South African Journal of Botany 105 (2016) 317–323

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

Realising the potential of herbarium records for conservation biology

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ARTICLE INFO

Article history:
Received 20 August 2015
Received in revised form 4 January 2016
Accepted 11 March 2016
Available online 18 May 2016

Edited by J Van Staden

Keywords:
Biological collections
Database
Historical records
Label information
Long-term data collections
Trait

ABSTRACT

One of the major challenges in ecosystem conservation is obtaining baseline data, particularly for regions that have been poorly inventoried, such as regions of the African continent. Here we use a database of African herbarium records and examples from the literature to show that, although herbarium records have traditionally been collected to build botanical reference "libraries" for taxonomic and inventory purposes, they provide valuable and useful information regarding species, their distribution in time and space, their traits, phenological characteristics, associated species and their physical environment. These data have the potential to provide invaluable information to feed into evidence-based conservation decisions.

1. Introduction

Globally, biodiversity is increasingly under threat due to changes in land use, climate and socio-economic factors. There is thus an increasing need for the long-term monitoring of biodiversity to ensure its effective conservation (Magurran et al., 2010). Few such monitoring projects have been in place for extended periods of time, particularly across the tropics and in the southern hemisphere (Magurran et al., 2010). Many countries have suffered from long financial and political instability and may lack up-to-date knowledge of their biodiversity (e.g. Figueiredo et al., 2009). Particularly in these areas it may be difficult to obtain baseline knowledge of species, communities and ecosystems with which to monitor how climate, land use and livelihood changes are affecting biodiversity, and thus to make informed conservation decisions (Lister, 2011). While the possibility exists to obtain data from old field-based studies, re-visit the sites of these studies, and repeat the sampling procedures to compare current and historical biodiversity (e.g. Thiollay, 2006), such inventory data are often scarce and difficult to obtain, and "thinking-outside-the-box" methods are called for (Sparks, 2007). More specifically, biological collections, though often not systematically collected (see Appendix A), have the potential to provide a variety of information not only about individual species, but also about their communities and habitats (Sparks, 2007).

One of the main, and original, purposes of herbarium collections is to serve as taxonomic 'repositories': storing specimens allows users to return to them over decades and centuries to check the identification of plants and study the characteristics of the given species. Reference collections used to identify species, to describe new species, or to produce

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http://dx.doi.org/10.1016/j.sajb.2016.03.017
0254-6299/

classifications of related species based on their morphological (e.g. Ross, 1973) – and, more recently, also genetic (e.g. Beck and Semple, 2015) – characteristics are of crucial importance for taxonomic purposes. Existing herbarium collections also house species awaiting description (Bebber et al., 2010). The taxonomic role of herbaria remains essential for measuring and setting conservation challenges and priorities (e.g. Rivers et al., 2010), as most conservation targets are based on taxon diversity (e.g. Küper et al., 2006) and, to a lesser extent, taxonomic relatedness (Winter et al., 2013); without the knowledge of what entails a species, such target-setting becomes impossible.

Over time, plant collections have been deposited in herbaria for various other functions besides understanding taxonomic relationships: to illustrate variation in morphology, to prepare floras and monographs, to provide voucher specimens for medicinal research and, by assembling data on phenology, to maximise the collection of fertile material of special significance to seed collections. Nevertheless, new purposes for herbarium specimens frequently arise, so that they are utilized for purposes for which they were initially not intended (Pyke and Ehrlich, 2010).

Here, we illustrate, using a case study, the contributions that herbarium specimens can make to providing a range of baseline data in space, thereby adding to the understanding and monitoring of biodiversity which can directly be used for conservation purposes. This work summarizes and builds on several previous studies that have emphasized the uses of herbarium data (e.g. Elith and Leathwick, 2007; Kalema, 2008; Loiselle et al., 2008; Cherry, 2009; Aikio et al., 2010; Pyke and Ehrlich, 2010; Vorontsova et al., 2010; Greve and Svenning, 2011). We employ an extensive dataset of African *Acacia* (sensu lato, including *Senegalia*, *Vachellia* and *Faidherbia*) for this purpose (Greve et al., 2012). In addition, we highlight the role that herbarium collections can make to monitoring biodiversity in time in the discussion.

2. Materials and methods

A large database of herbarium records of African *Acacia* was set up (Greve et al., 2012) using the BRAHMS databasing system (Filer, 2011). The database contains the majority of the collections housed in the following herbaria: National Botanical Garden of Belgium (BR), University of Coimbra (COI), East African Herbarium (EA), Royal Botanic Gardens Kew (K), Instituto de Investigação Científica Tropical (LISC), Missouri Botanical Garden (MO), and PRECIS data, which contains the digitized information of South African herbaria, mostly those of the National Herbarium of South Africa (PRE), Compton Herbarium (NBG) and KwaZulu-Natal Herbarium (NH), as well as extensive collections from several other African and European herbaria. In all, the database consists of approximately 31,000 unique entries, of which approximately 23,000 are georeferenced. The database not only contains the specimen identity data, but, for most specimens, the label information of the collections. This label information includes fields such as dates of collections, identity of collectors, geographical descriptors, characteristics of the plant, habitat information and common or local names, depending on what the collector recorded, and, for specimens not digitized by us, on what was copied from the labels into the database.

The collection locality of most herbarium specimens is indicated on the herbarium labels. Where GPS coordinates are not provided with the collection locality, the description locality can often be used to georeference the collection location using gazetteers and other mapping tools. This was done for the *Acacia* database: specimens that had no GPS coordinates associated with them were georeferenced if their locations could be determined with some accuracy (locations had to me more accurate than to district level).

To show the mapping application of herbarium specimens, the distribution of *Acacia sieberiana* DC was mapped in several different ways. All georeferenced *A. sieberiana* specimens were extracted from the *Acacia* database. Initially, the collection localities of *A. sieberiana* were mapped. As such raw collection localities only provide information on the specific areas where individual specimens have been collected, they provide limited information on where species could potentially occur. Thus, a second map of *A. sieberiana* was produced using boosted regression tree modelling (BRTs), a species distribution modelling technique, to better present the distribution of *A. sieberiana* across Africa. Models were constructed following the methods presented in Elith et al. (2008). All georeferenced localities of *A. sieberiana* were extracted from the *Acacia* database. Nine descriptors of environmental conditions were used to model the distribution of the species: altitude (Earth Resources Observation and Science, 1996), annual mean temperature, maximum temperature of the warmest month, mean temperature of the warmest quarter, annual precipitation, precipitation seasonality, precipitation of the driest quarter, precipitation of the coldest quarter (Hijmans et al., 2005) and fire incidence, a measure of the number of years an area burnt between 2000 and 2007, derived from Tansey et al. (2008). More details on model settings are provided in Appendix A.

Knowledge of the relationship between organisms and their environment allows predictions to be made of how distributions might shift under a climate change scenario. Therefore, we used the BRT model to project the distribution of *A. sieberiana* into the future (2080) using the UKMO-HadCM3 model under an A1B scenario (IPCC, 2007). For the future projections, the current climate variables on which the model had been trained were replaced with the equivalent climate variables for the future. To understand which areas will become more and less favourable for *A. sieberiana* in the future, the current probabilities of occurrence of the species were subtracted from the future probabilities.

To map a plant characteristic, the labels of all *A. sieberiana* specimens were searched for information on tree height. All specimens that had information on estimated tree height were extracted and mapped, with the locality records labelled to represent tree height.

Herbarium specimens can also provide information about plant phenology. Some of the herbarium specimens of *A. sieberiana* were examined to record presence of flowers, and for specimens that could not be accessed in herbaria, label information was examined for an indication that the trees from which these specimens had been collected were in flower at time of collection. Because each herbarium specimen was associated with a collection date, the spatial distribution of flowering phenology (i.e. month of flowering) for the species that were in flower at the time of collection could be mapped in space.

Best practices in specimen label writing include recording information about the specimen's environment. Therefore, herbarium collections can also provide information about the environment. As an example, we mapped a soil type, namely vertisols, across Africa. This was done by searching the *Acacia* database for the word 'vertisol' or one of the synonyms of vertisols ('cracking clays', 'black cotton soils', 'basalt clay' and 'black clay': Spaargaren, 2008). In addition, the distribution of an African vegetation type – *Combretum* woodlands – was plotted. Again, a search for the word '*Combretum*' was made in the label information column of the *Acacia* database, and all records of *Acacia* specimens that were described as growing in a locality where one or several *Combretum* species were dominant were extracted from the *Acacia* database. Using the geographic coordinates of the *Acacia* specimens associated with the extracted soil type and the extracted vegetation type, they could both be mapped.

Finally, we illustrated how information about species other than the collected specimens may be obtained from herbarium labels, using the widespread mopane tree, *Colophospermum mopane* (Benth.) Léonard, as an example. First, we extracted locality records for *C. mopane* from the Global Biodiversity Information Facility (GBIF; www.gbif.org), as this is a data portal that is widely used for plotting species distributions at large spatial scales, and plotted these locality records. We then additionally extracted all localities where *Acacia* specimens were recorded to be growing in association with *C. mopane* from the *Acacia* database by searching the label information of the database for '*Colophospermum*' and '*mopane*'.