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Locating sufficient plant distribution data for accurate estimation of geographic range: The relative value of herbaria and other sources

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ABSTRACT

In a megadiverse country such as South Africa, plant locality data are routinely sourced from the South African National Herbarium (PRE). Evidence suggests that large areas of the country remain poorly collected and that locality records are not always adequately represented in PRE. Our aim was to assess whether distribution information obtained exclusively from PRE adequately represented the known range of selected species. We also assessed the relative value of regional herbaria and supplementary sources of locality data. Locality information was sourced from PRE, 17 regional herbaria, sight records and literature for a subset of 121 ethnomedicinal plant species that are currently regarded to be threatened with extinction or of conservation concern according to the IUCN Red List criteria. Geographic range (km^2) was calculated using distribution information (Quarter-Degree Squares, QDS) obtained from PRE and non-PRE sources. The species' ranges were examined to compare the differences in range size and the overall proportion of QDS records represented in PRE and non-PRE sources. Supplementary data obtained from regional herbaria and other sources increased the number of known QDS records by ±45% per species across the various IUCN Red List threat categories, and the ranges increased by ±28% per species. As the threat status of a species increased, proportionally more QDS were likely to come from supplementary sources. Rarer species tended to be found only in herbaria within their province of occupancy. 'Return for effort' analyses indicated that QDS records should be sourced from PRE plus one other herbarium located within each province in which a species of interest occurs. QDS coverage within species' geographic ranges was under-represented using only data obtained from PRE, reducing the accuracy of species occurrences and distributions relying solely on information sourced from that repository. We demonstrate that this can impact on the accuracy of conservation planning resources such as Red Lists. Our results highlight the relative importance of regional herbaria.

1. Introduction

Accurate estimation of the geographic ranges of plants requires reliable and adequate data, and may be achieved through species distribution models (SDMs). Datasets self-evidently improve after expanding field collections (Feeley and Silman, 2011), accessing materials at a wider range of existing voucher repositories, and mining supplementary data sources such as literature and sight records. We ask: what is the relative value of these data sources for distribution information that adds significantly to the number of new location records? Which sources provide the best return for effort? Furthermore, how important are national herbaria (PRE in South Africa) relative to other sources of distribution data in estimating the geographic ranges of taxa? These questions are important for predicting where species occur and determining the degree to which they may be of conservation concern. Willis et al. (2003) have shown herbarium data to be valuable in applying the Red List (RL) criteria relating to distribution and, to some extent, the profile of populations. In view of this, Rivers et al. (2011) explored the question of how many herbarium specimens are needed to detect threatened species in Madagascar. In South Africa, some highly threatened medicinal plant species have extensive ranges (Williams et al., 2013). These workers observed that at times, the accuracy of medicinal plant Red Listing depended less on the number of herbarium specimens available than on where in the range the specimens were collected. Accordingly, Williams et al. (2013) addressed sample sourcing biases to avoid skewed range predictions, and consequent inaccurate assessments.

Objective 1 of the 2020 Global Strategy for Plant Conservation (GSPC) is that "*plant diversity is well understood, documented and recognized*". A target was set in support of this objective, viz. "*an assessment* [by 2020] *of the conservation status of all known plant species, as far as*

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possible … to guide conservation action" (Target 2; Raimondo, 2015). While no specific procedure was identified for performing the assessments, methods like the globally employed IUCN Red List and North America's NatureServe use herbarium specimen locality data as the primary or sole source of distribution data in their conservation assessments (Miller et al., 2013). South Africa employs the IUCN methodology to evaluate threats to its native species, and in 2009 completed the assessment of 20,456 indigenous plants, thereby becoming the first megadiverse country to fully assess the status of its flora (Raimondo et al., 2009). To achieve this, a range of information sources were utilised, both published and unpublished: digitised and undigitised specimen data, literature, botanical experts (including "*professional botanists and taxonomists, conservation officials, botanical consultants, and amateur enthusiasts with good knowledge of their local flora*"), monitoring programmes, and spatial data (Von Staden et al., 2009a).

The RL process requires that the best available information on distribution be collated, and threshold values for the RL criteria delimit the various categories of threat assigned to species. Historic locality data are routinely sourced from records in what was formerly PRECIS (PRE Computerised Information System), but recently renamed Botanical Database of Southern Africa (BODATSA). This database includes all collections at the South African National Herbarium (PRE) in Pretoria (Golding, 2001) as well as collections of selected taxa from regional herbaria managed by SANBI (South African National Biodiversity Institute). This digitisation process is ongoing. Distribution ranges are typically ascertained from these data and are used to determine approximations of the Extent of Occurrence (EOO) for each species. EOO equates to the area occupied by a taxon, and is a required parameter if species are to be listed under the B1 geographic range criterion (IUCN Standards and Petitions Working Group, 2008).

As a result of uneven sampling effort, large areas of South Africa remain poorly collected and thus under-represented by holdings in the main herbaria and museums (Robertson and Barker, 2006). These authors used a technique exploiting relationships between species richness and climate to determine that >60% of the quarter-degree grid squares (QDS) in the FSA region were undercollected and inadequately represented in PRE. Hence, there are concerns that (1) QDS coverage using only PRE data underestimates the geographic range of some species, and (2) species assessed using the B1 RL criteria could be allocated the wrong threat category unless additional sources are consulted.

To evaluate the quality of QDS coverage provided by PRE data and also the relative value of herbaria and supplementary locality data, we examined the distributions of plant taxa harvested for traditional medicine in South Africa. Plant harvesting/gathering is one of the lesser causes of plant extinctions in the country (Von Staden et al., 2009b). Nonetheless, groups like cycads, succulents and bulbous species are targeted by both horticultural collectors and traders of traditional medicine (Von Staden et al., 2009b). More than 2000 species of plants are used for traditional medicine in South Africa, of which 322 are regularly traded in herbal markets (Williams et al., 2013). Excessive domestic and commercial harvesting has resulted in significant decreases and local extirpations of some plant populations in South Africa, e.g. *Siphonochilus aethiopicus* (Schweinf.) B.L. Burtt (Crouch et al., 2003; Williams, 2007), and has led to 121 regularly traded medicinal plant species being RL assessed as threatened and/or of conservation concern (Williams et al., 2013). This subset of the South African flora represents an important group of species for closer investigation since they are valuable for traditional health care and livelihood support but face regional extirpation or even extinction through unsustainable harvesting.

To conduct this investigation, we obtained distribution data for highly traded and/or threatened medicinal plant species from the following sources: (1) PRECIS (now BODATSA), (2) 17 South African regional herbaria, (3) sight records (personal communications, observations), and (4) published literature. We anticipated that the inclusion of these sources in the calculation of the geographic range would minimise some of the collecting biases that exist in the national collection (e.g. Fish and Steyn, 2002, for Poaceae; Robertson and Barker, 2006) and other institutional repositories. Aside from spatial biases, taxonomic and temporal collecting biases have arguably also skewed herbarium holdings, the late 19th century fad for fern collecting being an example of one such driver. This hypothesis remains to be tested.

In this study we aimed to examine the following: (1) spatial bias in distribution ranges generated solely using the QDS records from PRE; (2) whether PRE data alone are adequate for estimating the geographic range of a species through calculation of the EOO, (3) the number of South African herbaria that should be consulted to optimise the number of QDS per species; and (4) the nature and locations of optimal data sources. We discuss these findings in the context of both widely and narrowly distributed taxa, the broader value of regional herbaria and supplementary locality sources, and the potential implications for Red List assessments. These findings also inform the efficiency/refinement of methods used to estimate geographic range and assess the conservation status of plant species in any country in which herbaria are significantly geographically distant from one another.

2. Methods

2.1. Species selection

Plants used for traditional medicine in South Africa were selected as a subset of the total South African flora, in part because the authors have extensive expertise in this field. From a checklist of 2061 traded and non-traded ethnomedicinal species (Williams et al., 2013) we selected 121 traded species that were threatened with extinction and/or of conservation concern, i.e. classified as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT) and Least Concern-Declining (Declining). 'Declining' is a category applied only in South Africa to species of local concern that do not qualify as threatened but that are declining in abundance nationally (Von Staden et al., 2009a). As case studies, three heavily utilised species known to have experienced local population extinctions through unsustainable harvesting were chosen to determine the relative contribution of PRE to range size assessments. These species were *S. aethiopicus*, *Mondia whitei* (Hook.f.) Skeels and *Warburgia salutaris* (Bertol.f.) Chiov. A further species known to be widely distributed and moderately utilised was also considered as a case study, viz. the geophyte *Boophone disticha* (L.f.) Herb.

2.2. Locality data sources

The degree reference system, based on latitude and longitude to a quarter-degree subdivision/square level, is a practical grid method for recording plant distribution data in southern Africa (Edwards and Leistner, 1971). Locality data in the form of Quarter-Degree Squares (QDS) were obtained for species stored at PRE from the BODATSA (PRECIS) database in 2008. These data inevitably included duplicate specimens lodged at PRE, and sourced historically from herbaria such as NBG, NH, NU, SAM and K (acronyms in Table 1). Older BODATSA (PRECIS) records without QDS were georeferenced when possible, using locality descriptions. The identification of specimens was reliant on determinations made at PRE and all regional herbaria cited in this study. The accuracy of these, and the quality of ongoing curation at these repositories, impacts on all studies that utilise foundational data. These data, information sources and the extent of digitization of the records were the status quo in 2008.

Using BODATSA (PRECIS) QDS data as the baseline distribution for a species, additional QDS records not already listed were sequentially added from 17 South African regional herbaria located in all nine provinces (Table 1; Fig. 1; Fig. S1). As sampling was cumulative, the identification of unique QDS records was affected by sampling order. Localities were also obtained from various literature sources (including protologues, floras, revisions) and botanical experts who