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Prioritizing West African medicinal plants for conservation and sustainable extraction studies based on market surveys and species distribution models

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ABSTRACT

Sub-Saharan African human populations rely heavily on wild-harvested medicinal plants for their health. The trade in herbal medicine provides an income for many West African people, but little is known about the effects of commercial extraction on wild plant populations. Detailed distribution maps are lacking for even the most commonly traded species. Here we combine quantitative market surveys in Ghana and Benin with species distribution models (SDMs) to assess potential species' vulnerability to overharvesting and to prioritize areas for sustainable extraction studies. We provide the first detailed distribution maps for 12 commercially extracted medicinal plants in West Africa. We suggest an IUCN threat status for four forest species that were not previously assessed (*Sphenocentrum jollyanum*, *Okoubaka aubrevillei*, *Entada gigas* and *Piper guineense*), which have narrow distributions in West Africa and are extensively commercialized. As SDMs estimate the extent of suitable abiotic habitat conditions rather than population size per se, their output is of limited use to assess vulnerability for overharvesting of widely distributed species. Examples of such species are *Khaya senegalensis* and *Securidaca longipedunculata*, two trees that were reported by market vendors as becoming increasingly scarce in the wild. Field surveys should start in predicted suitable habitats closest to urban areas and main roads, as commercial extraction likely occurs at the shortest cost distance to the markets. Our study provides an example of applying SDMs to conservation assessments aiming to safeguard provisioning ecosystems.

1. Introduction

Millions of African people rely on medicinal plants for their primary health care (Antwi-Baffour et al., 2014). The trade in herbal medicine is of considerable economic value, providing income for large numbers of people involved in collecting, processing, transport and sale of plants, even though most activities take place in the informal economic sector (Cunningham, 2001; Sunderland and Ndoye, 2004; Williams et al., 2007; Laird et al., 2010). The bulk of the herbal medicine in Africa is harvested from the wild, and there are indications that several species in high demand suffer from overharvesting and habitat degradation (Delvaux and Sinsin, 2009; Hamilton, 2004; IUCN, 2014; Street and Prinsloo, 2013; Sunderland and Ndoye, 2004). Since many people depend on herbal medicine for their health and income, the sustainable extraction of this commodity is essential. The Secretariat of the Convention of Biological Diversity (2010) and the FAO (2009) have called for direct action to conserve the vulnerable and culturally-valued species and their habitats to safeguard key provisioning ecosystem services, particularly those of importance to low income populations.

For most medicinal plant species, however, data on the effects of commercial extraction on their natural populations are unavailable. Even for the most commonly traded species of West Africa, detailed distribution maps do not exist. In order to guarantee a continuous supply of herbal medicine in the future, appropriate management plans must be designed, for which specified information on species occurrence and extraction localities is needed. Understanding trade networks is another key element in designing practical conservation and resource management plans for commercial species (Cunningham, 2001). Quantitative surveys that address volumes of medicinal plants traded have only been carried out for a few African countries, such as South Africa (Williams

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et al., 2007), Tanzania (McMillen, 2008), Ghana (Adu-Tutu et al., 1979; van Andel et al., 2012), Benin (Quiroz et al., 2014), Cameroon (Ingram and Schure, 2010; Ingram et al., 2012a), Gabon (Towns et al., 2014a) and Central Africa (Clark and Sunderland, 2004; Ingram et al., 2012b). Apart from heavily forested Gabon, where most vendors harvest their own stock (Towns et al., 2014a), source areas for other African countries are largely unknown. As market chains tend to be long and complex, most vendors purchase their commodities from intermediaries and remain unaware of exact harvesting locations (Belcher and Schreckenberg, 2007; Vodouhê et al., 2008; van Andel et al., 2012; Ingram et al., 2012b; Quiroz et al., 2014).

In the absence of detailed occurrence data, species distribution models (SDMs) are a promising tool to estimate the ecological niche of a species and to predict its reciprocal geographical distribution (Elith and Leathwick, 2009a,b; Franklin, 2009; Guisan et al., 2013). The maximum entropy algorithm is widely used by ecologists and conservation biologists to analyze species' niches and to map their geographic distribution using estimated habitat suitability values (Phillips et al., 2006). uses presence only data and performs well when few presence records are available (Aguirre-Gutiérrez et al., 2013; Elith et al., 2011; Wisz et al., 2008). Recently, SDMs have been used to map the potential ecological niches of endangered medicinal plant species (Babar et al., 2012; Ray et al., 2011), to predict the future availability of non-timber forest products in relation to climate and land use change (Heubes et al., 2012), and to identify areas of specific cultural value to Australian Aborigines related to the abundant occurrence of medicinal plants (Gaikwad et al., 2011). Herbarium vouchers with detailed collection localities are of great importance to perform these analyses.

The aim of this study was to use quantitative surveys of herbal markets in Ghana and Benin and SDMs to prioritize West African medicinal plant species for field studies on sustainability and conservation needs." More specifically, we sought to answer the following questions: (1) What are the distributions of commercially valuable medicinal plants in Ghana and Benin? (2) Can predicted distributions of these plants be used to assess their vulnerability to overharvesting? (3) Are spatial analyses useful to prioritize areas to study the sustainability of plant extraction in West Africa? (4) Can we suggest an IUCN threat status for heavily exploited medicinal species based on our results?

Our study contributes to the selection of priority species for sustainable management and the identification of probable extraction areas that could serve as a starting point for ground truthing of our models. Our models facilitate the mapping of provisioning ecosystem services, essential for the design of adaptive management strategies in regions where the extraction of non-timber forest products (such as medicinal plants) is crucial to local people's basic needs (Secretariat of the Convention on Biological Diversity, 2010; Guisan et al., 2013).

2. Material and methods

2.1. Species selection and occurrence data

A list of 14 medicinal species was selected that were in high commercial demand (reflected by the highest volumes traded on domestic markets in Ghana and Benin), harvested from the wild from unknown provenances, and naturally occurring in relatively undisturbed natural vegetation types, such as forest and savanna (Table 1). The combined criteria 'high economic trade value' and '(potential) unsustainable harvesting' were also used by Ingram et al. (2012a) to define 'priority non-timber forest products'. Data on daily volumes offered for sale were retrieved from quantitative inventories of 49 market stalls: 27 in Ghana, surveyed in 2010 (van Andel et al., 2012) and 22 stalls in Benin, surveyed in 2011 (Quiroz et al., 2014). Information on threat status of the selected species was retrieved from the IUCN Red List of Threatened Species (2014), and CITES (2014). Interviews with herbal medicine vendors and consumers provided additional information on (perceived) scarcity of species in Ghana and Benin (Quiroz and Van Andel, 2014; Quiroz et al., 2014; van Andel et al., 2012). Occurrence data for the 14 selected species (accepted names and synonyms) with their geographical coordinates were mined from the Global Biodiversity Information Facility Portal (GBIF, 2014) using the *gbif* function of the *dismo* library (Hijmans et al., 2005) in R (R Development Core Team, 2012). Our GBIF extract includes all collections of the 14 species from the BRAHMS database of Naturalis Biodiversity Center, as well as other major herbarium databases (e.g., Tropicos). We added a few localities of recent collections made by the authors but not yet uploaded in BRAHMS and GBIF. All collection localities are shown in Fig. 2.

2.2. Environmental predictors

To avoid modelling truncated niche dimensions as a result of delimitating the study area by 'artificial' political boundaries (Raes, 2012), we set the study area from West to Central Africa, ranging from 15° North to 10° South and from 17° West to 35° East, covering almost the entire species' ranges (Fig. 1). We used two datasets to extract the environmental predictors that were used in the SDMs: the 19 bioclimatic variables of the WorldClim dataset (www.worldclim.org; Hijmans et al., 2005) and the ISRIC Soil Database (http://www.isric.org/; Nachtergaele et al., 2009), both at a spatial resolution of 5 arcmin ($\sim$9.3 $\times$ 9.3 km at the equator). To account for possible collection effort biases we used the target background sample approach (Phillips et al., 2009). For that purpose we extracted all collection localities in the study area from collections in the BRAHMS database of Naturalis Biodiversity Center, resulting in 37,650 unique collection localities at the 5 arcmin spatial resolution. This layer indicates the presence of botanical collection localities and was added to the environmental predictors as a mask layer excluding all raster cells without botanical collections. To prevent problems with multi-collinearity that can result in model over-fitting (Dormann et al., 2013), we retained a set of 19 environmental predictors that were uncorrelated at collection localities (|Spearman's r| $\leqslant$ 0.7; Table S1). The selected WorldClim variables were: (1) Mean diurnal range (Bio2), (2) maximum temperature of warmest month (Bio5), (3) minimum temperature of the coldest month (Bio6), (4) mean temperature of wettest quarter (Bio8), (5) annual precipitation (Bio12), (6) precipitation of driest quarter (Bio17), (7) precipitation of warmest quarter (Bio18), and (8) precipitation coldest quarter (Bio19). The selected ISRIC variables were: (9) Exchangeable Aluminium percentage – % of ECEC (ALSA), (10) bulk density (BULK), 11) coarse fragments % >2 mm (CFRAG), (12) C/N ratio (CNrt), (13) Effective CEC (ECEC), (14) electrical conductivity (ELCO), (15) exchangeable Na percentage – as % of CECs (ESP), (16) pH in water (PHAQ), (17) sand % (SDTO), (18) available water capacity (TAWC), and (19) organic carbon content (TOTC).

2.3. Species distribution models

To assess the conservation priorities for medicinal plants in West Africa we used species distribution models (SDMs). A SDM identifies the relationship between (1) species' presence records and (2) environmental conditions at the collection sites of that species. The projection of the identified relationships in geographic space allows predicting where habitat conditions are suitable for a species to occur. From the suite of possible modelling algorithms we selected MAxEnt version 3.3.3k (Elith et al., 2011; Phillips et al.,