Structure and Spatial Distribution of the Abundance of *Spondias mombin* L. Populations in the Subequatorial Zone of Benin (West Africa)

Yolande Togni[*], Jean Cossi Ganglo

Laboratory of Forest Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin

Email address:

ytogni@yahoo.fr (Yolande Togni), ganglocj@gmail.com (Jean Cossi Ganglo)

[*]Corresponding author

Abstract: Conservation and sustainable use strategies for reliable management plans of valuable species are lacking due to the gap in basic scientific information on their structure and status. The objectives of this work were to study the structural characteristics and the spatial distribution of the abundance of *Spondias mombin* L. populations in the subequatorial zone of Benin. The data collection was based on the tessellation of study zone with ArcGIS analysis tools. The grid cell used was a square of 100 m side (1ha of surface). The occurrence of species in each grid was obtained using GBIF database. One hundred and seventy-five (175) trees of *S. mombin* were sampled through the four Phytodistricts of study zone. The main dendrometric variables measured from these individuals were diameter at breast height (1.30 m above ground level) and height. The parameters such as density, mean quadratic diameter, basal area and mean Lorey height were calculated. To study the spatial abundance distribution of *S. mombin*, we used Inverse Distance Weighting (IDW) interpolation method to realize abundance map from the occurrences. The results of structure showed a density of 3 trees/ha. The basal area was 1500 cm^2/ha and the mean quadratic diameter was 25.10 cm. The mean of Lorey height obtained was 12 m. The diameter structure showed a predominance of bell-shape distribution with a relative abundance of young individuals. The low numbers of individuals in some diameter classes, the erratic distribution and the presence of old population of *S. mombin* indicate the strong anthropogenic pressure on the species. The abundance map showed that the species was present in all the phytodistricts and covers 93% of the study area's municipalities. The conservation strategies, including both the species and its habitat, need to be developed to allow sustainable use of *S. mombin*.

Keywords: *Spondias mombin*, Structural Characteristics, Spatial Abundance Distribution, Subequatorial Zone of Benin

1. Introduction

The flora of tropical African countries, like that of Benin, has many species used in the diet and care of the population. Among these species is *Spondias mombin* L. of the Anacardiaceae family. The dietary and medicinal importance of this species has already been proven in several research works. For example, Ambé in his study on the wild edible fruits of the Guinean savannahs of Cote d'Ivoire [1], showed that *S. mombin*, is the thirteenth fruit consumed according to the consumption of local populations and the twenty-second fruit consumed according to the local knowledge of local populations. Adedokun and others investigated the socio-economics and medicinal utilization of *S. mombin* in three communities in Nigeria [2]; they revealed that the species is used in the treatment of cough, malaria, and fibroid. It would be an important aid to childbirth. Béné and others studied the medicinal plants used in the Department of Transua, District Zanzan (Côte d'Ivoire) [3], and *S. mombin* is quoted as a species used against vomiting, nausea, post and prenatal hemorrhage and fontanel. Kakpo and others carried out ethno-pharmacological investigation of medicinal plants used to treat typhoid fever in Benin [4]; their results showed that *S. mombin* was used in the treatment of typhoid fever. In

Benin, despite the interest in these species [4-7], their promotion is still not very effective although they can contribute to the food security of rural populations [8-11].

Conservation and sustainable use strategies for reliable management plans and management of this species are lacking due to the gap in basic scientific information on the structure and status of its populations [12-13]. The availability of basic scientific information on the structure and status of the populations of the species will help to improve the strategies to be developed for their valorization and conservation in the context of climate change in Benin. Density, basal area, distribution by diameter classes are among the most important parameters used to characterize a forest species [14-15]. Density is a good indicator of the quantity of the resource available and the silvicultural status of tree populations [16]. Basal area is a parameter that defines the intensity of interventions during forest management [17]. It is very practical and highly recommended in silviculture. Diameter structure describes the relative abundance of trees by diameter class and is essential to provide information on species ecology, possible silvicultural constraints and resource status

[14, 18]. What then are the main structural characteristics and the spatial distribution of the abundance of *Spondias mombin* L. populations in the subequatorial zone of Benin? Knowing these structural attributes would be a prerequisite to the development of conservation strategies for *S. mombin*. The objectives of the present study are therefore to determine the dendrometric characteristics of *Spondias mombin* L. in the subequatorial zone of Benin, to describe the diameter structure of this species and to study its spatial distribution in the area of interest.

2. Study Area

The subequatorial zone of Benin is located between latitudes 6°20' and 7°35'N and longitudes 1°33' and 2°49' E. Its administrative boundaries are the Republics of Togo to the West and Nigeria to the East, the Collines Department to the North and the Atlantic Ocean to the South. The sub equatorial zone of Benin is subdivided into 4 phytodistricts (Figure 1) whose biophysical characteristics [19] are summarized in Table 1.

Table 1. Biophysical characteristics of the phytodistricts of sub equatorial zone of Benin.

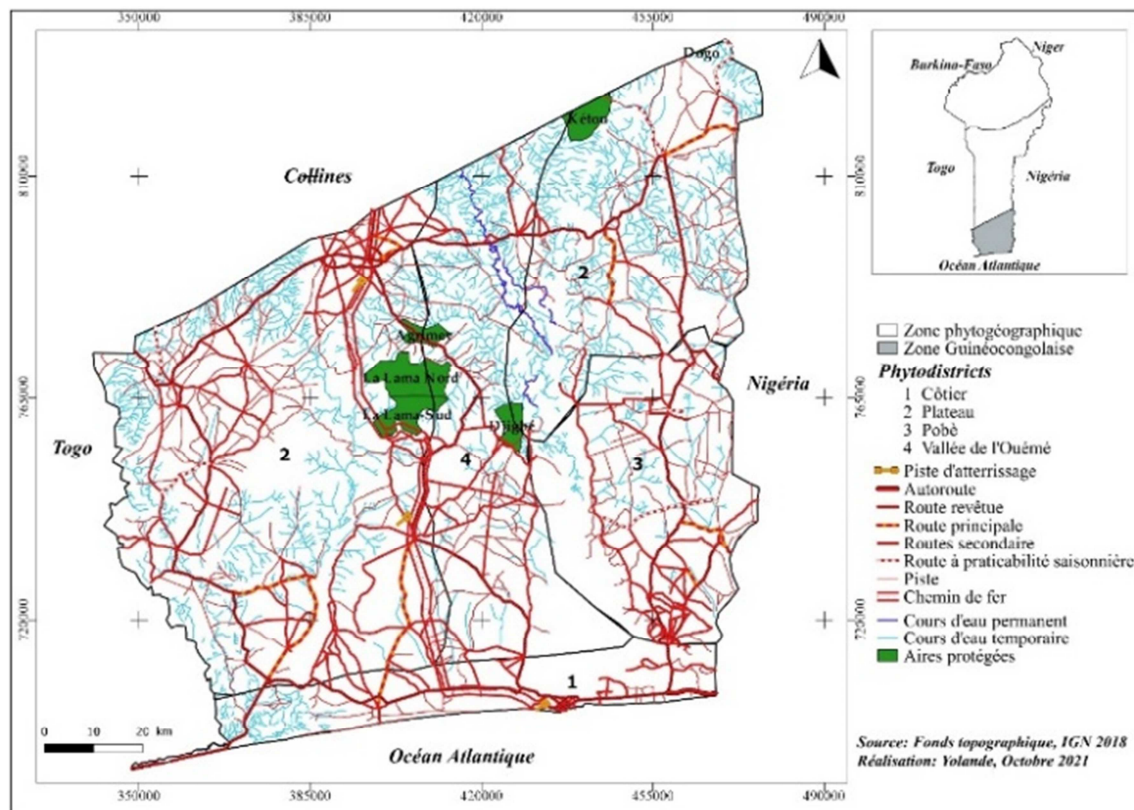| Phytodistricts	Climate	Main soil types	Main plant formations
"Côtier"	subequatorial with two rainy seasons (Rainfall: 900 to 1300 mm)	Sandy + Hydromorphic and halomorphic	Coastal forest and Mangrove
"Plateau"	Guinean with two rainy seasons (Rainfall: 900 to 1100 mm)	Ferralitic soil without concretions	Semi-deciduous forest
"Pobè"	Guinean with two rainy seasons (Rainfall: 1200 to 1300 mm)	Ferralitic soil without concretions	Semi-deciduous forest
"Vallée de l'Ouémé"	Guinean with two rainy seasons (Rainfall: 1100 to 1300 mm)	Hydromorphic soil	Swamp and Semi-deciduous forest

Figure 1. Map of subequatorial zone showing the four phytodistricts.

3. Methods

3.1. Method of Collecting Dendrometric Data

The data collection equipment is composed of GPS (Global Positioning System), π ribbons, pentadecameter, Suunto clisimeter, and digital camera. The data collection system is the subequatorial zone griddled, with ArcGIS 10.6, according to a square of 100m side. Each grid of the system has therefore 1ha the surface. The occurrences of the species studied were downloaded from GBIF site. After cleaning efforts that involved removing occurrence data lacking geographic coordinates and those outside the subequatorial zone, our area of interest, hundred and seventy-five (175) occurrences of *S. mombin*, were selected. Projection of these occurrences on the data collection system allowed us to set up the data collection grids, which were those containing at least one occurrence point of target species. The free version of applications Mobile Topographer 9.3.2 and QField 1.5.3 were used to locate and move in the sample grid. In each grid sampled, the diameter and height of the species were measured. The new individuals of this species were georeferenced (with GPS) and those who disappeared from the field were noted.

3.2. Data Processing and Analysis

The different dendrometric parameters calculated are density, mean quadratic diameter, basal area and Lorey height.

The density (N in trees/ha) was calculated with the formula:

$$N = \frac{n}{S} \qquad (1)$$

where *n* is the total number of trees per 1 ha plot; *S* = area of the plot (the grid) which is equivalent to 1 ha.

The mean quadratic diameter (Dg in cm) was calculated with the formula:

$$Dg = \sqrt{\frac{1}{n}\sum_{i=1}^{n} di^2} \qquad (2)$$

where *di* is the diameter in cm of tree *i* in the grid and n is the number of trees i in the grid.

The basal area (G in m²/ha) at the reference level (1.3 m from the ground) was calculated with the formula:

$$G = \frac{\pi}{40000S}\sum_{i=1}^{n} di^2 \qquad (3)$$

The Lorey height (HL in m), the height of individuals weighted by basal area, was calculated with the formula:

$$HL = \frac{\sum_{i=1}^{n} gihi}{\sum_{i=1}^{n} gi} \quad \text{with} \quad gi = \frac{\pi}{4}di^2 \qquad (4)$$

where *hi* is the total height in m of tree *i* in the grid.

The non-parametric Kruskal-Wallis test was used to analyze the differences in density, mean quadratic diameter, basal area and mean Lorey height across the phytodistricts of the subequatorial zone; the data collected were not normally distributed (Ryan-Joiner normality test). All statistical analyses were performed using R 3.5.0 software.

In order to analyze the diameter structure of the species, their populations were grouped into classes of 5 cm amplitude.

To study spatial distribution of the abundance of *Spondias mombin* L. populations in the subequatorial zone of Benin, we used Inverse Distance Weighting (IDW) with the occurrences downloaded from the GBIF site, the new georeferenced occurrences as well as the density of individuals of the target species. IDW is a standard interpolation procedure found in many GIS packages [20-21] and it is often used as the default surface generation method for attribute sample locations [22]. IDW estimates the unknown value z^* (*So*) at location *So* as with the exception that the weights λ_i are determined by:

$$\lambda_i = \frac{d_{io}^{-p}}{\sum_{i=1}^{n} d_{io}^p} \qquad (5)$$

where d_{io} is the distance between the prediction location, *So*, and each of the measured locations, *Si*. The power parameter p influences the weighting of the observed location's value on the prediction location's value. Effectively this means that as the distance increases between the observed sample locations and the prediction location, the weight the observed data point will have on the prediction decreases exponentially. The optimal p value of 1.3 was determined by minimising the root-mean-square prediction error through standard cross-validation techniques available in ArcGIS 10.6 using geostatistical analyst [23]. For this process neighbourhood parameters were set to a minimum of two points and a maximum of 15 points within the search radius.

4. Results

4.1. Dendrometric Parameters of S. mombin

The dendrometric parameters of *S. mombin* are recorded in table 2. Only "Plateau" phytodistrict has a density value lower than the overall estimated value for this parameter. The lowest values for mean quadratic diameter and Lorey height were observed in "Côtier" phytodistrict. "Pobè" is the phytodistrict with the highest basal area value. The value of the standard deviation of the mean quadratic diameter in "Pobè" show a great variability of this parameter at the level of this phytodistrict. The values of mean quadratic diameter and basal area in "Vallée de l'Ouémé" and "Pobè" phytodistricts were significantly different from those in "Plateau" and "Côtier" phytodistricts.
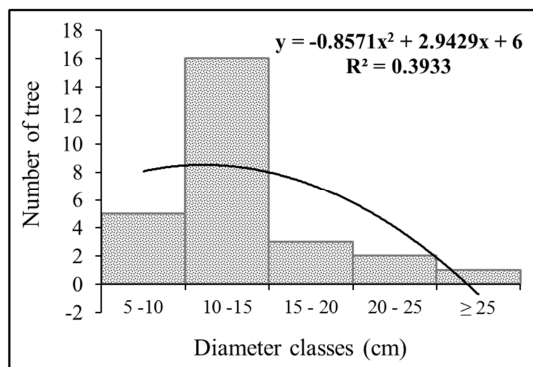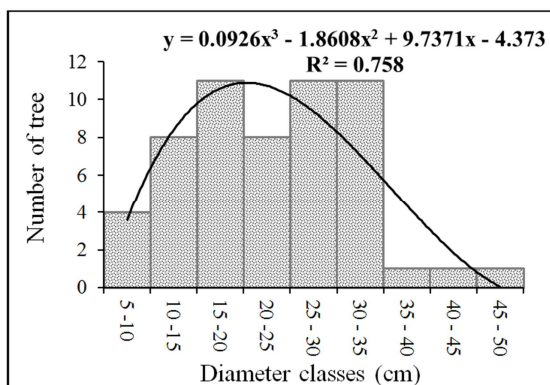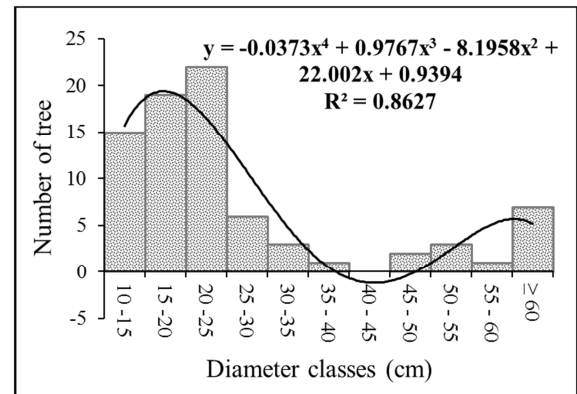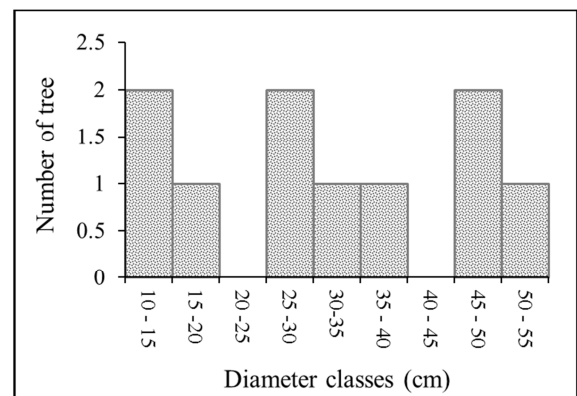
***Table 2.** Dendrometric parameters of S. mombin.*

Phyto-districts	N (tree/ha)	Dg (cm)	G (cm²/ha)	HL (m)
"Côtier"	3.9[a]±2.9	13.5[a]±4.6	700[a]±5	8.4[a]±2.4
"Plateau"	1.4[b]±1.1	23.5[a]±8.5	700[a]±6	12.8[a]±4.9
"Pobè"	2.8[a]±2.4	29.7[ab]±20.3	2900[ab]±044	11.6[a]±5.9
"Vallée de l'Ouémé	2.5[a]±0.6	30.3[ab]±9.2	200[ab]±17	13.4[a]±2.2
Set	2.2±1.9	25.1±14.3	1500±28	12.0±5.2

N means tree density, Dg means quadratic diameter, G means basal area, HL means Lorey Height. For each parameter, the same letter a, b, c or d in front of the values shows that there is no significant difference. The different letters in front of these values, on the other hand, show a significant difference.
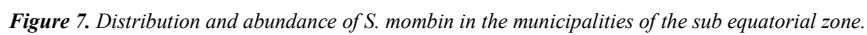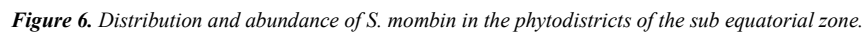
4.2. Diameter Structure of S. mombin

The density distribution by diameter classes of *S. mombin* individuals shows unimodal and bell-shaped distributions in "Côtier" (Figure 2) and Plateau (Figure 3) phytodistricts. In "Pobè" phytodistrict (Figure 4), two sub-populations can be identified, a young population whose individuals have a diameter of 10 to 40 cm and an older population which have individuals with a diameter > 40 cm. The distribution is therefore bimodal with a bell shape for each sub-population. In "Vallée de l'Ouémé" (Figure 5), the species has a trimodal and erratic distribution with individuals varying in diameter from 10 to 55 cm and with very low numbers, fitting very poorly with the usual theoretical distributions. In the "Côtier", "Pobè" and "Plateau" phytodistricts, individuals of the first diameter class are in low numbers. These different distributions fit better to a polynomial function.

***Figure 2.** Diameter structure of S. mombin in Côtier.*

$$y = -0.8571x^2 + 2.9429x + 6$$
$$R^2 = 0.3933$$

***Figure 3.** Diameter structure of S. mombin in Plateau.*

$$y = 0.0926x^3 - 1.8608x^2 + 9.7371x - 4.373$$
$$R^2 = 0.758$$

***Figure 4.** Diameter structure of S. mombin in Pobè.*

$$y = -0.0373x^4 + 0.9767x^3 - 8.1958x^2 + 22.002x + 0.9394$$
$$R^2 = 0.8627$$

***Figure 5.** Diameter structure of S. mombin in Vallée de l'Ouémé.*

4.3. Spatial Distribution of the Abundance of Spondias mombin L. Populations in Subequatorial Zone of Benin

Figure 6 presents distribution and abundance maps of *S. mombin* according to the phytodistricts of subequatorial zone. It shows that the species is present in all the phytodistricts of this zone, especially in the "Pobè" and "Plateau" phytodistricts. However, some of the populations of the species in the "Côtier" and "Vallée de l'Ouémé" phytodistricts have high densities (> 35 individuals per km²).

Figure 7 shows the distribution and abundance maps of *S. mombin* according to municipalities in subequatorial zone. The species is found in 93% of the municipalities in the study area. The abundance of *S. mombin* is seen in Bonou, Lokossa, Dangbo, Toffo, Ouidah, Zogbodomey, Sakété, Adjara, Akpro-Missérété, Avrankou, Adjohoun, Adjaouèrè, Kétou and Pobè. *S. mombin* is totally absent in Djidja, So-Ava, Za-kpota, Zagnanado, Bohicon and Covè municipalities.

Figure 6. Distribution and abundance of S. mombin in the phytodistricts of the sub equatorial zone.

Figure 7. Distribution and abundance of S. mombin in the municipalities of the sub equatorial zone.

5. Discussion

5.1. Dendrometric Parameters of the Species Versus Human Pressure

The dendrometric characteristics considered in this study are among those used as preliminary technical bases for defining management and biodiversity conservation objectives [15]. The lowest values of these parameters are observed in the "Côtier" phytodistrict. The mean comparison test carried out for these different parameters considering the phytodistricts of the study area shows a significant difference at the 5% probability threshold for density, mean quadratic diameter and basal.

The largest individuals of *S. mombin* were observed in the "Plateau", "Pobè" and "Vallée de l'Ouémé" phytodistricts. The mean quadratic diameter values of *S. mombin* observed in these phytodistricts are close to 30 cm reported for the species [24]. This tends to suggest that these phytodistricts are suitable for development and expansion of the species or are only little impacted by human activities. The second hypothesis seems more plausible since the proportion of pre-existing individuals who disappeared in "Côtier" phytodistrict is higher than in the other phytodistricts. However, for all four phytodistricts, the values of the mean Lorey height are relatively lower. While these values can reach 25 m [24-25]. This low elongation of the bole height in favour of the observed lateral growth could be explained by the pruning exerted by the populations on the individuals of *S. mombin*. Indeed, branch mutilation, over the years, limits growth in height and favouring instead growth in diameter [13, 26]. Such results were also obtained for some species in Benin. They are *Vitex doniana* [27]*, Tamarindus indica* [28], *Prosopis africana* [29] and *Haematostaphis barteri* [30]. The structure of these species showed that human activities have a negative effect on dendrometric parameters such as total height, regeneration and adult density, but a positive effect on mean diameter [27-30].

5.2. Diameter Structure of S. mombin

The different distribution patterns seen in "Côtier", "Pobè", "Plateau" and "Vallée de l'Ouémé" phytodistricts show a disturbance in the populations of *S. mombin* in the study area. Despite the low density of *S. mombin* individuals in the first diameter class in "Côtier", "Pobè" and "Plateau" phytodistricts, the species shows for the whole area of interest a relative abundance of young individuals compared to adult individuals. The abundance of small-diameter individuals ensures the future of the natural formation while the large-diameter individuals result from natural selection and are in fact the seed trees that ensure the sustainability of the stand [31]. Mbayngone and others asserted that such a distribution is typical of stable populations, likely to renew themselves through natural regeneration [32]. However, this cannot be interpreted as a good stand-specific conservation status of the species. The low density of large-diameter individuals shows the aging state of the individuals in the population of this species [33]. Low density of adult or seed individuals in the population of a species could also affect the recovery of the population of that species in the long term through lack of seeds, with the large diameter individuals being the ones able to fruit and provide regeneration [34-35]. The low number of large-diameter individuals is the result of both environmental factors such as strong winds and anthropogenic factors due to unsustainable exploitation through ignorance of the principles of rational management of these species. In addition to these factors, the erratic distribution seen in "Vallée de l'Ouémé" for *S. mombin* might suggest that the species is rare in this phytodistrict. However, the low numbers of individuals observed in the different diameter classes indicate the strong pressure exerted on the species in this area. This hypothesis is supported by the diameter of the individuals varying from 10 to 55 cm. It is therefore not a rarity of the species that explains this irregular structure but rather a sustained pressure exerted on the species.

5.3. Spatial Distribution of the Abundance of Spondias mombin L. Populations

The distribution of the species covers all phytodistricts and 93% of the municipalities in the study area. These results reveal a good distribution of species in the study area. Despite this specific representativeness in the study area, *S. mombin* is totally absent in Djidja, So-Ava, Za-kpota, Zagnanado, Bohicon and Covè municipalities. There are several reasons for this gap. It could be that the species are not really found in the municipalities concerned, that there is a lack of inventory in these municipalities, that there is no seed of this species in these municipalities, or that these communes don't have habitats favourable to the development and expansion of the species. When we are interested in the ecosystems hosting the target species, *S. mombin* is a species of the Sudanian and pre-forest savannah of Guinea found at the edge of forests or cultivated in villages on all types of soil [24]. It can therefore be said that the municipalities in which this gap is observed have at least one formation that can support the development and growth of this species. This conclusion is supported by the absence of the species in the municipality of So-Ava, which is known for fragile ecosystems [36], its vegetation being characterized by species of periodically flooded areas [37]. In addition to this municipality, the species was not found in the municipality of Djidja. The absence of occurrence in this municipality may be explained by the fact that the portion of the municipality included in the subequatorial zone does not host these species. The distribution of the species in Benin showed the presence of the species in other localities of the municipality. The absence of the species in Covè, Za-kpota, Zagnanado municipalities can be justified either by an absence of its seed in these municipalities or by a lack of inventory of the species in these localities. An inventory effort must be made to confirm or refute these different hypotheses.

6. Conclusion

The study of the structural characteristics and spatial distribution of the abundance of *Spondias mombin* L. populations in subequatorial Zone of Benin (West Africa) showed the predominance of individuals of small diameter and a disturbance in the populations of this species. The distribution and abundance maps revealed a good distribution of species in the subequatorial zone. Conservation strategies for *S. mombin* need to be developed to allow sustainable use of this species in the area of interest. These strategies should incorporate both the species and its habitat. The results of this study are relevant for this purpose but deserve to be deepened by studies related to the distribution and modelling of ecological niches of the studied species in order to implement better strategies.

Conflict of Interests

The authors declare that there is no competing interest.

Acknowledgements

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