Plant Ecology and Evolution 144 (3): 267–274, 2011
doi:10.5091/plecevo.2011.485

REGULAR PAPER

Effectiveness of conservation areas in protecting Shea trees against hemiparasitic plants (Loranthaceae) in Benin, West Africa

Thierry Dèhouégnon Houehanou*, Valentin Kindomihou & Brice Sinsin

Laboratory of Applied Ecology, University of Abomey Calavi, Benin
*Author for correspondance: houehanout@yahoo.fr

Background and aims – The Shea tree (*Vitellaria paradoxa*), a multi-purpose species highly valued for the oil obtained from its seeds, is commonly maintained in the semi-arid parklands in West African Sudanian zone. However, most of the trees were reported to be infested with mistletoes – plant parasites that may lead to death of the Shea tree and these parasites are known to be directly dispersed on their host by birds. This study therefore aimed to assess the potential effectiveness of protected area on preventing mistletoes proliferation on Shea tree individuals.
Methods – Infestations in two habitats: land use area (fields and fallows) and protected area of Pendjari hunting zone were compared. Overall 54 plots of 1 ha (100 m × 100 m) with 487 and 252 individuals of Shea tree in land use and protected area respectively were investigated. ANOVA was used to compare Shea tree infestation rate and infestation degree (with regard to diameter and height of infested Shea tree). Principal Component Analysis (PCA) was performed to correlate the habitats with infestation degree.
Key results – The results showed that about 80% of Shea tree individuals were infested in the land use area, this rate was significantly higher than the one of 27.3% observed in the protected area. Overall, heavily infested Shea trees had significantly larger trunks and heights, mainly in land use areas. The land use area was shown to be correlated with high and very high Shea tree infestation degrees while the others infestations degrees (very weak, weak and moderate) were correlated with both areas.
Conclusions – Shea trees growing in protected areas are better protected against mistletoe plant parasites than those on cultivated land. Various hypotheses to explain this result are discussed.

Key words – Mistletoes, protected area, Shea tree, *Vitellaria paradoxa*, parklands, conservation.

INTRODUCTION

The Shea tree (*Vitellaria paradoxa* C.F.Gaertn., Sapotaceae) is endemic to the Sudanian Region (White 1983) and a characteristic species of the woody flora in the wooded savannas of Africa (Hall et al. 1996). It has, over the last decades, become a widely valued species. The tree has tremendous economic importance in particular as a source of income in semi arid areas in Western Africa (Teklehaimanot 2004). The fruits have been shown to have high nutritional value for African rural people, when food stores run low (Maranz et al. 2004). The butter extracted from the kernel is a valued product (Hall et al. 1996) and constitutes the most important source of vegetable fat for food commodity and income (Agbahungba & Depommier 1989, Boffa 2000, Lamien et al. 2006). Therefore, its conservation mostly *in situ* has become necessary and is of interest for several researches.

The species is the most dominant tree in West African agroforestry parklands (Boffa 2000, Lovett & Haq 2000) and is seldom planted. The agroforestry parkland system is built on selection of desirable trees and includes not only preferred species, but also preferred individuals within species (Maranz & Wiesman 2003). These parklands are closely associated with indigenous farming activity (Neumann et al. 1998, Boffa 1999) and in some cases, a different tree species may occur in adjacent areas (e.g. protected forests) with similar soil types and rainfall regimes (Aubréville 1939, Maranz & Wiesman 2003). Even if there is some reduction of its population in agroforestry parklands compared to forest's population (Kelly et al. 2004, Djossa et al. 2008) (due to the vegetation clearing for agricultural activities), this species seems to be a good colonizer with potential vegetative propagation in the savannas (Nikiema 2005, Yidana 1994). However, during the past decades, parklands have continually suffered severe damage through drought, as well as mistletoes, insects and fungi infestations (Boffa 1999, Boussim 2002). Specifically, in parklands, Shea trees are threatened by pests such as plant parasites from the Loranthaceae family (Sallé et al. 1991, Boussim et al. 1993). These authors pointed out that 95% of the Shea trees in parkland in Burkina Faso and Mali were infested with three species of mistletoe parasites which were *Agelanthus dodoneifolius* (DC.) Polh. & Wiens, *Tapinanthus globiferus* (A.Rich.) Van Tieghem and *T. Ophiodes* (Sprague) Danser. Among them, *A. dodoneifolius* is the most frequent parasite and *V. paradoxa* (Shea tree) is the major parasitized host (Boussim et al. 1993, Boussim 2002). Referring to reports on mistletoes species, the effects on their hosts include generally the reductions in growth vigour, fruiting and seed production (Mathiasen et al. 2008) and death of the whole host tree under drought conditions (Boffa 1999, Boussim et al. 2004). Consequently mistletoes must mean a drain of Shea tree resource. Knowing the physiological behaviour of mistletoes on their host plants, it was obvious that mistletoes parasites induced nutrients and water deficiency to Shea tree hosts (Lamien et al. 2006). In addition, mistletoes are stem parasites that occur worldwide and are dispersed by birds (Wenny 2001, Mathiasen et al. 2008). Boussim et al. (1993) reported in particular that the mistletoes of Shea tree are mainly dispersed by yellow fronted barbet bird (*Pogoniulus chrysonocus*). Generally, birds swallow mistletoe fruits whole and ingest the seed and viscin (Reid 1991, Watson 2004, Mathiasen et al. 2008). Once the bird has eaten the seed, it is either regurgitated or defecated, but the seed is still covered with some of its viscin coat, which allows it to adhere to potential hosts (Mathiasen et al. 2008). Also preventing mistletoes from invading Shea trees (for example through conservation *in situ* of Shea tree individuals, in protected area) will help to preserve the Shea tree gene flow.

While the magnitude of the current mistletoe infestation of Shea tree has received some attention in previous studies (Boussim et al. 1993, Odebiyi et al. 2004), further investigations on the ecological factors that facilitate the large proliferation of these parasites are needed and are seldom assessed. This will allow developing parklands management strategies and protecting effectively Shea tree against mistletoes. Moreover protected areas are recognized as the most important core for *in situ* conservation (Chape et al. 2005) and some studies (Bruner et al. 2001, Rice & Bruner 1999, Nelson & Chomitz 2009) have shown their effectiveness for tropical biodiversity conservation. With that respect, it is expected from protected areas, low Shea tree infestation by mistletoes. Therefore the current study was then conducted to test the two following hypotheses: (1) The protected area is effective as a barrier against Shea tree infestation by mistletoes; (2) large Shea trees are more susceptible to infestation by mistletoes.

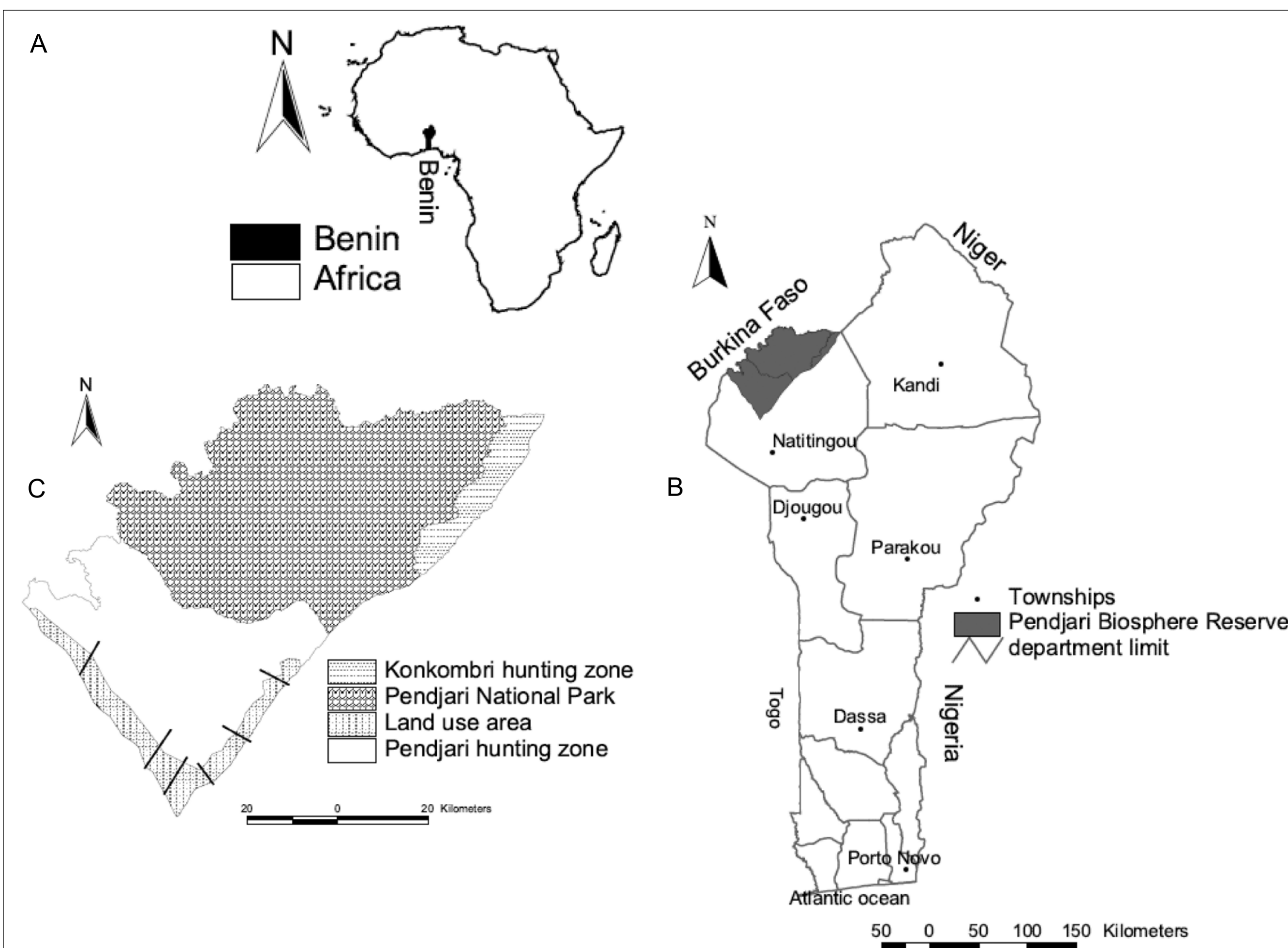

Figure 1 – Study area: A, Benin in Africa; B, Pendjari Biosphere Reserve in Benin; C, the position of investigated transects.

METHODS

Study area

The study was carried out in two habitats: the Pendjari Biosphere Reserve and its adjacent surrounding land use areas (fig. 1C). The reserve covers 4666.4 km^2 and is composed of Pendjari National Park (2660.4 km^2), Pendjari hunting zone (1750 km^2) and Konkombri hunting zone (251 km^2). It is located in the Sudanian zone of northern Benin (10°40'–11°28N and 0°57'– 2°10'E) in West Africa (fig. 1A & B). The Pendjari Biosphere Reserve is part of the largest West African ecosystem of Protected Areas, named WAPO and was declared a Game Reserve in 1954, upgraded to a National Park in 1961, and instituted as a Biosphere Reserve in 1986 (PAG2 2005). The climate is tropical with an average annual, unimodal rainfall of 1100 mm. The monthly mean temperature ranges from 19 to 34°C. The annual potential evapotranspiration is about 1500 mm. The monthly mean values of relative moisture range from 25 to 85%. The rainy season starts in April or May, followed by a dry season from November to March (Sinsin et al. 2002). The main soil type occurring in the Pendjari Biosphere Reserve is tropical ferruginous soil (Adomou 2005).

The reserve is divided into three areas (the core and the two hunting areas) where timber logging and agricultural activities are prohibited. The surrounding land use area (fig. 1C) is dominated by agroforestry parklands composed of agricultural fields and fallows. In this area the agricultural activities are intensive. This landscape is characterized by the presence of mistletoes-infested Shea trees (fig. 2).

Sampling and measurement

Protected area of Pendjari hunting zone and its adjacent land use areas (i.e. fields and fallows), were investigated along transects (fig. 1B).The transects have been used to establish the plots of both areas in similar environment. Six replicate transects were installed from the land use area to protected area zone. On each transect, 1 ha plots (100 m × 100 m) were established. A total of 33 and 21 plots were established in the land use area and in the protected area, respectively. The inequality of investigated plots number between areas was due to the inequality of the width of land use area around the protected area. Shea trees were inventoried in each plot (table 1). All infested Shea trees were measured for dbh (diameter at breast height) and for height. The number of infestation points was recorded for each infested Shea tree individual.

Data analysis

The infestation rate (IR) was computed for each plot as follows:

Table 1 – **Number of plots established by replicate and by habitat, n = number of inventoried Shea tree individuals (infested or not).**

Replicates	1	2	3	4	5	6	Total
Land use area	5 (n = 62)	7 (n = 101)	7 (n = 134)	5 (n = 54)	3 (n = 33)	6 (n = 103)	33 (n = 487)
Protected area	3 (n = 48)	2 (n = 45)	3 (n = 30)	5 (n = 45)	5 (n = 37)	3 (n = 47)	21 (n = 252)
Total	8 (n = 110)	9 (n = 146)	10 (n = 164)	10 (n = 99)	8 (n = 70)	9 (n = 150)	54 (n = 739)

Figure 2 – A, view of agroforestry parklands around the Biosphere Reserve of Pendjari; B, a Shea tree branch with a mistletoe species.

$$\text{IR} = \frac{n_i}{N} \times 100$$

with n_i and N respectively representing the number of infested individuals and the total number of individuals Shea trees in the plot.

Logarithmic transformation of the infestation rate was performed to meet the normality of data and the distribution of data was tested to check it. Data were analysed using ANOVA according to the General Linear Model (GLM) with two crossed factors (habitat and replicate) in Minitab 14. This crossing factor allows us to test the difference between habitats (protected and land use area) and eventual difference between replicates.

The degree of infestation of each Shea tree individual was evaluated. Considering previous categorizations of mistletoe infestations (Bousim et al. 1993, Odebiyi et al. 2004), five levels of infestation degree were defined as follows:

D_1: very weak infestation (1–5 points of infestation on a tree)
D_2: weak infestation (6–10 points of infestation on a tree)
D_3: moderate infestation (11–15 points of infestation on a tree)
D_4: high infestation (16–20 points of infestation on a tree)
D_5: very high infestation (more than twenty points of infestation on a tree).

We compared infestation degree with regard to diameter and height using simple ANOVA. The percentage (P, %) of shea trees individuals belonging to each infestation degree was calculated for each plot as:

$$\text{P} = \frac{d_i}{N}$$

with d_i the number of infested Shea tree individuals belonging to the infestation degree *i* and N overall number of Shea tree individuals in the plot.

A matrix (plot × infestation degree) containing the values of P was obtained. A Principal Component Analysis (PCA) was performed on this matrix to correlate the habitat variable with the infestation degree using SAS software (SAS Inc. 1999). Pearson correlation was calculated and tested between infestation degree and diameter of infested Shea tree.

RESULTS

Infestation rate

The mean infestation rate by plot differed significantly between the land use area and the protected area with 80% and 27.3%, respectively ($F = 25.01$, $p < 0.05$). The difference between replicates was not significant ($F = 0.58$, $p > 0.05$) while the interaction between replicates and habitats was ($F = 3.75$, $p < 0.05$). The mean number of infestation point per tree was respectively 4.75 and 14.33 in protected and in land use areas.

The pattern of infestation degree

Figure 3 shows the pattern of infestation resulting from the principal component analysis with 65.5% of the variance being explained by the two first axes. Table 2 showed that the infestation degree D_4 and D_5 were highly and positively correlated with axis 1 and contrasted the very weak infestation degree (D_1) that was negatively correlated with the same axis. Weak and moderate infestation degree (D_2 and D_3) were significantly and positively correlated with axis 2. Taking into account these results, as well as the figure 3 that showed the projection of habitat variable on the two axes, we concluded that the land use areas were correlated with high and very high infestation degrees (D_4 and D_5), while the others infestation degrees were correlated with both areas.

Figure 4 presented the variation in percentage of Shea tree individuals with regard to infestation degree. It revealed that in protected area, there were fewer Shea tree individuals showing a high infestation degree than in land use area.

The structure of dbh (diameter at breast height) and height of infested Shea tree with regard to area

The structure of the dbh data showed highly significant differences between the infestation degrees ($F = 21.44$, $p < 0.05$) in land use area. Figure 5 presents the mean values and the standard error of dbh for each infestation degree and also showed that trees with a heavy infestation had significantly larger trunks. Similar results had been found in the protected area where the degree of infestation significantly differs among trees ($F = 3.37$, $p < 0.05$). The mean dbh of infested Shea tree was 19.1 cm and 24.01 cm while the minimum infestation dbh was 7.96 cm and 9.55 cm respectively in protected and in land use area. The Pearson correlation coefficient between number of infestation point and dbh exhibited a value of $r = 0.55$, $P < 0.001$ in land use area and $r = 0.42$, $P < 0.05$ in protected area.

Regarding the height (fig. 6), a highly significant difference occurred among the infestation degree in land use area ($F = 27.80$, $p < 0.05$), while no significant difference was found in the protected area ($F = 3.32$, $p < 0.05$). The mean height of infested Shea tree was 7.42 m and 7.31 m and the minimum infestation height, 3.82 m and 3.66 m respectively in protected and land use areas.

DISCUSSION AND CONCLUSION

Land use and infestation of Shea trees by mistletoe

The infestation rate (80%) found in the peripheral agroforestry parklands of the protected area is close to the ones observed in similar areas in Nigeria (81%; Odebiyi et al. 2004)

Table 2 – Correlation between linked infestation degree and Principal Component Analysis axes.

Infestation degree	Axis 1	Axis 2
D_1	-0.62	0.60
D_2	-0.01	0.79
D_3	0.25	0.63
D_4	0.83	0.12
D_5	0.83	0.15

and in Burkina Faso (94.9%; Boussim et al. 1993). However, in this study lower values were obtained in the protected area. This significant difference implies that anthropogenic pressures may facilitate the infestation of Shea trees by mistletoes. Indeed, largest Shea tree individuals occurred in land use area throughout West Africa (Lovett & Haq 2000, Kelly et al. 2004, Djossa et al. 2008), due to agricultural activities such as plough, reduction of tree density, crop fertilisation, weeding (Lamien et al. 2004, Okullo et al. 2004, Kelly et al. 2007) and also due to the reduction of bush fire (Lamien 2001). This situation combined with the fact that the number of infestation points was highly and significantly correlated to the size of the trunk may explain the high infestation rate in land use area. The study also showed that the highest infestation degrees occurred exclusively in land use area. This would be linked to the correlation between Shea tree size and number of infestation points. The lower mistletoes infestation rate of Shea tree in protected area compared to its adjacent agroforstry parklands, is similar to the one observed elsewhere (Green et al. 2009). Indeed, these latter authors found difference in infection level in ephemeral river valleys (Wadis) in Israel. Wadis with high mistletoe infection were adjacent to those containing no infections. This was explained by the flight behaviour of the main bird disperser, which does not typically move among Wadis (Green et al. 2009). Therefore, future investigations should be required on behaviour of the main bird disperser of mistletoe on Shea tree.

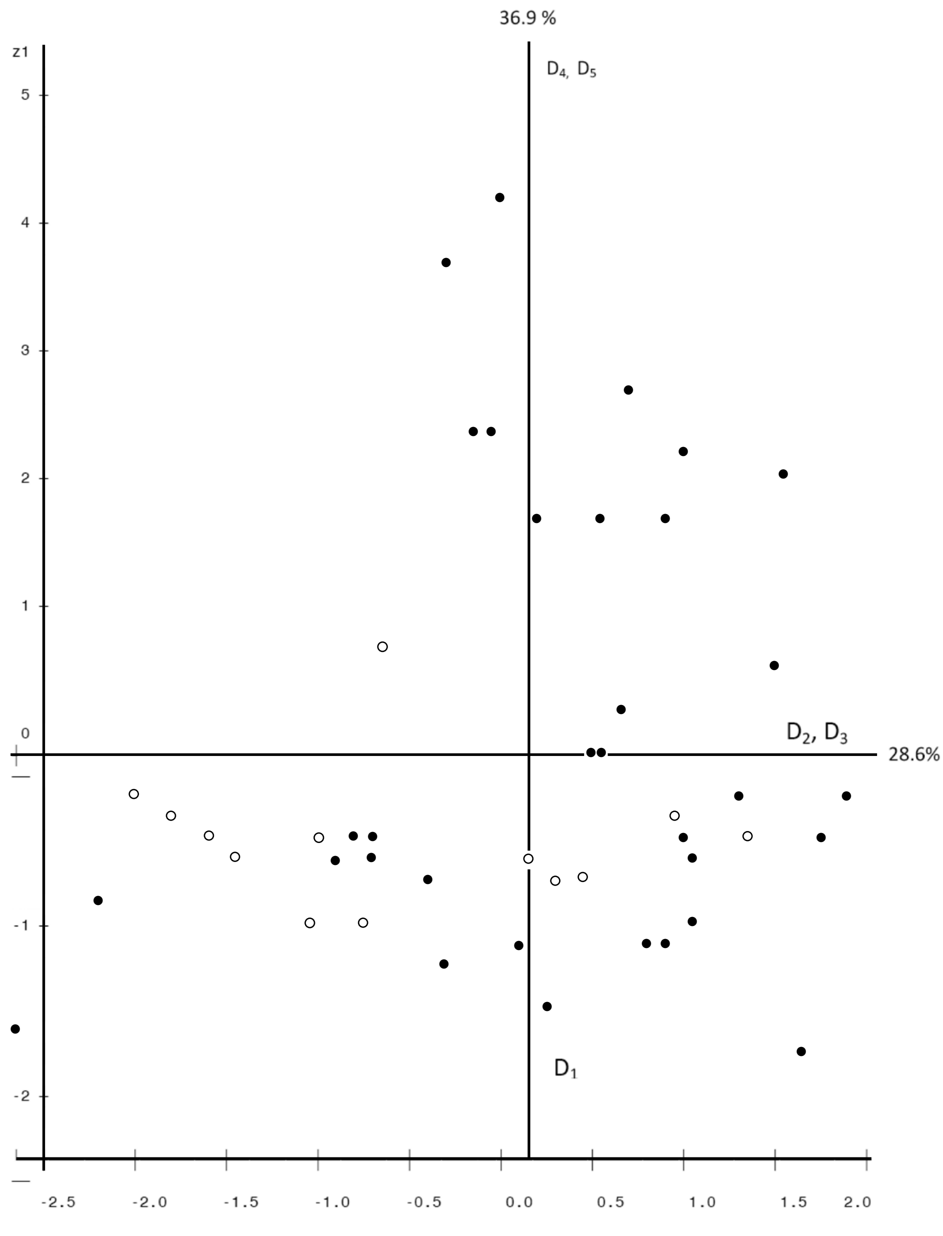

Figure 3 – Projection of habitat variables on the two axes of Principal Component Analysis.Symbols: ● land use area; ○ protected area.

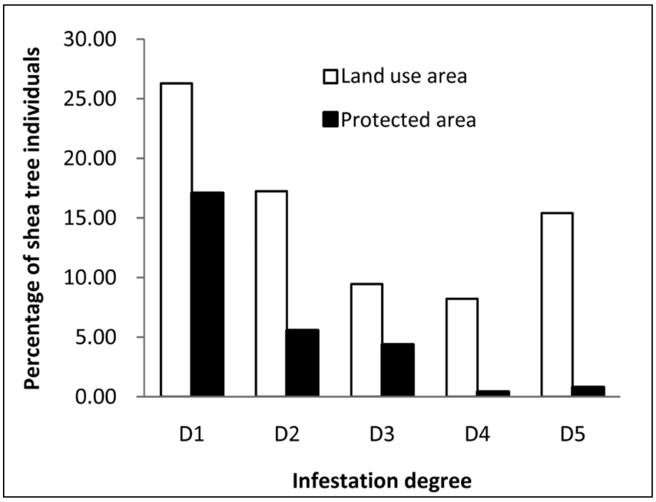

Figure 4 – Variation in percentage of Shea tree individuals belonging to infestation degrees by habitat.

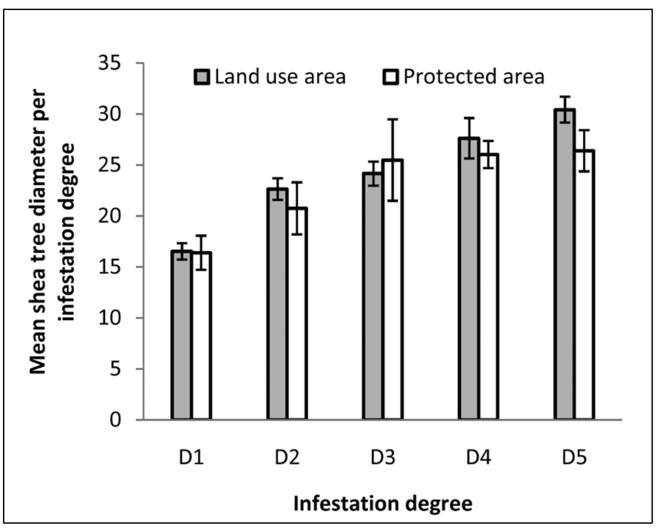

Figure 5 – Mistletoe infestation level vs. dbh of Shea tree (means ± SE).

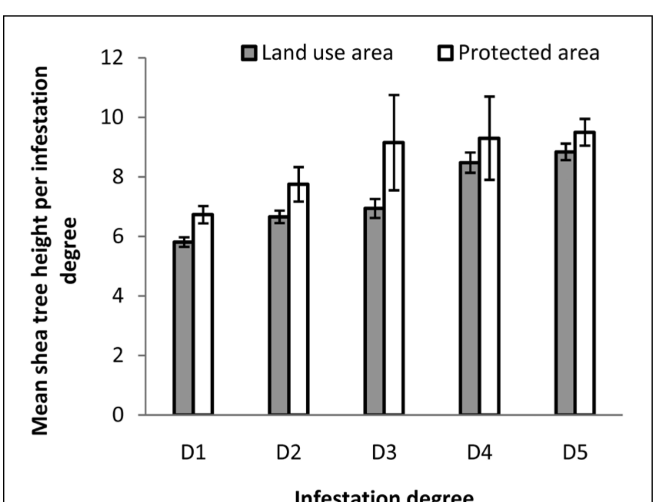

Figure 6 – Mistletoe infestation level vs. height of Shea tree (means ± SE).

Infestation degree with regard to host size

We found in this study that Shea trees with high degrees of infestation had larger trunks in both land use and protected areas although it was emphasized in land use area. This could indicate that larger trees are older trees and thus, that mistletoes had more time to grow on it and induced several infestation points. Similar result had been observed in Israel (Ward et al. 2006) with *Ziziphus spina-christi* (Rhamnaceae) infested by the mistletoe *Plicosepalus acaciae* (Loranthaceae); in New Zealand (Bannister & Strong 2001) with *lleostylus micranthus* mistletoe on different host species and in Australia (Reid & Stafford Smith 2000) with mistletoe *Amyema preissii* (Loranthaceae) on its host *Acacia victoriae* (Mimosaceae). However, the fact that the Shea tree individuals are indeed older in land use area than in the protected area has not been documented yet. What process could explain the high infestation rate of Shea trees observed in land use area, compared to the lower infestation rate observed in protected area?

Ecological factors explaining the higher infestation rates of shea trees by mistletoes in land use area compared to protected area

Several factors are able to induce high infestation rate in land use area. The high infestation rate of Shea trees can be the result of active distribution of mistletoes seeds by its main disperser. Boussim et al. (1993) indicated that the yellow fronted barbet (*Pogoniulus chrysonocus*) was the main direct seed disperser among the four bird species observed on mistletoes fruiting. This species seems to be more mobile and has fearful behaviour (Boussim et al. 1993). Mistletoes seeds could thus be more dispersed in land use area as anthropogenic activities create a noisy environment in land use area, a fact that would induce rapid movement of this bird among trees because of its fearful behaviour. Moreover, the invasion of Shea tree by mistletoes in land use area might also be related to the bird association with human settlements (but not proved yet) as reported by Rödl & Ward (2002) regarding the yellow-vented bulbul bird (*Pycnonotus xanthopygos*), disperser of *Plicosepalus acaciae* mistletoes. Thus, we can assume that the main bird disperser of mistletoes on Shea tree would be abundant in land use area. Martínez del Rio et al. (1996) showed that seed transmission of *Tristerix aphyllu*s on *Eulychnia acida* and *Echinopsis skottsbergii* host increased when its bird disperser (*Mimus thenca*) was abundant. The directed seed dispersal of mistletoes on Shea tree host in land use area comparatively to protected area and the relationship between the main bird disperser and human settlements can be investigated in the future for a better understanding of Shea tree infestation rate.

The relationship between the host condition and its parasite might affect also the infestation rate. Particularly, favourable conditions might be provided for the mistletoe's settlement in the land use area. Mistletoes are most robust on the most vigorous host trees (Bickford et al. 2005, Mathiasen et al. 2008, Glatzel & Geils 2009). By nutritional relationship, Loranthaceae species tap the host's phloem for carbon and inorganic nutrients (Bowie & Ward 2004) and the concentration of nutrients in the mistletoes depends on the one of its host (Glatzel & Geils 2009). Moreover, agricultural practices positively influence Shea tree condition and consequently its development with higher level of flowering and production occurring on farmland (Kelly et al. 2007, Lamien et al. 2004, Djossa et al. 2008). As the parasites grow better in land under cultivation, more seeds are being scattered, which might explain the high mistletoe infestation rate in land use area.

The relatively low level of infestation rate of Shea trees in protected area could also be linked to the higher diversity of host tree species in this area. Mistletoes also parasitize other tree species and in land use area, agricultural activities reduce significantly the diversity of host trees. Consequently, the infestation rate might be reduced on Shea tree in the protected area as other tree species are parasitized. This also means that lower tree diversity in farmed land increases the probability that a bird visits a Shea tree after visiting a tree from the same species, which increases the infestation rate of Shea tree. Also, with low tree diversity, birds can have a diet focussed on hemiparasite, increasing therefore its propagation. In the context of lower tree diversity, it would be necessary to test in the future whether larger tree diversity in parklands is related to overall lower infestation rates.

In conclusion, data from this study indicate clearly that protected area have reduced infestation levels of Shea tree by mistletoes in comparison with nearby land use area. Because of climate change (a factor that contributes to increase aridity), the infested Shea tree could be more vulnerable due to the combined parasitic and drought effects on the trees (Bousim et al. 2004). Protected area have proven to play an efficient role in tropical biodiversity conservation (Bruner et al. 2001). Therefore, the present study highlights its potential for conserving a more viable Shea tree population, less infected by mistletoes.

ACKNOWLEDGEMENTS

We are grateful to the financial support provided by the BIOTA (Biodiversity Monitoring Transect Analysis) project. We thank also Odone Lifam and Christian Adjahossou for their help with data collection; Marcel Houinato and Brice Tenté for their advices during this research; Wilfrid Bonou for the collaboration during the data analysis and to Steven Runo and Peter Neuenschwander for reading the first version of this paper. Our acknowledgements go also to anonymous reviewers whose comments have improved this paper.

REFERENCES

Adomou C.A. (2005) Vegetation patterns and environmental gradients in Benin. Implications for biogeography and conservation. PhD thesis, Wageningen University, Wageningen, The Netherlands.

Agbahungba G., Depommier D. (1989) Aspects du parc à karités-nérés (Vitellaria paradoxa Gaertn. f. Parkia biglobosa Jacq. Benth) dans le sud du Borgou (Bénin). Bois et Forêts des Tropiques 222: 41–54.

Aubréville A. (1939) Forêts reliques en Afrique Occidentale Française. Revue de Botanique Appliquée 19: 479–484.

Bannister P., Strong G.L. (2001) The distribution and population structure of the temperate mistletoe lleostylus micranthus in the Northern Cemetery, Dunedin, New Zealand. New Zealand Journal of Botany 39: 225–233. doi:10.1080/0028825X.2001.9512733

Bickford C.P., Kolb T.E., Geils B.W. (2005) Host physiological condition regulates parasitic plant performance: Arceuthobium vaginatum subsp. cryptopodum on Pinus ponderosa. Oecologia 146:179–189. doi:10.1007/s00442-005-0215-0

Boffa J.-M. (1999) Agroforestry Parklands in sub-Saharan Africa. FAO Conservation Guide 34. Rome, FAO. [available at http://www.fao.org/DOCREP/005/X3940E/X3940E00.HTM]

Boffa J.-M. (2000) West African agroforestry parklands: keys to conservation and sustainable management. Unasylva 51: 11–17. [available at ftp://ftp.fao.org/docrep/fao/x3989e/x3989e03.pdf]

Boussim I.J., Guinko S., Sallé G. (1993) Tapinanthus parasite du karité au Burkina Faso. Bois et Forêts des Tropiques 238: 45–65. [available at http://bft.cirad.fr/revues/notice_fr.php?dk=397458]

Boussim I.J. (2002) Les phanérogames parasites du Burkina Faso: inventaire, taxonomie, écologie et quelques aspects de leur biologie. Cas particuliers des Loranthaceae parasites du karité. PhD thesis, Ouagadougou University, Ouagadougou, Burkina Faso.

Boussim I. J., Guinko S., Sallé G., Tuquet C. (2004) Mistletoes of the agroforestry parklands of Burkina Faso. Agroforestry Systems 60: 39–49. doi:10.1023/B:AGFO.0000009403.36419.20

Bowie M., Ward D. (2004) Water and nutrient status of the misletoe Plicosepalus acaciae parasitic on isolated Negev Desert population of Acacia raddiana differing in level of mortality. Journal of Arid Environment 56: 487–508. doi:10.1016/S0140-1963(03)00067-3

Bruner A.G., Gullison R.E., Rice R.E., da Fonseca G.A.B. (2001) Effectiveness of parks in protecting tropical biodiversity. Science 291: 125–128. doi:10.1126/science.291.5501.125

Chape S., Harrison J., Spalding M., Lysenko I. (2005) Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B 360: 443–455. doi:10.1098/rstb.2004.1592

Djossa B.A., Fahr J.T., Wiegand T., Ayihouenou B.E., Kalko E.K., Sinsin B.A. (2008) Land use impact on Vitellaria paradoxa C.F. Gaerten. Stand structure and distribution patterns: a comparison of Biosphere Reserve of Pendjari in Atacora district in Benin. Agroforestry Systems 72: 205–220. doi:10.1007/s10457-007-9097-y

Glatzel G., Geils B.W. (2009) Mistletoe ecophysiology: host-parasite interactions. Botany 87: 10–15. [available at http://www.fs.fed.us/rm/pubs_other/rmrs_2009_glatzel_g001.pdf]

Green A.K., Ward D., Griffiths M.E. (2009) Directed dispersal of mistletoe (Plicosepalus acaciae) by Yellow-vented Bulbuls (Pycnonotus xanthopygos). Journal of Ornithology 150:167–173. doi:10.1007/s10336-008-0331-9

Hall J.B., Aebischer D.P., Tomlinson H.F., Amaning E.O., Hindle J.R. (1996) Vitellaria paradoxa, a monograph. Bangor, United Kingdom, School of Agricultural and Forest Sciences, University of Wales.

Kelly B.A., Hardy J.O., Bouvet J-M. (2004) Temporal and spatial genetic structure in Vitellaria paradoxa (Shea tree) in an agroforestry system in southern Mali. Molecular Ecology 13: 1231–1240. doi:10.1111/j.1365-294X.2004.02144.x

Kelly B.A., Gourlet-Fleury S., Bouvet J-M. (2007) Impact of agroforestry practices on the flowering phenology of Vitellaria paradoxa in parklands in southern Mali. Agroforestry Systems 71:67–75. doi:10.1007/s10457-007-9074-5

Lamien N. (2001) Organisation structurale et état sanitaire des populations fructifères de karité (Vitellaria paradoxa Gaertn.) de la région de Bondoukuy. Mémoire de DEA en Biologie et Ecologie Végétales. Université de Ouagadougou, Burkina Faso.

Lamien N., Ouédraogo S.J., Diallo O.B., Guinko S. (2004) Productivité fruitière du karité (Vitellaria paradoxa Gaertn. C. F., Sapotaceae) dans les parcs agroforestiers traditionnels au Burkina Faso. Fruits 59: 423–429. doi:10.1051/fruits:2005004

Lamien N., Boussim J.I., Nygard R., Ouédraogo J.S., Odén P.C., Guinko S. (2006) Mistletoe impact on Shea tree (Vitellaria paradoxa C.F. Gaertn.) flowering and fruiting behaviour in savanna area from Burkina Faso. Environmental and Experimental Botany 55: 142–148. doi:10.1016/j.envexpbot.2004.10.010

Lovett P.N., Haq N. (2000) Evidence for anthropic selection of Shea nut tree (Vitellaria paradoxa). Agroforestry Systems 48: 273–289. [available at http://www.icuc-iwmi.org/files/Publications/Evidence%20for%20anthropic%20selection.pdf]

Maranz S., Wiesman Z. (2003) Evidence for indigenous selection and distribution of the Shea tree, Vitellaria paradoxa, and its potential significance to prevailing parkland savanna tree patterns in sub-Saharan Africa north of the equator. Journal of Biogeography 30:1505–1516. doi:10.1046/j.1365-2699.2003.00892.x

Maranz S., Kpikpi W.,Wiesman Z., De Saint Sauveur A., Chapagain B. (2004) Nutritional values and indigenous preferences for Shea fruits (Vitellaria paradoxa C.F. Gaertn. F.) in african agroforestry parklands. Economic Botany 58: 588–600. doi:10.1663/0013-0001(2004)058[0588:NVAIPF]2.0.CO;2

Martínez del Rio C., Silva A., Medel R., Hourdequin M. (1996) Seed dispersers as disease vectors: bird transmission of mistletoe seeds to plant hosts. Ecology 77: 912–921. doi:10.2307/2265511

Mathiasen R.L., Nickrent D.L., Shaw D.C., Watson D.M. (2008) Mistletoes pathology, systematics, ecology and management. Plant disease 92: 988–1006. doi:10.1094/PDIS-92-7-0988

Nelson A., Chomitz K.M. (2009) Protected Area effectiveness in reducing tropical deforestation. A global analysis of the impact of protection status. Evaluation Brief 7. Washington, D.C., The World Bank. [available at http://ccmin.aippnet.org/pdfs/IEG-Evaluation_Brief_7_Protected_Areas_2009.pdf]

Nikiema A. (2005) Agroforestry parkland species diversity: uses and management in semi-arid West Africa (Burkina Faso). PhD thesis, Wageningen University, Wageningen, the Netherlands. [available at http://edepot.wur.nl/121636]

Neumann K., Kahlheber S., Uebel D. (1998) Remains of woody plants from Saouga, a medieval West African village. Vegetation History and Archaeobotany 7: 57–77. doi:10.1007/BF01373925

Odebiyi J.A., Bada S.O., Omoloye A.A., Awodoyin R.O., Oni P.I. (2004) Vertebrate and insect pests and hemi-parasitic plants of Parkia biglobosa and Vitellaria paradoxa in Nigeria. Agroforestry Systems 60: 51–59. doi:10.1023/B:AGFO.0000009404.96034.58

Okullo J.B.L., Hall J.B., Obua J. (2004) Leafing, flowering and fruiting of Vitellaria paradoxa subsp. nilotica in savannah parklands in Uganda. Agroforestry Systems 60:77–91. doi:10.1023/B:AGFO.0000009407.63892.99

PAG2 (2005) Plan d'Aménagement Participatif et de Gestion 2004–2013. Bénin, Parc National de la Pendjari.

Reid N. (1991) Coevolution of mistletoes and frugivorous birds. Australian Journal of Ecolology 16:457–469. doi:10.1111/j.1442-9993.1991.tb01075.x

Reid N., Stafford Smith M. (2000) Population dynamics of an arid zone mistletoe (Amyema preissii, Loranthaceae) and its host Acacia victoriae (Mimosaceae). Australian Journal of Botany 48: 45–58. doi:10.1071/BT97076

Rice R., Bruner. A. (1999) Park effectiveness in the tropics. In: Conservation International, Washington, D.C. in International Workshop on Management Effectiveness of Protected Areas, June 14–16, CATIE, Turrialba, Costa Rica. Hosted by WWF Central America Regional Office.

Rödl T., Ward D. (2002) Host recognition in desert mistletoe: early stages of development are influenced by substrate and host origin. Functional Ecology 16: 128–134. doi:10.1046/j.0269-8463.2001.00592.x

Sallé G., Boussim J., Raynal-Roques A., Brunck F. (1991) Le karité une richesse potentielle, perspectives de recherche pour améliorer sa production. Bois et Forêts des Tropiques 228: 11–23. [available at http://bft.cirad.fr/revues/notice_fr.php?dk=403048]

SAS Inc. (1999) SAS/STAT Users Guide. Cary, USA, SAS Institute.

Sinsin B., Tehou A.C., Daouda I., Saidou A. (2002) Abundance and species richness of larger mammals in Pendjari National Park in Benin. Mammalia 66(3):369–380. doi:10.1515/mamm.2002.66.3.369

Teklehaimanot Z. (2004) Exploiting the potential of indigenous agroforestry trees: Parkia biglobosa and Vitellaria paradoxa in sub-Saharan Africa. Agroforestry Systems 61: 207–220. doi:10.1023/B:AGFO.0000029000.22293.d1

Watson D.M. (2004) Mistletoe: a unique constituent of canopies worldwide. In: Lowman M.D., Rinker H.B. (eds) Forest Canopies: 212–223. San Diego, California, Academic Press.

Ward D., Shrestha M.K., Musli I. (2006) Are invasive mistletoes killing Ziziphus spina-christi? Israel Journal of Plant Sciences 54: 113–117. doi:10.1560/IJPS_54_2_113

Wenny D.G. (2001) Advantages of seed dispersal: a re-evaluation of directed dispersal. Evolutionary Ecology Research 3: 51–74. [available at http://www.inhs.uiuc.edu/~dwenny/documents/EER2001.pdf]

White F. (1983) The vegetation of Africa, a descriptive memoir to accompany the UNESCO/AETFAT/UNSO. Natural Resources Research 20: 1–356.

Yidama I.A. (1994) Pollination in Shea trees. Cocoa Research Institute, Ghana. Annual report 1992/93.

Manuscript received 28 Jul. 2010; accepted in revised version 22 Mar. 2011.

Communicating Editor: Tariq Stévart.