Journal of Arid Environments 135 (2016) 104–114

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Modeling the distributions of useful woody species in eastern Burkina Faso

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ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form
27 August 2016
Accepted 29 August 2016

Keywords:
Environmental factors
Human impact
Semi-arid savanna
Species distribution modeling
West Africa

ABSTRACT

Useful woody species contribute enormously to maintain livelihoods in rural areas of West Africa and are strongly influenced by environmental conditions and human activities. To assess species-specific responses to these factors, we studied potential distributions and richness patterns of useful woody species in relation to several environmental factors in a communal and protected area in eastern Burkina Faso. We applied species distribution models, separately for adults and juveniles. While potential distributions of adults can be interpreted as the current state of the species, modeled distributions of juveniles give hints about the species' future development. Our results reveal that elevation and precipitation were the most influencing environmental factors on potential distributions of both juvenile and adult richness. Furthermore, we demonstrated that overall modeled adult richness (the same in communal and protected area) and juvenile richness (more successful in protected area) of woody species reacted differently to human disturbances. However, the fact that the responses to human activities differed widely between species and often even between adults and juveniles of the same species emphasizes the difficulty of giving simplified statements about the human impact on useful woody species. We discuss whether woody species might persist under increasing human pressure in the future.

1. Introduction

Non-timber forest products (NTFPs) (e.g. bark, fruits, and leaves) from a wide range of useful woody species contribute enormously to maintain livelihoods in rural areas of West Africa. They provide amongst others food, fodder, medicine, and cash income (e.g. Belem et al., 2007; Kristensen and Balslev, 2003; Paré et al., 2010). Environmental factors, e.g. precipitation, topography, and soil properties have a strong impact on their occurrences and performances. Especially precipitation and soil water availability strongly affect the occurrences of woody plants as water is generally the limiting factor for plants in the tropics (Hawkins et al., 2003). Increasing woody richness with increasing precipitation from north to south has been demonstrated by several studies in West Africa (Heubes et al., 2013; Márquez, 2010; Schmidt et al., 2008; Thiombiano et al., 2006).

In addition to the impact of environmental factors, human activities, such as agriculture, animal husbandry, and harvesting, also strongly influence the occurrence and performance of useful woody species. However, this human impact does not necessarily lead to a decline of these woody species. The responses to human disturbances are rather diverse and depend amongst others on the way and degree of species use and protection (Ticktin, 2004), the species' characteristics, and their ecological preferences (Jurisch et al., 2012; Schumann et al., 2011).

In traditional agroforestry systems of West Africa, several useful woody species with edible fruits are protected by farmers on fields, while several other useful woody species are cut when fields are prepared. Some of these species protected on fields (e.g. *Adansonia digitata*) are still well preserved in spite of the high human impact (Dhillion and Gustad, 2004; Schumann et al., 2010). In contrast, other useful woody species protected on fields such as *Sclerocarya birrea* and *Tamarindus indica* (Fandohan et al., 2010; Gouwakinnou

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http://dx.doi.org/10.1016/j.jaridenv.2016.08.017
0140-1963/

et al., 2009) as well as several non-protected useful woody species (e.g. *Afzelia africana, Khaya senegalenis, Pterocarpus erinaceus*) are negatively affected by human activities and are therefore declining (Gaoue and Ticktin, 2007; Houehanou et al., 2013; Nacoulma et al., 2011b). In turn, other non-protected species (e.g. *Detarium microcarpum*) seem to indirectly profit from human activities and are able to compensate the adverse human impact by their specific species' characteristics (e.g. vegetative regeneration) (Jurisch et al., 2012).

In order to improve knowledge whether useful woody species might be able to survive under or even profit from increasing human pressure and changing environmental conditions in the future, more detailed studies that investigate these species-specific responses to environmental conditions and human activities are needed. So far, most of the studies dealing with this topic investigated the relations of useful woody species to human activities by comparing the demographic profiles of those species in protected areas with those of adjacent human-modified communal areas (Gouwakinnou, 2008; Nacoulma et al., 2011b; Schumann et al., 2011). Even though many efforts have been made in understanding the responses of useful woody species to human impact in West Africa, demographic studies are very time-consuming and other approaches are required to rapidly obtain urgently needed data in the context of changing environmental conditions and increased human impact for a larger set of species. Species distribution modeling can be used to rapidly estimate spatial distributions of woody species in relation to environmental conditions given that appropriate and sufficient occurrence and environmental data are available. This approach is particularly suitable for regions where area-wide sampling is impeded due to missing accessibility (Elith et al., 2006) as in most protected areas of West Africa.

In this study, we investigated the potential distributions of useful woody species in relation to several environmental factors (climatic, edaphic, and topographic) in eastern Burkina Faso by using a species distribution modeling approach. We compared the potential distributions of several useful woody species in a protected area with those in the surrounding human-modified communal area. As both areas display relatively similar environmental conditions (e.g. both have the same increasing precipitation gradient from north to south and the same flat terrain with some local elevations), this comparison allows assessing the influence of human activities on the potential occurrences of the useful woody species.

As the juvenile stage of woody species is very sensitive to human-induced disturbances and as a lack of recruitment may indicate declining population trends in the future, we modeled separately for juveniles and adults. While potential adult distributions can be interpreted as the current state of the species, potential juvenile distributions give hints about the species population development in the future and indicate whether they might persist under future increasing pressure in human-modified landscapes. We discuss species showing similar tendencies in their responses to human impact. Specifically, we sought to answer the following questions:

(i) How do environmental factors and human activities influence the potential richness of the useful woody species?
(ii) Are the potential distributions of juveniles and adults of the useful woody species differently affected by human activities?

2. Material and methods

2.1. Study area

The study site is located in a semi-arid area in the eastern part of Burkina Faso (province Tapoa) and covers an area of 3094 km^2 (Fig. 1). The study site belongs to the north Sudanian vegetation zone (Guinko, 1984). Annual precipitation ranges from 700 to 860 mm (Hijmans et al., 2005) and increases continuously from the north to the south of the study area. The rainy season is from May to October followed by a dry season from November to April. The terrain is generally flat with elevations ranging from 180 to 340 m above sea level (a.s.l.) (Electronic Appendix Fig. 1) The mountain chain “Gobnangou” and some small local hills in the middle part of the study site reach the highest altitudes in the study area (>300 m a.s.l.). This mountain chain is situated between the two villages “Kabougou” and “Tansarga” and beyond in south-western direction (Fig. 1, Electronic Appendix Fig. 1).

The vegetation is characterized by a mosaic of various types of savannas and dry and gallery forests (details in: Nacoulma et al., 2011a). Human population density is relatively low with 23.5 inhabitants per km^2 (data from 2006) in the province Tapoa (INSD, 2012). People live mainly from agriculture (cereals and cotton) and extensive livestock breeding.

The study site comprises a protected area (W National Park and hunting zone) and its surrounding communal area. The W National Park is a trans-boundary (Benin, Burkina Faso, and Niger) biosphere reserve of UNESCO-MAB (Man and the Biosphere Program, November 2002). Both areas display relatively similar environmental conditions, but differ in the kind and level of human pressure. Human disturbance is very low in the protected area and very high in the communal area:

- The protected area is managed by water provision for wildlife (i.e. water holes) and prescribed fires that are ignited in October or November every year. Park managers set early fires to open the vegetation and increase the visibility of animals for tourists (Clerici et al., 2007), to mitigate the effect of accidental late fire, and also to stimulate an off-season re-growth of perennial herbs. Livestock grazing, hunting, and fuel wood extractions are prohibited in the park and hunting zone, while exploitation of some NTFPs (e.g. straw, baobab fruits) by neighboring local communities is authorized and regulated. Nevertheless, poaching as well as illegal harvesting and livestock grazing take place.
- The communal area includes croplands, fallows of different ages, non-arable savanna sites, and small buffer areas. A farming system with alternating cycles of cultivation and fallows is practiced. Fallowing is an important management practice in West Africa for maintaining soil productivity, because most traditional farmers cannot afford fertilizer use (Tian et al., 2005). Characteristic for this farming system is the preservation of some important tree species (e.g. *Adansonia digitata, Parkia biglobosa, Vitellaria paradoxa*) on croplands. In-between, some savanna sites are not used for agriculture due to their unfavorable soil and habitat conditions (e.g. too dry, wet, or rocky). However, they are strongly affected by other human activities, e.g. extensive livestock grazing by cattle, sheep, and goat, fires, and harvesting of various natural products (including fuel wood, thatching materials, poles for construction, edible and medicinal plants).

2.2. Data collection

2.2.1. Occurrence data of useful woody species

In total, 53 woody species (Electronic Appendix Table 1) are known as highly useful for this region, based on local information in the communal area of the W National Park (Koadima, 2008).

Occurrence data of these useful woody species were extracted from several vegetation inventories in the study area (Erpenbach et al., 2013; Nacoulma et al., 2011a), i.e. from 208 vegetation plots