i) it is a taxonomic synonym (i.e., the original concept behind the name is not regarded as distinct from another taxon), (ii) the name does not conform to nomenclatural rules and thus cannot be used (illegitimate names, names not validly published, etc.), and (iii) names that cannot be placed because of a lack of knowledge (e.g., because the protologue only gives scarce information, type specimen could not be located, etc.).
- An indication of the different levels of knowledge regarding the naturalness of taxa as currently defined. A recently proposed approach (Borsch & al., 2018) flags taxa in a backbone treatment as "green" when species limits were studied with evolutionary methodology; "red" when initial results of evolutionary analyses point to a currently accepted species delimitation that probably does not correspond to a natural unit; or "grey" (or yellow online) when no thorough analysis of species limits has yet been carried out.
- A similar "traffic light" approach may be taken with regard to insecurities relating to the circumscription of taxon concepts as mentioned above.

■ WFO PROVIDES MUTUAL BENEFITS FOR REGIONAL FLORAS AND TAXONOMIC EXPERT NETWORKS

WFO facilitates collaboration and access to data by being the comprehensive resource on the world's plants maintained and verified by the taxonomic community. The preparation of Floras needs expertise on the occurrence of taxa in a given geographic region but also expertise on the delimitation of species and genera; this usually requires analyses including specimens from beyond the Flora area. On the other hand, the preparation of global treatments and knowledge syntheses on certain plant lineages as forwarded by the Taxonomic Expert Networks needs to cover specimens worldwide. The research of Taxonomic Expert Networks may go deeper in delimiting species and genera but will be limited in overall taxonomic coverage.

Authors who are treating "their" plant group in a particular geographic region, could thus contact Taxonomic Expert Networks or even get involved in the respective Taxonomic Expert Networks. This contact will potentially help to harmonize the use of names and concepts across the globe, thus positively reinforce a consensus taxonomy. As a future perspective, Taxonomic Expert Networks can manage joint information sources in which structured descriptive data, both morphological and molecular, become available along with their links to specimens.

It needs to be underscored that the field of plant taxonomy is a good example where digitization has already created a much-improved research environment. This includes better access to information (e.g., through JSTOR Global Plants, GBIF and BHL) and communication that is facilitated by electronic media. But different attitudes to collaboration in the

current community are also relevant, shifting more and more from projects where an individual author has worked alone on a monograph for many years to teams that approach a taxonomic synthesis in the sense of integrative taxonomy. G.F. Smith & al. (2017) have accentuated the compatibility of the traditional monographic SPPFW-approach with WFO, but they also pointed out that SPPFW has failed to gain sufficient traction in the botanic community. However, we also have to acknowledge that the commitments by many institutions worldwide helped to implement the WFO. The recognition given through the Convention on Biological Diversity provided additional motivation to this engagement, as the WFO responds to a globally adopted priority (i.e., GSPC Target 1). The institutions supported both individuals to take leading roles and providing in kind and other support that facilitated the hire of several technical staff. The wider availability of significant electronic datasets was also a major driver. Ten to fifteen years ago, many of these datasets hardly existed that allow the WFO to make full use of the advances in information technology to integrate with and support the scientific community.

Partnership of members of the taxonomic community with WFO will further increase the visibility and recognition of Taxonomic Expert Networks (some specialist taxonomic websites are not easy to find). Such collaboration will also strengthen Taxonomic Expert Networks by facilitating access to names with connected metadata (as an "electronic starting package" that contains the information in a draft form on which the Taxonomic Expert Networks can build upon) and descriptions available for their study groups. This is already being practiced in some cases and has the potential to be developed as a service of WFO to the taxonomic community. From the perspective of Flora projects, the open-access WFO approach will not only further the accessibility and visibility of Flora treatments but also their utility by linking names and a wide variety of descriptions to the current Taxonomic Backbone.

■ WFO CONTRIBUTES TO THE KNOWLEDGE BASE NEEDED FOR HALTING BIODIVERSITY LOSS AND FOR SUSTAINABLE DEVELOPMENT

The WFO project is fundamental to the achievement of many of the GSPC targets, particularly those that require comprehensive and authoritative information and baselines on plant diversity. The GSPC targets are "nested" within the Aichi Targets, and the achievement of GSPC targets is recognized as a contribution to their achievement (Convention on Biological Diversity, 2010). National CBD authorities are asked to report on progress on both Aichi and GSPC targets, and use of the WFO as a national reporting tool will help nations comply with these responsibilities. Through the GSPC, the WFO is linked to governmental mainstreaming and is therefore of relevance to National Biodiversity Strategy and Action Plans (NBSAPs). The global perspective on all plant species provided by the WFO, including the taxonomy, distribution, native status, and habitats of plant species, is not only a direct response to Target 1 of the CBD but will also facilitate the efforts to achieve Targets 5–11. Some notable targets in which the WFO will contribute specifically to their achievement are the following:

- *Target 2: An assessment of the conservation status of all known plant species, as far as possible, to guide conservation action*. – A good understanding of the taxonomic basis for plant species is essential for meaningful conservation assessments.
- *Target 5: At least 75 per cent of the most important areas for plant diversity of each ecological region protected with effective management in place for conserving plants and their genetic diversity.* – Distribution information included in the WFO will help to identify and highlight particular important areas of high plant diversity.
- *Target 7: At least 75 per cent of known threatened plant species conserved in situ*.
- *Target 8: At least 75 per cent of threatened plant species in ex situ collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes*. – Information on endemism and conservation status (Target 2) included in the WFO will provide a means to identify priorities and monitor the achievement of Targets 7 and 8 and thereby will assist national-level implementation.
- *Target 9: 70 per cent of the genetic diversity of crops including their wild relatives and other socio-economically valuable plant species conserved, while respecting, preserving and maintaining associated indigenous and local knowledge*. – WFO can provide a reference point for the compilation of national, regional, and global lists of plants of socio-economic importance.
- *Target 10: Effective management plans in place to prevent new biological invasions and to manage important areas for plant diversity that are invaded*. – WFO will include descriptions of species known to be invasive in other regions but not yet recorded from a particular territory and so not included in local Floras.
- *Target 11: No species of wild flora endangered by international trade*. – Information contained in WFO will be particularly valuable to help in monitoring the achievement of this target and for the work of related Conventions, e.g., CITES.
- *Target 14: The importance of plant diversity and the need for its conservation incorporated into communication, education, and public awareness programmes*. – We hope that the publicity generated for the WFO could play a part in increasing awareness of the world's plants and the issues of their conservation among the public, as well as increasing knowledge among both the public and special interest groups such as biodiversity policy makers, citizen scientists, conservationists, and ecologists.

- *Target 16: Institutions, networks and partnerships for plant conservation established or strengthened at national, regional, and international levels to achieve the targets of this Strategy.* – Developing the international consortium that will provide the content of WFO will contribute to the achievement of Target 16.

While the WFO was initially designed to be primarily a reference for conservationists, it developed into an important source of botanical information for a wide range of other users, including the general public. If in the future WFO provides taxonomic data directly to GBIF to facilitate linkage of specimen or observation data with quality taxonomic information, Targets 2 and 5 (also 8) will become substantially more tractable. The WFO stands ready to provide data to the CoL and to contribute for implementing the vision of a single global unified list of species (Garnett & al., 2020) that is based on scientific rigor and broad community participation. For example, WFO is designed to be an important source for those compiling national biodiversity strategies, Red Lists and other biodiversity conservation policies and action plans thus benefiting a community in need of a globally credible resource. The already available distributional data from a wide range of sources, such as national-level Floras, allows for a resolution of the Geographical component in the WFO. Implementing these coming development phases of the WFO will be a big step forward towards a solid knowledge base that can globally support biodiversity conservation and management.

In the context of the global Sustainable Development Goals (SDGs) and the need to provide a data-driven decision-making basis for biodiversity management and conservation, WFO provides a valuable new common source for information on vascular plants and bryophytes that is up to date and increasingly globally consistent. As an authoritative resource, WFO is backed by the global research community, which ensures that new knowledge (i.e., newly discovered species, new distribution records, new results on genus and species limits and respective taxon concepts) can be incorporated in a timely manner.

In this context, it is also noteworthy that progress on GSPC Target 1 has been monitored through the regular CBD Plant Conservation Reports, as well as on a national basis in National Reports submitted to the CBD by individual Parties to the Convention. Monitoring progress on the GSPC went ahead pretty well throughout the decade from 2010 to 2020 and was reported to the CBD extensively (see https://www.plants2020.net/global-implementation/). Many of the GSPC targets were designed to be "SMART" measurable targets, which helped to ensure that they were easy to act as indicators themselves. The data in the WFO acts in itself as a pretty good indicator of progress on the achievement of GSPC Target 1. Preparing the post 2020 global biodiversity framework (Convention on Biological Diversity, 2020) should therefore consider these achievements and promote science-based and data-driven decision making to achieve its goals, thereby building upon collaboration with the global scientific community.

WFO has already demonstrated that the botanical community can come together very effectively and apply their institutional resources and individual efforts to a project that is of huge global significance. Funders should note that there are well-defined work packages, both at the level of general WFO data structures and Taxonomic Expert Networks that can match funding requirements in individual countries as well as in bi- or multilateral contexts. WFO and its Taxonomic Expert Networks are a globally distributed structure that allows for countries to invest locally in their research communities (Flora production and scientific research) and at the same time participate in a global programme. This is important in times when on a global level basic science funding (including Flora projects and taxonomy) is decreasing. Currently, national-level Floras in many countries survive from in-kind contributions of institutions or consortia of institutions – although taxonomically sound data on plant diversity are a basic requirement to meet national biodiversity targets. Further considering that the progress rates of country-level Floras are slow in many countries, awareness should grow that modern Flora writing can benefit from current (global) sources and networks such as the WFO.

■ CONCLUSIONS

The World Flora Online is the first-ever comprehensive and authoritative global source of information on the world's plant diversity, compiled, moderated, and updated by an expert and specialist-based community and actively managed by those who have compiled and contributed the data it includes. The strength of the project is that it is committed to the FAIR principles (Wilkinson & al., 2016): FINDABLE—The WFO-ID serves as a global unique identifier for each name. WFO provides all data associated with the name, with its proper attribution and rights metadata. Users can use the WFO portal to search for information, and WFO's API allows machines to search and retrieve information from the system. ACCESSIBLE—WFO keeps all original input on its file server. Human-readable metadata and data can be accessed through the WFO portal, directly or as a download in DwC-A format or as simple text. Additionally, WFO provides an API that allows users and machines to interact with the system to search, access and download information as HTML or JSON. WFO currently stores and makes available versions of the taxonomic backbone on its file server, which will also be submitted periodically to a trusted repository. INTEROPERABLE—WFO uses an adapted Darwin Core data format und DwC-A for data input and output (WFO, 2019b,c). Users can download the information in DwC-A or as simple text. WFO's API enables users and machines to programmatically access content. It also provides documentation in RestDoc format for each endpoint through an OPTIONS request. REUSABLE—WFO recognizes all data providers in the portal and clearly state their usage licenses. WFO also cites and links to the sources if data providers indicate us to do so.

This way, the WFO approach considerably increases quality and the credibility of taxonomic information for end-users of taxonomy. For the global scientific community, the dedicated support of such a collaborative spirit is also very relevant to further promote additive workflows in plant taxonomy in a way that facilitates its development as a mega-science. Complying to rigorous scientific quality measures, the Taxonomic Backbone will promote information discovery on plants by connecting these data to the correct plant names. As such, WFO is relevant to all applied fields dealing with the diversity of plants. Specifically, it will provide input to the CoL and constitute a consistent taxonomic backbone for GBIF.

The ultimate success of WFO will be measured by the level of community buy-in to the initiative, which in turn is likely to depend on the availability of clear communication channels and user-friendly editing tools, both of which promote specialist participation. Community participation will also be key to the sustainability of the resource. If we can foment a community-wide sense of ownership and collective responsibility, WFO will have a much greater chance of long-term success. The partnership approach that has been developed since the earliest beginnings of the project is, therefore, of fundamental importance. If it is seen as an endeavour led by only a few very large institutions, it will fail to engender broad participation by winning hearts, minds, and funding. As a global initiative, it needs the support of all countries, in particular the CBD signatories, and the botanists working in those countries.

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■ AUTHOR CONTRIBUTIONS

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Appendix 1. Overview of major floristic data sources in the world.

A Flora is understood to be a publication with a consistent, synthetic treatment of plants within a region, typically including a single classification (taxonomic backbone), taxon descriptions, and other content (e.g., identification keys, illustrations). A Flora is an original source of information used by WFO, usually with different authors for different taxa. To be incorporated into WFO, a Flora has to be a citable publication in digital format, with marked-up data elements. This can be achieved through scanning the printed treatments in regional or national-level Floras (see respective categories in this Appendix). Other Floras are "born digital" and publish original accounts in digital format right away. Since the editorial workflows and publication standards for such e-Floras are still developing, we also list frequently used websites providing comprehensive information for countries, as long as they present this with a unified classification for all plants in their area and the source of the content is traceable (both original and compiled from previous individual publications). To be incorporated into WFO, the content has to be versioned in order to be citable. Checklists, regional and national, in print or online, provide a consistent taxonomic backbone reviewed by taxonomic experts. Although they contain little other "content", they significantly contribute to unify nomenclature and taxonomy for a region.

Floras and other sources already ingested into the WFO are highlighted with an asterisk (see Table 2).

AFRICA

Continental and regional-level checklists

African Plant Database (version 3.4.0). Conservatoire et Jardin botaniques de la Ville de Genève and South African National Biodiversity Institute, Pretoria, http://www.ville-ge.ch/musinfo/bd/cjb/africa/, 62,049 species including Madagascar with 11,477 species.

Euro+Med Plant Base (Euro+Med, 2006–) covers the North African countries adjacent to the Mediterranean sea; 44,417 species and subspecies of vascular plants in total; includes an extensive bibliography, vernacular names, occurrence data for countries, native status; constantly updated in the EDIT platform; http://ww2.bgbm.org/EuroPlusMed/.

Regional Floras

*Flore d'Afrique Centrale** (Flore d'Afrique Centrale Editorial Committee, 1948–); covers the Democratic Republic of the Congo, Rwanda and Burundi, 60% complete for an estimated number of 6000 species of vascular plants.

*Flora Zambesiaca** (Flora Zambesiaca Managing Committee, 1950–); Botswana, Malawi, Mosambique, the Caprivi Strip (Namibia), Zambia and Zimbabwe; 90% complete.

*Flora of tropical East Africa** (Turrill & al., 1952–2012); Kenya, Tansania and Uganda; treats 12,500 species of vascular plants; complete; in print and as pdf.

Flore d'Afrique du Nord (Maire, 1952–1987); Algeria, Morocco, Tunisia, Libya and Egypt; treats 60% of the estimated 9000 species and subspecies of vascular plants; remains unfinished; in print.

*Flora of west tropical Africa** (Hutchinson & Dalziel, 1927–1936, 1954–1972, 2014 [rev. e-book ed.]); Nigeria, Ghana, Sierra Leone and The Gambia.

Appendix 1. Continued.

The Flora of southern Africa (Codd & al., 1963–2005); covers Basutoland, Namibia, South Africa, and Swaziland, treats about 18% of the flora; not continued; in print.

Flora of Ethiopia and Eritrea (Tewolde & al., 1989–2009); treats about 7000 species of vascular plants; complete (see Demissew, 2014), but not updated; in print.

Checklists at national level

Catalogue des plantes vasculaires du Niger (Peyre de Fabrègues & Lebrun, 1976); in print.

Catalogue des plantes vasculaires du Mali (Boudet & al., 1986); in print.

Flore de la Côte-d'Ivoire: Catalogue systématique, biogéographie et écologie (Aké-Assi, 2001, 2002).

An annotated checklist of the vascular flora of Guinea-Bissau (Catarino & al., 2008); lists 1507 species of vascular plants; in print and as pdf.

Plants of Angola (Figueiredo & Smith, 2008); lists 6961 species but diversity may be more than 7100 species; in print.

Catalogue des plantes vasculaires du Burkina Faso (Thiombiano & al., 2012), lists 2067 species of vascular plants with ecological information, in print and as pdf.

Catalogue of the plants of Madagascar (Madagascar Catalogue, 2012–); 11,626 species from an estimated 14,000; continuously updated; http://www.tropicos.org/Project/Madagascar

Floras at national level

Flora Capensis (Harvey & Sonder, 1859–1865, vols. 1–3; Thiselton Dyer, 1896–1933, vols. 4–7; Hill, 1933); covers Northern, Western and Eastern Cape and KwaZulu-Natal Provinces; 11,731 species; not updated; in print.

Conspectus florae Angolensis (Carisso & al., 1937–1977); lists ca. 3500 species (45% of the flora) with descriptions and illustrations; has come to a halt; in print.

Flore du Gabon (Aubreville & al., 1961–); so far treats 5500 of an estimated 7000 species of vascular plants, active project; in print.

Flore du Cameroun (Aubréville & al., 1963–); so far treats 3500 of an estimated 8300 species of vascular plants, has recently been revived.

Flore illustrée du Sénégal (Berhaut, 1971–1988); in print.

Flora of Tunisia (Pottier-Alapetite, 1979–1981); in print.

Flora of Libya (Ali & al., 1979–1990); in print.

Flore analytique du Togo (Brunel & al., 1984); treats 2302 species with identification keys and extensive evaluation of specimens, but more recent estimates are more than 3134 species of vascular plants (Fousseni & al., 2014); not updated, in print.

Flore de Mauritanie (Barry & Celles, 1991); synoptic treatment of 1700 species; in print.

Flora of Somalia (Thulin, 1993–2006); treats 3165 species, complete; not updated, in print.

Plants of the northern provinces of South Africa: Keys and diagnostic characters (Retief & Herman, 1997); complete; synoptic treatment with keys; in print and as pdfs.

Flora of Egypt (Boulos, 1999–2005); treats ca. 2100 species; in print.

Flore pratique du Maroc (Fennane & al., 1999–2015); synoptic Flora with keys and illustrations; in print.

Flore analytique du Benin (Akoègninou & al., 2006); treats 2800 species of vascular plants; in print.

Flora de Guinea Ecuatorial (Velayos & al., 2012–); about 10% of an estimated 12,000 species of vascular plants treated, ongoing project, in print.

Flora of the Greater Cape Floristic Region (Manning & Goldblatt, 2012, vol. 1; Snijman, 2013, vol. 2); complete; synoptic treatment with keys; in print and as pdfs.

Plants of the Free State: Inventory and identification guide (Retief & Meyer, 2017); complete; synoptic treatment with keys; in print and as pdfs.

Flore illustrée du Tchad (César & Chatelain, 2019); treats 2098 species of vascular plants with short descriptions and illustrations of diagnostic characters; in print and as pdf.

A Flora of the Eastern Cape Province (Bredenkamp, 2019); complete; synoptic treatment with keys; in print and as pdfs.

e-Floras and websites

Flora of Zimbabwe (Hyde & al., 2002–); 4195 species; contains short descriptions, fotos and specimen data and is continuously updated; https://www.zimbabweflora.co.zw.

Flora of Mozambique (Hyde & al., 2007–); 6206 species; contains short descriptions, photos and specimen data and is continuously updated; http://www.mozambiqueflora.com.

Flora of Zambia (Bingham & al., 2011–); 6829 species; contains short descriptions, photos and specimen data and is continuously updated http://www.zambiaflora.com.

*e-Flora of South Africa** (SANBI, 2016); covers South Africa; 23,170 taxa (species level and below), with roughly 20,000 descriptions available from various sources, integrates the Floras that were elaborated for different provinces; continuously updated with new versions. The taxonomic backbone follows the South African National Plant Checklist (SANPC, 2019).

eflora Maghreb (Chatelain & al., 2018–); covers Morocco, Algeria, Tunisia; http://efloramaghreb.org.

AMERICAS

Continental-level checklist

Vascular plants of the Americas (Ulloa Ulloa & al., 2018–); integrates existing national-level checklists and covers ca. 125,000 species (http://www.tropicos.org/Project/VPA).

Regional Floras

*Flora Mesoamericana** (Davidse & al., 1974–); covers southern Mexico and Central America, and the 6 volumes published include 8725 or 48% of the region's 18,000 species.

*Manual of vascular plants of northeastern United States and adjacent Canada** (Gleason & Cronquist, 1991); treats 4285 species; a revised new edition is in progress (http://sweetgum.nybg.org/science/projects/northeastflora/).

*Flora of North America** (Flora of North America Editorial Committee, 1993–); Canada and U.S.A.; 21 volumes so far published treat 14,655 species of vascular plants of an estimated 18,600 species; R. Rabeler pers. comm.); pdf of printed volumes, but not updated; http://beta.floranorthamerica.org/Published_Volumes.

Flora of the Guianas (Görts-Van-Rijn & al., 1985–); covers French Guiana, Guyana and Suriname; active project; so far treats 2433 species of seed plants, 193 ferns and fern allies, 272 bryophytes and 129 lichens, from an estimated total of about 15,000 species; partly digitized (949 angiosperm species so far), species descriptions also published online together with a checklist using the EDIT Platform; http://portal.cybertaxonomy.org/flora-guianas/.

Appendix 1. Continued.

Floras at national level (including Floras for major parts of countries)

Flora Brasiliensis (Martius & al., 1840–1906); copiously illustrated and describing nearly 22,767 species, is still one of the most extensive treatments of the Flora of a megadiverse tropical country ever completed. The digitized work is available online in a fully searchable manner, with the original names standardized and related to an updated taxonomy (Shepherd & Canhos, 2005).

Flora of Peru (MacBride, 1936–1960); treats about 80% of the species known at the time, which is only a part of the estimated total; largely outdated, in print.

*Flora de Panama** (various authors 1943–1980); treats 6200 species with descriptions in the form of separate articles in the *Annals of the Missouri Botanical Garden*; species number appears to be considerably higher; not updated; in print and online (http://legacy.tropicos.org/Project/PAC).

Flora de Venezuela (Lasser, 1968–1984); incomplete, print only.

Flowering plants of Jamaica (Adams, 1972), print only.

Flora of Ecuador (Harling & al., 1973–); is continuously being published and will cover about 16,000 species of mainland Ecuador (Jørgensen & León-Yánez, 1999), print only.

Flora of the Lesser Antilles (Howard, 1974–1989); print only.

Flora de Veracruz (Gómez-Pompa & Sosa, 1978–); covers the state Veracruz, Mexico; 2830 taxa treated (37% of 5500 species estimated); http://www1.inecol.edu.mx/floraver/ (as pdf).

Flora of the Bahama Archipelago (Correll & Correll, 1982); print only.

*Flora de Colombia**** (Flora de Colombia Editorial Committee, 1983–); with 830 species treated has been marked up completely in xml for integration with other digital resources.

Flora del Paraguay (Spichinger & Bocquet, 1983–); published in print only.

Descriptive Flora of Puerto Rico and adjacent islands (Liogier, 1985–1997); print only.

Flora de la República de Cuba (Greuter & al., 1989–); an active project with about 30% of the 6775 species treated (R. Rankin, pers. comm.). The descriptions will in future be also published online in connection with the checklist of vascular plants of Cuba (Greuter & Rankin, 2017) held in an EDIT Platform database, and thus electronically available for WFO.

Flora del Bajio (Rzedowski & Calderón de Rzedowski, 1991–); covers the states Guanajuato, Querétaro, Michoacán and Mexico; 2830 taxa treated (50% of 5700 vascular plant species expected); http://inecolbajio.inecol.mx/floradelbajio/# (as pdf).

Flora of Tehuacán (Dávila Aranda & al., 1993–); covers the Tehuacán-Cuicatlán Valley in the states of Oaxaca and Puebla; 1646 taxa treated (54% of 2700 species expected); http://ibiologia.unam.mx/Flora/index.html (as pdf).

Flora de Chile (Marticorena & Rodríguez, 1995–2003); apparently discontinued, is also available only in print.

Flora of the Venezuelan Guayana (Steyermark & al., 1995–2005); states of Amazonas, Bolívar and Delta Amacuro of Venezuela; 9400 species; in print; a few families are online: http://www.mobot.org/mobot/research/ven-guayana/.

*Flora de Nicaragua** (Stevens & al., 2001); approx. 6000 species, updated online in Tropicos.

*Manual de plantas de Costa Rica** (Hammel & al., 2003–2020); treats 9359 species of seed plants, but the 1565 ferns and relatives are missing; marked-up pdfs available.

Flora Argentina (Zuloaga & al., 2012–); with 10,006 species, of which 40% are covered in the 11 published volumes. The data are fully accessible online.

Regional checklists

Checklist of the plants of the Guiana Shield (Funk & al., 2007); 8933 species of vascular plants, print only.

Catálogo de las plantas del cono sur (Zuloaga & al., 2008); treats 18,139 species for an area which includes Argentina, southern Brazil (Paraná, Santa Catarina and Rio Grande do Sul States), Chile, Paraguay and Uruguay, and thus partly overlaps with the Flora do Brasil.

Checklist of seed plants of the West Indies (Acevedo-Rodríguez & Strong, 2012); Caribbean Islands, lists about 12,000 species.

National-level checklists

Flora of Panama: Checklist and index (D'Arcy, 1987); lists 9616 species; in print.

Catalogue of the flowering plants and gymnosperms of Peru (Brako & Zarucchi, 1993); 17,119 angiosperms and 24 gymnosperms; not updated; the estimate for the country is 25,000 species with more than 2000 new species and floristic records already published individually since 1993 (D. Montesinos, pers. comm).

Nuevo catálogo de la flora vascular de Venezuela (Hokche & al., 2008); in print.

Catálogo de las plantas vasculares de Bolivia (Jørgensen & al., 2014); lists 15,345 accepted species and synonyms revised by specialists; there are already ca. 400 further taxa (species newly described and new records) being added in an online update (A.F. Fuentes, pers.comm.): https://Tropicos/org/Project/BC.

Catálogo de plantas y líquenes de Colombia (Bernal & al., 2015–); in print and online, lists 26,279 species as of 1 May 2020.

e-Floras and websites

*Flora do Brasil*** (Flora do Brasil 2016–); an updated inventory cites 36,027 species and 2915 infraspecific taxa of vascular plants and bryophytes. Building on this checklist, the Brazilian Flora 2020 project set out in 2016 to build an online Flora do Brasil (BFG, 2018), but the rapid initial progress was curtailed abruptly due to the economic crisis of 2018 (BFG, 2018). By July 2019, a total of 19,585 descriptions of vascular plants and bryophytes (R. Campostrini Forzza, pers. comm.) were available on the 2020 portal, which is in the process of being fully incorporated into WFO.

ASIA

Regional checklists

Conspectus florae Asiae Mediae (Vvedensky, 1968–1993); covers Kazakhstan (without northern part), Uzbekistan, Turkmenistan, Tajikistan; treats 9341 species, with recent additions (Kamelin & Khassanov, 2015); in print.

Caucasian flora conspectus (Takhatajan, 2003–2012); covers parts of the Russian Federation (northern Caucasus) as well as Armenia, Azerbaijan and Georgia; so far vols. 1–3 with 4417 species, about 2000 more expected; active project; in print and online as pdf (https://www.binran.ru/resursy/informatsionnyye-resursy/tekuschie-proekty/caucasian-flora/).

Euro+Med Plant Base (Euro+Med, 2006–); covers countries largely adjacent to the Mediterranean sea to the Caucasus (Armenia, Azerbaijan, Cyprus, Egypt [Sinai peninsula], Georgia, Lebanon, Palestinian territories, Russian Federation [north Caucasus], Syria, Israel, Jordan, Turkey); 44,417 species and subspecies of vascular plants in total; constantly updated in the EDIT platform; http://ww2.bgbm.org/EuroPlusMed/.

Regional Floras

Flora of British India (Hooker, 1875–1897); covers an area of present-day Afghanistan, Bangladesh, India, Malaysia, Myanmar, Nepal, Pakistan, Singapore, Sri Lanka and Tibet; complete treatment of the 14,312 vascular plant species recognized in the area in the late 19th century; for some countries

Appendix 1. Continued.

such as India, the Flora still is the only work that covers all families, although, for example, for India, it includes only ca. 60% of the assumed species diversity.

Flora of the USSR (Komarov & al., 1934–1964); covers a vast geographical area in East Europe, North, Central and Southwest Asia with 17,520 species; new species and nomenclature updated by Cherepanov (1973) with an additional 6250 taxa added; available also in English translation; in print and as PDF (https://www.biodiversitylibrary.org/bibliography/43751#/summary); it remains an important source of information and for many areas the only complete coverage of the flora.

Flora Malesiana (Van Welzen, 1948–); Series 1, *Seed plants*: vols. 4–23, 1948–2019, active project; Series 2, *Pteridophytes*: vols. 1–4, 1959–2012, active project. Note: Series 1, vol. 1, *Malaysian plant collectors and collections* published in 1950; vols. 2 and 3 were never published); covers Malaysia, Singapore, Indonesia, Brunei Darussalam, the Philippines, Timor-Leste and Papua New Guinea; so far, treats ca. 29% of the estimated 45,000 species of vascular plants in the area; treatments partly updated; online access to highly structured information derived from digitized volumes is available (Roos & al., 2011); https://floramalesiana.org.

Flore du Cambodge, du Laos et du Viêtnam (Aubreville & al., 1960–); so far treats 2310 species of vascular plants, which is less than a quarter of the flora; active project; in print; in French.

Flora Iranica (Rechinger, 1963–2016); covering Iran and adjacent countries; published treatments of more than 10,000 species of vascular plants; completed but not updated, in print.

Flora of the Arabian Peninsula and Socotra (Miller & al., 1996–); covers Saudi Arabia, Yemen, Oman, United Arab Emirates, Quatar, Bahrain, and Kuwait; two volumes published treating one-third of an estimated 4300 species; ongoing project; in print.

Flora of Pan-Himalaya (Hong, 2015–2017); so far, four volumes published, treating 978 species of an estimated 20,000; active project; in print.

Floras at national level (including Floras for major parts of countries)

Flora Turkmenii (Fedtschenko & al., 1932–1960); complete; treats 2607 species; in print.

Flora Uzbekistana (Korovin & al., 1941–1962); complete; treats 4147 species; in print.

Flora Azerbajdžana (Karjagin & al., 1950–1961); complete, treats 4072 species; in print.

Flora Kirgizskoi SSR (Schischkin & Vvedensky, 1952–1965, with additions); complete; treats 3576 species; in print.

Flora Armenii (Takhtajan, 1954–2010); complete, treats 3260 species; in print.

Flora of Kazakhstana (Pavlov, 1956–1966); complete; treats 5631 species; in print.

Flora Tadzhikskoi SSR (Ovczinnikov, 1957–1991); complete; treats 4447 species; in print.

Flora of Turkey and the East Aegean Islands (Davis, 1965–1985; and later supplements); comprehensive treatments of 9202 species; complete but not updated; in print.

*Flora of Pakistan** (Nasir & al., 1970–); about 5000 of an estimated 6000 species treated; in print; available via Tropicos (Hoch, 2000–), http://legacy.tropicos.org/Project/Pakistan.

Flora of Thailand (various editors since 1970: now Santisuk & al.); 6246 species in 250 families covered from estimated total of 10,000–12,500 species; to be finished in 2024; see Middleton, 2003; Parnell & al., 2003; some species brought online with Scratchpads (Cámera-Leret, 2015–); in print, in English.

Sakartvelos flora [Flora of Georgia] (Ketskoveli & Gagnidze, 1971–2011); almost complete (volume 17 with Poaceae still missing); treats ca. 3800 of an estimated 4300 species; in print.

Flora of China (Wu Z.-Y. & al., 1994–2013); complete treatment of 31,362 species of vascular plants; in print and marked-up pdfs available; http://efloras.org/flora_page.aspx?flora_id=2.

Flora of Bhutan (Grierson & Long, 1983–2002); complete; treats 5600 species; printed volumes, but also pdfs available; not updated.

Plantae vasculares Orientis Extremi Sovietici [Vascular plants of the Soviet Far East] (Kharkevich, 1985–1996); complete; provides data on the eastern part of the Russian Federation with 4113 species (Kozhevnikov & Rudyka, 2002); in print.

Flora of Siberia (Malyshev & al., 1987–2003); covers Russia from the Urals to watershed ranges along the Pacific; complete, treats 4510 species; also available in English; in print.

Flora of Japan (Iwatsuki & al., 1993–); treats three-quarters of the estimated 4500 vascular plants; active project; in print.

Flora of Taiwan (Huang, 1993–2003); ca. 4000 vascular plant species covered; not updated; in print and as pdfs; http://tai2.ntu.edu.tw/ebook.php?ebook=Fl.%20Taiwan%202nd.

Flora of India (Hajra & al., 1995–); ca. 4500 taxa treated of an estimated 18,000 vascular plant species (100 of 300 families); in print and as pdf.

Illustrated Flora of Vietnam (Phạm Hoàng Hộ, 1999–); treats well over two-thirds of estimated 8000 species of vascular plants; active project; in print; in Vietnamese.

Resimli Türkiye Florası [Illustrated Flora of Turkey]; two volumes have been published (Güner & Ekim, 2014; Güner & al., 2018); vol. 1 with introductory chapters; vol. 2 includes 395 species; expects to treat more than 10,000 species; vol. 1, print only; vol. 2, available in both print and electronic formats (http://satis.ang.org.tr/urun/resimli-turkiye-florasi-cilt-2-ekitap/).

Flora of Korea (Park, 2015–); will treat the estimated 3400 species; 8 of 10 volumes published; in print.

Flora of Uzbekistan (Sennikov, 2016–); so far, three volumes with 375 species out of a total 4340 species; active project; in Russian and English with simultaneous preparation of a digital version (see Sennikov & al., 2016).

National-level checklists

A checklist of the trees, shrubs, herbs, and climbers of Myanmar (Kress & al., 2003); lists 11,800 species; in print and as pdf.

Türkiye Bitkileri Listesi Damarlı Bitkiler [A checklist of the Flora of Turkey, vascular plants] (Güner, A. & al., 2012); 9996 species; complete; in print.

Türkiye Bitkileri Listesi Karayosunları [A checklist of the Flora of Turkey, bryophtes] (Erdağ & Kürschner, 2017); 942 species; complete; in print.

Conspectus florae Rossiae Asiaticae (Baikov, 2012); covers Siberia and the Russian Far East; a complete checklist including 6696 species; in print.

Species Catalogue of China (SCC Editorial Committee, 2013–); Volume Plants, 13 books, includes 464 families, 4001 genera, 36,152 species of bryophytes and vascular plants; in print; an electronic version as Catalogue of Life China released on 22 May 2020 (http://sp2000.org.cn/).

Nomenclatural checklist of Flora of Georgia (2nd ed.; Nakutsrishvili & Churadze, 2018); includes 4275 species but mostly without synonymy; taxonomy in the first edition was based on Cherepanov (1995), then adjusted to Takhtajan, 2003–2012) in the 2nd edition for the available families in the conspectus (M. Mosulishvili, pers. comm); in print.

Vascular plants of Azerbaijan: A nomenclatural checklist of nonflowering plants (Salimov & al., 2019); includes 115 species plus infraspecific taxa; in print and pdf. Ongoing project with the publication of flowering plants planned.

e-Floras and websites

*Flora of Nepal** (Watson & al., 2011–); about 10% of Nepal's 7000 species treated; active project; one of the first "born digital" Flora projects, taking an entirely digital approach to capturing, managing and publishing floristic data, with Flora accounts generated from this in print and electronic formats; www.floraofnepal.org.

Appendix 1. Continued.

Co's digital Flora of the Philippines (Pelser & al., 2011–); covers 10,165 species; with checklist and photographs but lacks descriptions; www.philippineplants.org.

AUSTRALIA AND OCEANIA

Floras at national level (including Floras for major parts of countries)

Flora of Australia (Flora of Australia, 1981–); so far treats of 11,600 of the 28,700 taxa of land plants in Australia; active project; in print up to 2015; subsequent treatments electronic (Flora of Australia, 2019); a summary report on the state of the flora published by the Australian Biological Resources Study (for details and updates see Flora of Australia, 2019).

e-Floras and websites

Flora of New Zealand (Breitwieser & al., 2010–); 14 fascicles for ferns and lycophytes, 45 for bryophytes and 5 for seed plants are available, published as pdf.

National-level checklists

Australian Plant Census (APC) for Australia, Council of Heads of Australasian Herbaria (CHAH), http://www.chah.gov.au/apc/index/html.

EUROPE

Continental-level checklist

Euro+Med Plant Base (Euro+Med, 2006–); covers the whole of Europe eastwards to the Ural mountains, but extends to all countries adjacent to the Mediterranean sea and the Caucasus (see also under Asia; treats 32,980 species and 11,437 subspecies of vascular plants for Europe; 44,417 taxa in total; includes an extensive bibliography, vernacular names, occurrence data for countries, native status; constantly updated in the EDIT Platform; http://ww2.bgbm.org/EuroPlusMed/.

Regional Floras

Illustrated Flora of Central Europe (Hegi & al. [different editors in later editions], 1906–2016); covers Austria, Germany, Switzerland, and some adjacent geographical regions with detailed monographic treatments that are updated depending on families in 2nd and 3rd editions.

Flora Europaea (Tutin & al., vols. 1–5, 1964–1980; 2nd ed., vol. 1, 1992); included 11,557 species, a taxonomic backbone (now completely integrated and updated in Euro+Med Plant Base) along with determination keys and short descriptions.

Flora partis Europaeae URSS (Fedorov & Tzvelev, 1974–1994, vols. 1–8) and its successor after the breakdown of the Soviet Union, the *Flora Europaeae orientalis* (Tzvelev, 1996–2004, vols. 9–11); 11 volumes, complete, cover all countries of the former USSR in eastern Europe (Belarus, Estonia., Lithuania, Latvia, Moldova and Ukraine) by providing short descriptions included in keys.

Flora Iberica (Castroviejo, 1986–2018); covers Portugal, Spain and Andorra and is complete except for the last volume dedicated to the Poaceae (in prep.); in print and as pdf (http://www.floraiberica.es/).

Flora of Great Britain and Ireland (Sell & Murell, 1996–2008); complete in five volumes with detailed descriptions, print only.

Flora Nordica (Jonsell & al., 2000–2010); covers all Scandinavian countries and Iceland, but only three volumes were completed, including 1130 species of an estimated number of 4600; print only.

Nouvelle flore de la Belgique, du Grand-Duché de Luxembourg, du nord de la France et des régions voisines (Ptéridophytes et Spermatophytes) (Lambinon & Verloove, 2012, 6th ed.); ca. 1500 species with keys, brief descriptions and additional information.

New Flora of the British Isles, 4th ed. (Stace, 2019); covers Great Britain and Ireland, includes ca. 5000 taxa; print only.

Floras at national level (including Floras for major parts of countries)

Flora Reipublicae Bulgaricae (Jordanov, 1963–); almost complete, 11 volumes so far, with descriptions and keys; print only.

Flora SR Srbije (Josifović, 1970–1986); complete; 10 volumes with keys and descriptions; print only. The second edition (1992–2012) has two volumes so far (print only).

Mala Flora Slovenije, 3rd ed. (Martincić, 1999); descriptive keys; print only.

Norsk Flora, 7th ed. (Elven, 2005); descriptions for 2880 Norwegian plants; print only.

Flora dell'Isola di Sardegna (Arrigoni, 2006–2015); complete, 6 volumes with descriptions; print only.

Flora Nizhnego Povolzhya [Flora of the Lower Volga Area] (Skvortzov & Reshetnikova, 2006–2018); covers the southeast part of the Russian Federation, has new original descriptions (in Russian).

Flora Ilustrată a României: Pteridophyta et Spermatophyta, 3rd ed. (Ciocârlan, 2009); descriptive keys for 3759 species of the Romanian flora.

Flora Belarusi [Flora of Belarus] (Parfenov, 2009–2017); 3 of 6 volumes are published.

Flora Corsica, 2nd ed. (Jeanmonod & Gamisans, 2013); 2724 taxa with descriptive keys; print only.

Flora Gallica (Tison & Foucault, 2014); contains more than 6000 taxa with descriptive keys; print only.

Flora d'Italia, 2nd ed. (Pignatti, 2017–2019); 4 volumes, print only.

Flora Helvetica, 6th ed. (Lauber & al., 2018); provides short descriptions and photographs for ca. 3200 species but has no synonymy; in print as well as smartphone app (www.flora-helvetica.ch/app, www.flora-helvetica.ch/app_fr.

Klíč ke květeně České republiky, 2nd ed. (Kaplan & al., 2019); descriptive keys for ca. 3700 taxa; print only.

Heukels' Flora van Nederland [Heukels' Flora of the Netherlands] (Duistermaat, 2020); 24th ed.; covers 2525 taxa of which 2139 have short descriptions, whereas 386 are reported with short characteristics; print only.

Flora of Greece (2021–); a new project that builds upon on a recent comprehensively annotated checklist (Dimopoulos & al., 2013), will deliver detailed treatments for the 7810 plant taxa of Greece, being created in the EDIT Platform for Cybertaxonomy it will be both in print and online (portal.cybertaxonomy.org/flora-greece/); the first of 10 volumes will appear in 2021.

National-level checklists

Index Florae Croaticae (Nikolić, 1994–2000); covers vascular plants; three volumes; print only.

Checklist of non-vascular and vascular plants of Slovakia (Marhold & Hindák, 1998).

Vascular plants of Ukraine: A nomenclatural checklist (Mosyakin & Fedoronchuk, 1999); contains ca. 5100 species, includes the Crimean peninsula.

Checklist of vascular plants of the Czech Republic (Danihelka & al., 2012); contains 3557 species; in print and as pdf (http://www.preslia.cz/P123Danihelka.pdf).

Appendix 1. Continued.

Vascular Plants of Greece: An annotated checklist (Dimopoulos & al., 2013); contains 7810 species and subspecies of vascular plants with information on occurrence in the 13 floristic regions of Greece, and IUCN conservation status information; is continuously updated online (http://portal.cybertaxonomy.org/flora-greece/content).

An updated checklist of the vascular flora native to Italy (Bartolucci & al., 2018); includes 8195 taxa (https://doi.org/10.1080/11263504.2017.1419996).

Kritichka lista vrsta vaskularie flore srbije [An annotated checklist of the vascular flora of Serbia] (Niketić & Tomović, 2018); the first volume (ferns, lycophytes, gymnosperms and monocots) contains 1004 taxa; in print and as pdf.

Checklist of vascular plants of Albania (Barina & al., 2018); contains 5480 accepted taxa; as pdf (https://doi.org/10.11646/phytotaxa.378.1.1).

Checklist of the vascular plants of Finland: Suomen putkilokasvien luettelo (Kurtto & al., 2019); an updated checklist of 3236 species present in the wild; in print and as pdf. (https://helda.helsinki.fi//bitstream/handle/10138/307238/checklist_plants_finland.pdf).

Belgian Species List (2020); contains 1502 species of vascular plants, 2633 of species of plants (vascular and non-vascular), with backbone information, scientific names, English, French, Dutch and German names, photos, threat information, distributional information (http://www.species.be/en/59170).

Nederlands Soortenregister [The Dutch Species Register] (2020); covers all organisms and lists 3077 vascular plants and 424 bryophytes with ecological status of the species in the Netherlands; continuously updated online (http://www.nederlandsesoorten.nl).

e-Floras and websites

Flore de la France Métropolitaine; a Flora of France available on the site of the AssociationTela Botanica (2001–); based on the recently updated BDNFF (Base de Données Nomenclaturale de la Flore de France) and partly complemented with descriptions from the old French flora of Coste (1900–1906).

Flora of Cyprus – A dynamic checklist (Hand & al., 2011–); treats 2031 taxa of vascular plants; includes bibliography and photographs; continuously updated (http://www.flora-of-cyprus.eu/).