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Woody Vegetation Dynamics in the Eastern Sahel, Trend and Causes: A Case Study from Sudan

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Abstract

The Sahel region of Africa is known for being one of the most climate-prone regions in the world. However, the life of its residents is largely dependent on renewable natural resources, especially natural plants, the productivity of which is directly related to the climate and therefore climatic fluctuations along with human influence have exerted great pressures on this resource. Ecological studies have shown some debate about the direction and causes of vegetation change in the area. The aim of this study was to assess local perceptions of woody vegetation changes in Abukarinka locality in Eastern Darfur State in Sudan which is situated in the eastern part of the African Sahel. Semi-structured interviews were performed with 25 groups of informants from 5 villages. The results showed a drastic change in the abundance of woody plant species in the area. More than 75 percent of the 39 listed woody species were declining, with more than 30 percent identified as threatened, including many plants of great economic value. The increasing species are mostly drought-tolerant plants, especially those whose growth was restricted mainly to non-arable areas. A few species have been listed as locally extinct. Human factors, especially land clearing for agriculture and firewood production, have been classified as the main drivers of vegetation change in the region. This study concluded that the woody vegetation in the area is in a state of significant deterioration, and this supports the results of several local studies in other parts of the Sahel. All this indicates the existence

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of many local pockets in which the direction of vegetation development contradicts the prevailing general pattern, i.e. re-greening, which has been confirmed by several remote sensing studies.

Keywords: African Sahel; vegetation change; woody species; local perception; declining.

INTRODUCTION

African Sahel is one of the world's most attractive regions for ecologists due to its fragile environment, which is characterized by a highly variable climate, as well as being a densely populated region. However, the livelihood of most of the local population depends mainly on renewable plant and animal resources, the productivity of which is largely related to environmental conditions.

Ecological studies investigating the relative importance of climatic and anthropogenic causes of vegetation change in the region began in the 1930s, (e.g. Stebbing, 1935; 1938; Aubreville, 1949) and intensified after the severe droughts that struck the region in the 1970s and 1980s (Vetaas, 1993; Olsson, 1993; Lykke *et al*., 1999; Hermann *et al*., 2005; Wittig *et al*., 2007; Karlson and Ostwald, 2014; Kusserow, 2017). Despite early studies in the area, historical data on vegetation and climate in most areas of the Sahel are extremely scarce. Therefore, many studies have found remote sensing, local knowledge, or the combination of the two as reliable and faster alternatives to bridge the gap.

The geographical distribution of the woody vegetation research is uneven in the Sahel, with dominance within a few countries in West African Sahel (e.g., Mali, Burkina Faso, Niger, and Senegal). This pattern is driven by multilateral research collaborations, availability of in-situ data and research infrastructure, and political stability (Karlson & Ostwald, 2016).

While several studies, especially those relying on remote sensing, have indicated a regional regreening pattern across many parts of the Sahel region ((Anyamba and Tucker, 2005; Herrmann *et al*., 2005; Olsson *et al*., 2005; Sendzimir *et al*., 2011; Kusserow, 2017), investigations of local ethnobotanical knowledge (e.g. Lykke *et al*., 1999; Maranz, 2009; Sop and Oldeland, 2013) have reported a sharp

decline in woody species, especially those of economic value. This may have caused some controversy about the direction of vegetation change as well as its causes. However, ground-truthing of vegetation trends in the Sahel remains difficult, as landscapes and human activities are not uniform and even if the region is well known the actual causes of trends remain unclear (Ali and Lebel, 2009; Tappan *et al*., 2004) and degradation or greening can be obscured or neutralized by mixed spectral information from changes of adjacent objects.

The vegetation in Northern Sudan is part of the Sahel zone, which represents a macro gradient from the Sahara Desert to dry tropical Acacia forests in the south. This zone has gone through various changes in the last century, and many studies have related the changes to anthropogenic factors (Tothill, 1944; Ayyad and Ghabbor, 1986; Le Houérou, 1989). More recent research (e.g. Herrmann *et al*., 2005; Seaquist *et al*., 2008; Measho *et al*., 2019) identified climatic variables as the major driving force behind vegetation dynamics in the Sahel, without overlooking the important impact people might have on vegetation at local scales. In contrast to the drought periods during the 1970s and 1980s, the Sahel zone is moister now and in many parts the vegetation is regenerating (Anyamba and Tucker, 2005; Herrmann *et al*., 2005; Heumann *et al*., 2007). However, northern Sudan and Nigeria are thought to be regions in the Sahel where human impact is inhibiting the increase in vegetation cover that otherwise could be expected from the positive trend in rainfall (Herrmann *et al*., 2005; Hiernaux *et al*., 2009).
The aims of this study were to assess the trend of change in woody plant species in the region, as well as to identify the main drivers of the changes from the perspective of the local people.

MATERIAL AND METHODS

The study area

Abukarinka is one of the localities of Eastern Dar fur State in Western Sudan (Figure 3). It is situated between longitudes (25^{o}– 27^{o} E) and latitudes (10^{o}-13^{o} N), and at elevation of 449 m.a.s.l. In a phytogeographical term, the area is a part of the African Sahel, which represents a macro gradient from the Sahara Desert to the north and the dry tropical Acacia forests in the south. The climate is

characterized by a marked seasonality with a long dry season (October to June) and a short rainy season (July to September) with mean annual precipitation of less than 700 mm. The natural vegetation is sparse and varies from grassy or shrubby steppes to shrubby or woody savannas mainly of Acacia types. Economic activity is dominated by agriculture and pastoralism, with about 75% of the population being farmers and pastoralists. The main agricultural products include peanuts, millet, sorghum, and hibiscus. Large numbers of cows, camels, and sheep are found throughout the state, which is a prominent characteristic of the state in relation to the rest of Sudan.

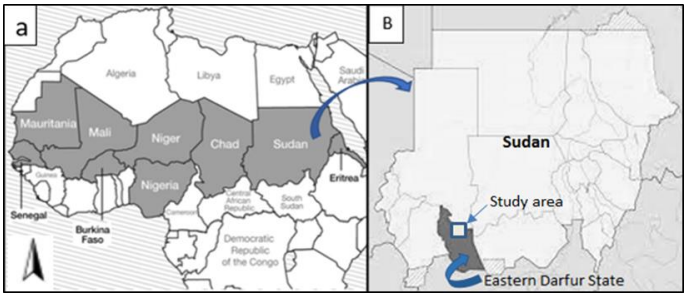

Figure 1. a) Sahelian countries, b) Sudan map showing the location of the study area within Eastern Darfur State

Vegetation data

A total of 25 groups of informants from 5 villages were interviewed using semi-structured interviews. Villages were selected on the basis of at least two criteria: 1) population size of the village shall be large enough (several hundred) in order to allow interviews; 2) Villages should be geographically dispersed as much as possible to ensure that they represent the entire study area to the maximum extent. We found that the group interview was more effective than the individual questionnaire in collecting the data required for this study because it gives informants an opportunity to discuss among themselves and remind each other and thus more accurate data was expected. Four to six groups of informants, each including seven to ten people, were interviewed in each village. In all groups, only men were questioned, including the young (20-40 years old) and the elderly (over 40 years old). The reason for focusing on these age groups is that the elderly can trace history and give abundant information about the past while

the young, as current farmers and herders, are more aware of the current situation of vegetation. An attempt was made to sample some female participants; however, this was often not possible because of a certain conservatism that still rules most of the traditional societies in the Sahel (*see* Sop and Oldeland, 2013). The twenty-five groups were asked to list all woody plants used and the observed structural vegetation changes. For each species mentioned, informants were requested to give their perception of its dynamics over the past decades, whether increasing, decreasing or stable (neither increasing nor declining), threatened or disappeared. People were also requested to rank the factors driving the observed changes (drought, cultivation, and other anthropogenic impacts). Free listing techniques, where informants list all the species they first come to think about, were used for the naming of species for each of the questioned categories, because the aim was to focus on the most important species and people tend to mention important species first (Sop and Oldeland, 2013). People were asked to mention only woody species (trees, shrubs and lianas) and only species mentioned by 20% or more were included in the results.

Plants have been scientifically identified from their vernacular names as described in the "Flowering Plants of the Anglo-Egyptian Sudan (Andrews, 1953, 1957). All data were statistically analyzed using Microsoft Excel (2010).

RESULTS AND DISCUSSION

The overall trend of woody vegetation change

For the entire study area, a total of 39 woody plant species, from 15 plant families, were listed by informants (Figure 2). The majority of these woody species belong to two plant families, Mimosaceae and Fabaceae with 9 species for each. In line with previous similar studies (Wezel and Lykke, 2006; Sop and Oldeland, 2013) only species listed with a minimum frequency of 20 per cent were considered in the analysis in order to exclude species mentioned by only few respondents and thus might be arbitrary. The main drawback in doing this is that rare species, known only by a reduced number of informants, might be overlooked. However, previous studies (e.g. Lykke *et al*., 1999; Sop and Oldeland, 2013) have shown that there is generally a strong informant consensus on species that are relevant

for the community. To minimize the problem of ignoring rare species, a large number of people (7-10) were included in the discussions as recommended by Wezel and Lykke (2006).

As shown in Figure 3, more than 75% of the listed species were reported to be in state of decline, i.e., either decreased or completely disappeared from the local flora. While only 10% was rated as having increased. The remaining species were classified as either stable (8%) or new (5%). This result shows that the woody vegetation in the study area is in a state of significant degradation as is the case in many other areas of the African Sahel.

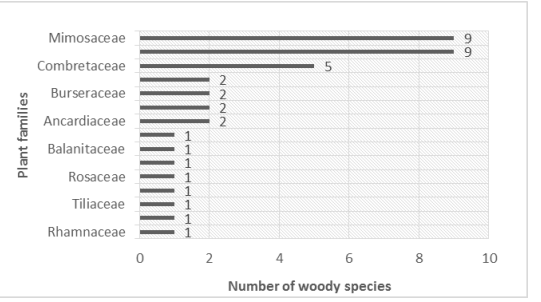

Figure 2. Distribution of woody species among plant families

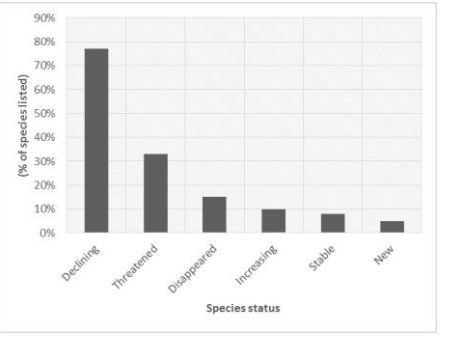

Figure 3. Perception of woody vegetation changes as estimated by local informants

Declining and threatened species

According to informants and as shown in Figure 3, 77% of woody species in the region are in a declining state. This finding supports the findings of several other studies (e.g. Wezel and Lykke, 2006; Sop and Oldeland, 2013; Gonzalez *et al.*, 2012; Trichon *et al.*, 2018) that confirmed the importance of intensive human harvesting in the

decline of valuable woody species in the Sahel region. However, the accompanying decrease in the abundance of some non-valuable species, such as Acacia nubica, may indicate another human factor more effective than normal human use in driving this change. Among the woody species that have declined significantly: *Acacia seyal*, *Acacia Senegal*, *Acacia melifera*, *Adensonia digitate*, *Boswellia baprifera*, *Albizia lebbeck*, *Acacia sieberana*, *Boscia senegalensis*, *Combretum aculeatum*, *Guiera senegalensis*, Dalbergia melanoxylon, *Diospyros* mespilliformis and *Khaya senegalensis*, whereas *Acacia nubica* and *Cassia fistula* are examples for non-valuable species.

More than 30 percent of all reported species were believed to be threatened (Figure 3). The most threatened species were *Adensonia digitate*, *Combretum aculeatum*, *Dalbergiamelanoxylon*, *Diospyros mespilliformis* and *Khaya senegalensis*. Most of these threatened species are species that informants believe have a very weak ability to regenerate naturally, a factor that impairs their ability to withstand the severe human pressure. This result is consistent with that of several studies (e.g. Lykke *et al*., 1999; Wezel and Haigis, 2000; Sop and Oldeland, 2013) that reported not only a severe degradation of the woody species in the Sahel, but also the weak ability of most of them to regenerate naturally.

Increasing species

Among all the 39 reported woody species, only four species (≈ 10%) were perceived to have increased: *Calotropis procera*, *Acacia nilotica*, *Combretum hartmannianum* and *Azadirachta Indica*. The first three are endemic species while the latter is an exotic species that most likely arrived in the area in the 1920s, long before the great drought in the Sahel region, so locals consider it part of the native flora. All these four species are drought-resistant and well-adapted to the semi-arid environment of the Sahel. However, local informants cited some other reasons they believed would also make sense in explaining this increasing trend. *Calotropis procera* and *Acacia nilotica* plants have increased mainly because their growth is restricted to areas that are not suitable for cultivation and thus are saved from removal. The former thrives in deserted agricultural fields that are no longer suitable for replanting, while the latter thrives in waterlogged soils, i.e., catchment areas during the rainy season. In addition, *Calotropis procera* is toxic and has a soft trunk that is not suitable for

construction or fuelwood and thus does not suffer much from human consumption. *Combretum hartmannianum,* as described by informants, is a plant of high medicinal value, as it is used locally to treat various diseases such as yellow fever, liver disorder, as well as fever and diuretics. Therefore, locals consider it a natural pharmacy that must be preserved instinctively, especially in an area where access to pharmaceutical drugs has been and remains difficult. The medicinal value of this tree was confirmed from other areas of the Sahel (Maydell (1990). *Azadirchta indica* known commonly as Neem tree is a tree species of Indian subcontinent. It is widely believed that Neem has been brought to Africa by the diligent colonial foresters who appreciated its value in producing shade, fuel, wood and oil for lamps (National Research Council, 1992). The shade and wood values of this plant encouraged locals to plant it in yards and parklands, and these places may have served as points from which seeds are dispersed into the wild and fallow lands.

Stable species

These are the species whose relative abundances remained almost unchanged compared to the past. They comprise three plant species: *Anogeissus leiocarpa*, *Balanites aegyptiaca*, and *Guiera senegalensis*. For *G. senegalensis*, according to informants, this species was common in the past and then declined significantly during the last decades of the twentieth century as people used it extensively for fencing their homes. But the recent shift towards more stable fencing materials, such as clay and brick, has significantly reduced human pressure on this shrub, giving it an opportunity to grow and thrive again. *B. aegyptiaca*, is a tree native to the semi-arid regions of the world. Most studies conducted in the Sahel region indicated either a stable status or an increasing trend in the abundance of this woody plant (Müller and Wittig, 2002; Lykke *et al*., 2004; Vincke *et al*., 2010; Sop et al., 2011). As reported in other areas of the Sahel, the local informants attributed the stable pattern of this species to its potential to re-sprout after cutting and its ability to reproduce vegetatively through sucker roots, particularly, in fallows.

Anogeissus leiocarpa is a tall deciduous tree native to the savannah of tropical Africa. It has been identified by the informants as a species with a high regenerative capacity mainly because it produces large number (> 30) of seeds per fruit that disperse easily by

wind in addition to its ability to succeed in abandoned agricultural fields. This finding is consistent with that of Neumann & Müller-Haude (1999) in Burkina Faso, which indicated the frequent distribution of this species in locations with shallow, poor soils, unfavourable for agriculture.

New species

Only two woody species have been reported as new to the region: *Albizia lebbeck* and *Prosopis sp.* (Mesquite). *A. lebbeck*is a tree of south Asian origin that has been introduced to northern Sudan since the sixties of the last century (Elzaki *et al*., 2012). However, it is not known exactly when this species reached the study area in western Sudan but probably after the great Sahelian drought (63-1973), that is why the local people consider it as a new species unlike the other non-native species that reached the area before that period, such as *A. indica*, and are considered as part of the local flora. This tree has succeeded in the area, as said the respondents, due to its aesthetic and shade values the factor that motivated many local people to grow it in parklands. *Prosopis sp.* (mesquite plant) is a tropical and subtropical tree or shrub of American origin, mainly found in the arid and semiarid regions of the world. It was introduced to Northern Sudan in 1917 by the Ministry of Forestry of the colonial government in order to combat desert encroachments southwards. In the light of its current prevalence rate, informants believe that this invasive species may dominate the area soon. They provided the following reasons: it is extremely drought resistant, can grow in a wide range of soil types ranging from sand dunes to clay soils; its ability to coppice after damage; animals do not graze its vegetative parts instead, some animals, such as goats, facilitate its rapid geographical distribution by feeding on its pods and thereby discharging its non-digestible seeds into nature with their dung. The invasive ability of this species has also been reported by several scientific studies (e.g. Nilsen *et al*., 1983; Shiferaw *et al*., 2004; Dzikiti *et al*., 2013) which also indicated the ability of its seeds to long hibernate under drought conditions, the ability of its roots to grow at a depth of 53 meters (175 feet), in addition to its allelopathic potential that prevent germination and growth of other plant groups. Several studies conducted in other parts of Sudan (e.g. Vetaas *et al*., 2012; Abdel Magid, 2014) described this species as a potential upcoming invasive species.

Locally extinct (disappeared) species

Among the 39 reported woody species,6 species were perceived to be locally extinct: *Boscia senegalensis*, *Boswellia paprifera*, *Cerasus mahaleb*, *Commefora molmol*, *Grewia tenax*, and *Tectona grandis*. But this finding should be taken with some caution because a similar study conducted by Sop and Oldeland (2013) in the Sahel region of Burkina Faso showed that the species listed by informants as having disappeared may not always reflect the reality of the larger study area. Most of those species were found in the field during botanical investigations. However, this may indicate that most of these species were so rare that it became so difficult to verify their existence in the field without careful botanical investigation. Some of these species were also reported to be highly threatened in other parts of the Sahel e.g. *Grewia tenax*, *Boscia senegalensis* in west Africa (Wezel and Lykke, 2006; Sop and Oldeland, 2013), and *Boswellia paprifera* in east Africa (Gebrehiwot *et al*., 2003; Ogbazghi *et al*., 2006).

Remarks on the re-greening of the Sahel

In light of these results, the following points can be drawn regarding the process of re-greening the Sahel, which many recent studies have indicated (e.g. Eklundh and Olsson, 2003; Olsson *et al*., 2005; Hermann *et al*., 2005; Olsson and Hall-Beyer, 2008; Reij and Smaling, 2008; Tougiani *et al*., 2009):

1 - Nearly all valuable woody species have declined, many of which are either locally extinct or threatened and hence there is no indication that they are recovering.

2- The observed decrease in the level of landscape greening indicates that the rate of compensation of vegetation cover, especially woody vegetation, is not commensurate with the level of improvement in rainfall rates that followed the years of the great drought of the African Sahel

3- Most of the greenery that can be seen in the landscape is mainly due to the increase of a few non-valuable species, which were rare in the past or new, such as the toxic *Calotropis procera* and the invasive *Prosopis sp*. respectively. Therefore, re-greening, although limited, has no real impact on the life of local residents.

These remarks are in consistent with those of Sop and Oldeland (2013) who indicated that if such re-greening process exists in the

Sahel region, it might be rather a marginal phenomenon and may be the result of an increase in a few numbers of species and does not reflect the fact that most woody species have declined. They also support what have stated by Hermann *et al*. (2005) that re-greening is not uniform across the Sahel and there are some pockets at local scale where human impact hypothetically inhibited the greening trend in the order of magnitude expected from the positive trend in rainfall conditions, referring particularly to northern Sudan and Nigeria.

Causes of vegetation change

More than 50 percent of the informants listed the major cause of vegetation change to be agricultural expansion (Figure 4). The most prominent points in support of this opinion are:

- Most woody species were drastically declined, except those that grow away from agricultural influence, such as *Acacia nilotica* in watershed areas unsuitable for cropping and *Calotropis procera*, *Balanites aegyptiaca*, and *Prosopis sp*. in deserted agricultural fields.
- The reported decrease of some non-valuable species, such as *Acacia nubica* and *Cassia fistula* along with multipurpose species, indicates a human factor that is more influential than normal human consumption, i.e., land clearance for cultivation.
- The recent shift in the land use pattern of many people from a purely pastoral life to agriculture or a combination of both (Figure 5) means that more land has been cleared for farming.

All the Other listed causal factors were classified as secondary with comparative superiority of firewood production. This means that the human factor is the main driver of vegetation change in this region. This is in line with Wittig *et al*. (2007) and Paré *et al*. (2010) who reported intensive cultivation as a major factor in vegetation change in the Sudano-sahelian region of Burkina Faso. Nevertheless, it is important to refer to several other studies (e.g. Mahamane and Mahamane, 2005; Hiernaux *et al*., 2009) in the Sahel, especially in its drier northern part, that reported climatic factors, mainly drought, as the main driver. It is clear from these results that the causative factors that lead to the change of vegetation cover across the greater Sahel region differ from one place to another and this depends to a

large extent on the local environment as well as the type of land use practiced.

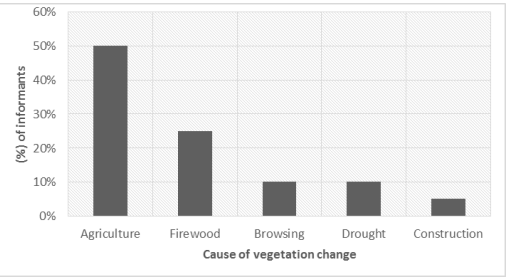

Figure 4. Main drivers of vegetation change as reported by the informants

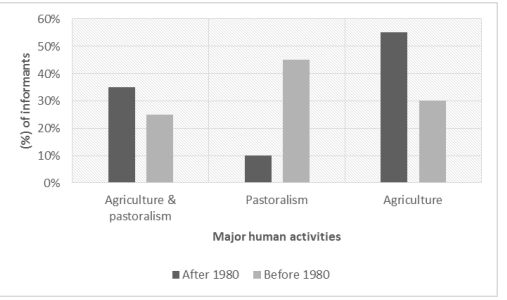

Figure 5. The shift in human activities (post-drought period vs. pre-drought period

CONCLUSIONS

It is clear that the woody vegetation in the area is in a state of massive decline. Many species are threatened and some have become extinct locally. The few species that have increased in abundance are those that grow far from agricultural influence, such as *Acacia nilotica* in waterlogged soils, *Calotropis procera* in abandoned agricultural fields, or those grown in home gardens and parks, such as the *Albizia lebbeck* and *Azadirachta Indica*. Land clearing for cultivation has been reported to be the main causative factor for vegetation change and firewood production is ranked second but with much less impact. This study concluded that the woody vegetation in the area is in a state of significant deterioration, and this supports the results of several local studies in other parts of the Sahel. All this confirms the existence of many local pockets in the Sahel where the

direction of vegetation development contradicts the prevailing general pattern, i.e., re-greening, which has been confirmed by several remote sensing studies.

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