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Structural characterization of over-exploited forest species: Case of *Garcinia kola* Heckel (Clusiaceae) in Côte d'Ivoire

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The purpose of this study is to define the structural characteristics and spatial distribution of endangered *Garcinia kola* in Côte d'Ivoire, in order to ensure sustainable management of the species. The study was conducted in two natural growth zones (Affery and Biankouma) of the species and involved 94 trees with a minimum diameter of 10 cm measured at 1.30 m from the ground. The data collection method consisted of a mobile inventory within 100 m × 100 m plots. The study revealed that *G. kola* has an aggregated distribution. Both stands are dominated by medium class trees, [30-40 cm], [40-50 cm], [50-60 cm]. Modeling of all trees in each stand, divided into diameter classes according to the Weibull distribution, shows that *G. kola* has a low regeneration potential, with a shape parameter c = 2.41 and 1.74. In addition, basal area and tree density are very low. Sustainable management of this species therefore requires awareness of its domestication.

Key words: *Garcinia kola*, structural characterization, sustainable management, spatial distribution.

INTRODUCTION

Côte d'Ivoire lost nearly 84% of its forest cover between 1960 and 2000 (Koné et al., 2014). Anthropogenic activities (extensive agriculture, gold panning and uncontrolled exploitation of fuelwood and timber) due to rapid population growth are the main causes (MEDD, 2016). However, many plant species have become extinct or rarefied, mainly during the last century (Djaha and Gnahoua, 2014), among which is *Garcinia kola* Heckel (Clusiaceae). *G. kola* is one of the forest species of socio-economic interest much appreciated by local populations (Kouamé et al., 2016). About this species, all parts (from the top to the root) are used by man. Indeed, seeds are sought for their stimulating effects, aphrodisiacs, bad cholesterol cleaners and liver protectors (Iwu et al., 1999) Seeds are also used in drugs to treat multiple gastrointestinal and pulmonary conditions (Guedje and Fankap, 2001; Ebomoyi and Okojie, 2012). Thus *G. kola* is used as a remedy for the treatment of

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diseases such as diarrhoea, laryngitis, gonorrhoea, headaches and gastritis: *G. kola* bark is also used as a purgative (Ajebesone and Aina, 2004). The pulp is also consumed. The supply of minerals, vitamins and amino acids contained in these fruits makes them complementary foods, sometimes essential, during the lean season for local forest populations. In addition, the plant has a market value inside and outside of Côte d'Ivoire (Koffi et al., 2015). The economic value of the seeds fluctuates from two to six USD per kilogram (Kouamé et al., 2016).

Yet, excessive demands for *G. kola*, are leading to depletion of the resource. This species is on the IUCN Red List of Threatened Species, as vulnerable (Cheek, 2004). To overcome this problem, it is essential to establish a good conservation strategy for this species. Indeed, to reach this goal a good description of its structure, the distribution of individual stem characteristics is necessary (Rabhi et al., 2016). However, scientific information on spatial distribution and the structuring of *G. kola* in Côte d'Ivoire still remains fragmentary. This information is very important because it allows the identification of potential areas where the species is abundant and thus guides the selection of areas where particular conservation measures for the species can be undertaken (Kebenzikato et al., 2014). It is why we are specifically studying, on one hand, the structure, as well as the analysis of dendrometric parameters, on the other hand, the spatial distribution of *G. kola* in two agro-ecological localities of Côte d'Ivoire. This approach will allow us to know the current conservation or disturbance status of the species and to consider better sustainable management strategies.

METHODOLOGY

Study sites

The study was carried out in two agro-ecological areas of Côte d'Ivoire for three years, from 2015 to 2018. One is in the west (Biankouma) and the other in the south (Affery). Figure 1 shows the geographical location of the study area. The choice of these areas was made after several prospecting studies with wholesale and field merchants. The surveys revealed that most of their supply of "petit kola" grains originated in these two areas. Biankouma is a department in the west of Côte d'Ivoire and is part of the Tonpki region, characterized by mountainous relief, ferralitic and hydromorphic soils. This locality is located at 635 km from Abidjan between 7˚44'00" North and 7˚37'00" West. During the year the temperature generally varies from 17 to 33°C with an average of 24°C. The rainfall varies between 1300 and 2400 mm per year and the vegetation consists mainly of humid forest.

Affery, the second study area, is located in the south of Côte d'Ivoire in the department of Adzopé, 101 km from Abidjan between 6°18'54'' North and 3°57'37'' West. Affery is located in a humid tropical climate zone. This climate gives it a relatively constant temperature which oscillates around 27.5°C with four seasons of uneven lengths. The annual rainfall is 1300 mm on average. The town of Affery is characterised by the presence of many hills whose average altitude does not exceed 100 m. They are separated by long valleys that look like precipices from which several marigots and rivers sometimes leave. The vegetation is dominated by tropical rainforest.

Sampling and data collection

The data collection method consisted of a mobile inventory (Rabiou et al., 2015; Ouattara et al., 2016) within 100 m × 100 m plots (Habou et al., 2014). This method was used given the low apparent density of *G. kola* in the natural formations studied. It not only accounts for the structural heterogeneity of the stands but also allows for the enumeration of sufficient individuals to obtain a reliable estimate of density and demographic structure (Goba et al., 2019). Distances traveled were estimated using a GPS. A total of 300 plots were installed at each study site. In each plot, dendrometric measurements involved all georeferenced *G. kola* individuals with a diameter equal to or greater than 10 cm at a height of 1.30 m from the ground (dbh > 10 cm). The circumference of the trees was measured with a tape measure. This measurement was used to determine the diameter of each tree.

Data analysis

Analysis of the spatial structure of G. kola

Garcinia kola trees being slightly scattered, we used ArcGIS software to calculate the distances between the trees. The distances were calculated using the T-Square Sampling Procedure, described by Besag and Gleaves (1973). The method consisted of randomly selecting a number of points within the study area, each point is where *G. kola* were found. For each random point, two measurements were taken: the first measurement is the distance from the random position (x) to the nearest individual (y); the second measurement is the distance between (y) and its nearest neighbor (z) provided that the angle formed by xyz is greater than 90° (Figure 2). On the basis of the data from the T-square method, it was possible to test the hypothesis of a random distribution according to the formula implemented by Hines and Hines (1979):

$$H_T = \frac{2n(2\Sigma(xi)2+\Sigma(zi)^2}{\{(\sqrt{2}\,\Sigma(xi)+\Sigma(zi))\}^2} \quad (1)$$

where H_T= Hines statistical test to check if the data is random, n= sample size (number of random points), Xi= distance between random point and nearest individual, Zi= distance between the individual closest to the random point and its nearest neighbor, H_T =1.27, the distribution is random, H_T < 1.27, the distribution is uniform, and H_T > 1.27, the distribution is aggregated.

Dendrometric structure of G. kola

Trees distribution by diameter classes: The inventoried trees were grouped into diameter classes to produce a histogram of diameter structures. These classes were distributed as follows: 10-20, 20-30, 30-40, 40-50, 50-60, 60-70 and 70-80 cm. The histogram was used to display the structure of the population (Glèlè et al., 2016). Thus, for the trees of each locality (Affery or Biankouma), the diameter structure has been established Student's t-test for independent samples were used to compare the means of the different dendrometric parameters of *G. kola* in the different study area. There is a significant difference between sites at the 5% significance level. Three Weibull distribution parameters were used to represent the theoretical structure of woody stands. This distribution is based on the probability density function defined by Rondeux (1999) and is

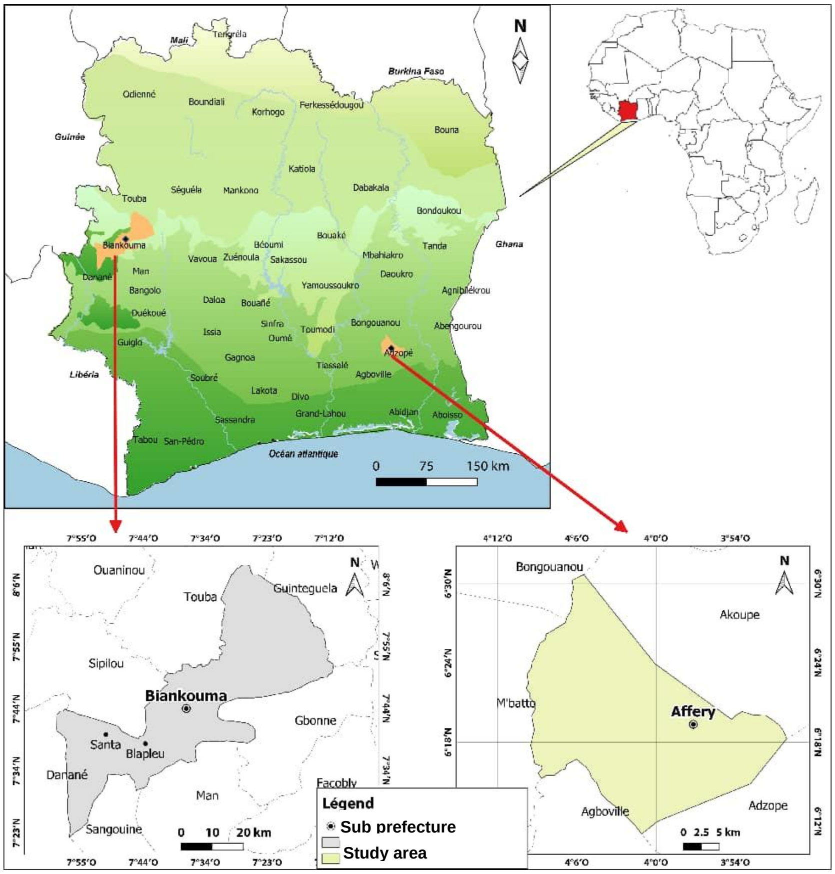

Figure 1. Location of study sites in Côte d'Ivoire, (A): location of Côte d'Ivoire in West Africa (B): location of Biankouma and Affery (C): location of surveyed sites.

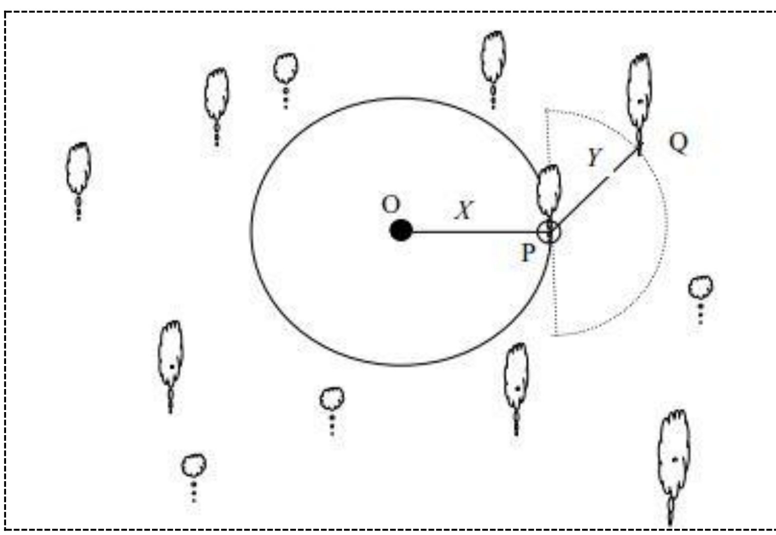

Figure 2. T-Square sampling procedure. From a random tree "O" in the study area, the distance Xi to the nearest individual "P" is measured. Distance *Xi* to the nearest individual P is measured. A second distance *Zi* from P is measured to individual "Q" closest to P, with the constraint that the angle OPQ > 90° (T-Square distance). The procedure is repeated for a series of *n* random points.
Source: Masumbuko et al. (2008).

Table 1. Interpretation of the Weibull distribution as a function of the value of the shape parameter « c ».

Value of parameter « c »	Interpretation
c < 1	The distribution is J-reversed, characteristic of multispecies stands with high regeneration potential
c = 1	The distribution is described as exponentially decreasing. This structure is characteristic of populations with a high potential for regeneration, but with a problem of survival during the transition between stages of development
1 < c < 3,6	The distribution is skewed positive or skewed right. This structure is characteristic of populations with low regeneration potential due to exogenous actions especially in small diameter classes
c = 3,6	The distribution is symmetrical; normal structure, characteristic of species populations with low regeneration potential due to exogenous actions or characteristics of the species
c > 3,6	The distribution is skewed negative or skewed left. This structure is characteristic of monospecific stands with a predominance of older, large- diameter individuals

Source: Glèlè et al. (2016).

presented under the function:

$$f(x) = \frac{c}{b}\left[\frac{(x-a)}{b}\right]^{c-1} exp^{\left[-\left(\frac{(x-a)}{b}\right)^{c}\right]} \quad (2)$$

where : *x* = diameter of the trees, *f* (x) = probability density value at point x; *a* = position parameter (in this study *a* = 10 cm for diameter) (Glèlè et al., 2016); *b* = scale; it is related to the central value of the diameters of the trees in the stand under consideration; *c* = shape parameter related to the considered diameter structure.

The structure of the groupings has been adjusted to the Weibull model because of its great flexibility and ease of interpretation (Bonou et al., 2009). This Weibull distribution can take several forms depending on the value of the shape parameter "*c"* (Table 1) related to the diameter structure (Kebenzikato et al., 2014). All analyses were performed with the software XLSTAT Ecology software version 2014.5.03.

To verify the significance of the adjustment, between the observed frequency of a diameter class considered and the theoretical frequency expected according to the Weibull function (Agresti, 2010), a log-linear analysis was performed (Caswell, 2001).

Basal area: The basal area was calculated by summing the land area of all trees in each sub-sampling unit defined within a plot. This value is usually expressed in m²/ha. The basal area calculated for 1 ha allowed an approximate extrapolation for all sites explored. Thus, an average basal area was determined for each study site. It is calculated by the following relationship:

$$G_{1,30} = D^2 \text{x} \frac{\pi}{4} \quad (3)$$

where $G_{1.30}$ is the basal area at 1.30 m from the ground and D is the diameter of a tree.

RESULTS

Spatial distribution by T-square sampling method

The Hines and Hines test applied, gives a H_T value equal to 3.37 to Affery and 2.49 at Biankouma (Table 2). Those values are higher than 1.27. Comparison of these values with the critical values listed in the Hines and Hines table reveals that there is a significant difference with the random distribution at α = 0.05. Therefore, the natural population of *G. kola* shows an aggregated distribution in Affery and Biankouma.

G. kola diameter class structure and Weibull distribution fit

Measurement of the diameter at 1.30 m from the ground of all the *G. kola* individuals sampled permitted their distribution into diameter classes. Figure 3 shows the results for each stand.

The majority (27.6%) of the trees in Affery were between 40 and 50 cm in diameter. Trees with a diameter between 30 and 40 cm are 25.2% while 12.2% have a diameter between 20 and 30 cm. The diameter classes [50-60 cm] and [60-70 cm] express, respectively 21.9 and 8.1% of the individuals. All these individuals belong to the middle stratum. Next, 1.7% of the individuals have a diameter between 10 and 20 cm and are considered to belong to the shrub stratum. Finally, the upper stratum is represented by the individuals with a diameter of more than 70 cm and concerns 3.3% of the trees surveyed.

Table 2. Parameters calculated for T-Square sampling in both stands.

Statistical parameter	Population	
	Affery (*n* =37)	**Biankouma (*n* =37)**
Surface area (km^2)	33.08	30.79
Σ (*xi*)	4166.11	4034.28
Σ (*xi*)^2	1313832.56	1250306.03
Σ (*zi*)	3281.32	4445.87
Σ (*zi*)^2	1210746.81	1514006.87
Hines and Hines test	3.37*	2.49*

n: number of random positions in the study area; H_T: statistical test of Hines and Hines; *xi* = distance between the random point and the nearest individual; *zi* = distance between the individual closest to the random point and its closest neighbor; * = *p*<*0*,05.

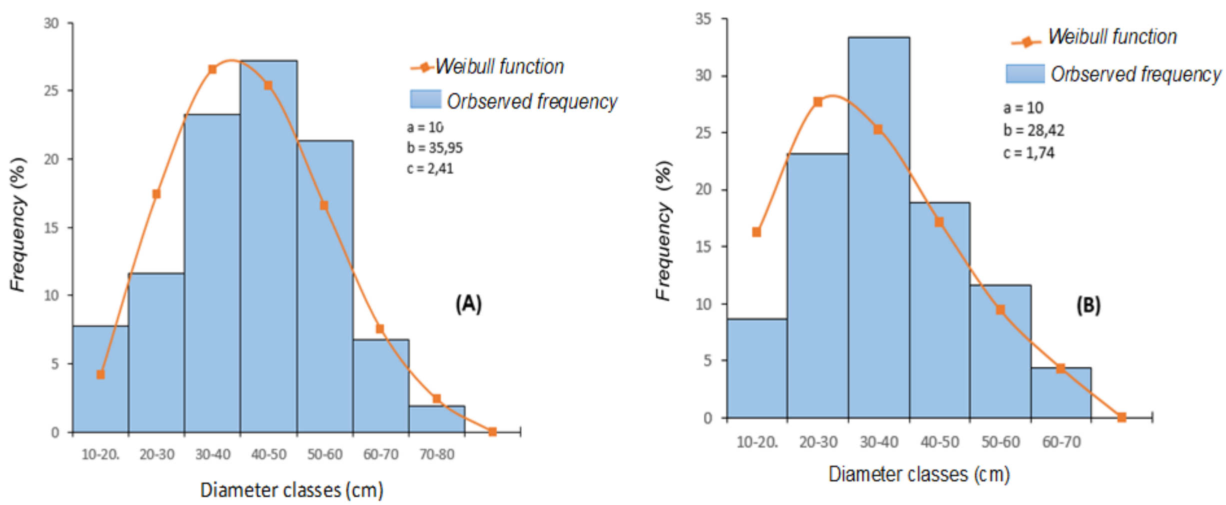

Figure 3. Tree diameter class structures of *Garcinia kola* with Weibull distribution adjustment (A) Affery and (B) Biankouma.

In Biankouma locality, the majority of trees (33.3%) have a diameter between 30 and 40 cm, while 23.18% of trees have a diameter between 20 and 30 cm. All these trees belong to the middle stratum, which is the most represented. The upper stratum is not represented because there are no individuals with a diameter greater than 70 cm. Between 10 and 20 cm in diameter there are 8.7% of trees.

The fit of the theoretical Weibull distribution to the observed diameter class distributions in the two stands is as shown in Figure 3. The two populations, (A) Affery and (B) Biankouma have a structure with a shape parameter *c* between 1 and 3.6 (1 < *c* < 3.6). This shape parameter is 2.4 for the *G. kola* population in Affery and 1.74 for the Biankouma population. These distributions are said to be asymmetric positive or straight asymmetric. Trees of average diameter classes are the most represented. The log-linear analysis performed shows a good fit of the Weibull distribution with the data of the observed distribution for diameter structures (p>0.05) at the 5% threshold.

Dendrometric characteristics of the two stands

The results of the analysis of variance on the dendrometric characteristics of the two *Garcinia kola* stands show significant differences (P<0.05) in mean diameter and basal area (Table 3). The comparative analysis of dendrometric characteristics shows that basal area and mean diameter are higher in the Affery population compared to the Biankouma population. The mean diameter and basal area of trees in Affery are 43.16 cm and 0.0048 m^2/ha, respectively, while in Biankouma they are 36.17 cm and 0.0026 m^2/ha. However, tree densities in the two populations are relatively close with less than 1 tree/ha. There is no significant difference (P>0.05) in tree density in the two populations. In Affery it is 0.0246 trees/ha while it is 0.0368 trees/ha in Biankouma.

DISCUSSION

The study of the spatial structure of *G. kola* within the two

Table 3. Dendrometric parameters of *Garcinia kola* in Affery and Biankouma stands.

Population	Average diameter (cm)	Basal area (m^2/ha)	Density (tree/ha)
Affery	43.16	0.0048	0.0026
Biankouma	36.17	0.0246	0.0368
Probability (*P*)	0.001**	0.005**	0,809

Values followed by "**" are significantly different at the 5% cut-off (student t-test for independent samples); V=Coefficient of variation.

agro-ecological zones (Affery and Biankouma), revealed an aggregated distribution of trees. There are many possible explanations for the aggregated distribution in *G. kola*. Indeed, the aggregated spatial distributions of some tree species can be interpreted as reflecting variations in environmental characteristics (Dajoz, 2003; Silvertown, 2004). The habitats of the two agro-ecological zones (Affery and Biankouma) constitute favorable environments for the development of *G. kola*. They are wetlands with an average temperature of 30°C. According to Ntamag (1997), a relative humidity of 76.34% with temperatures between 21 and 32°C is favorable for the development of *G. kola*. In India, a study on *G. indica* reveals that precipitation and temperature are the main factors that favor the distribution of this species (Palkar et al., 2020).

Moreover, the distribution of the species is done according to the environmental conditions (Thammanu et al., 2021). Thus, the species would aggregate where environmental conditions are favorable for their development. The same would be true for *G. kola*. Furthermore, aggregation appears to be a consequence of the short distance at which seeds are dispersed (Hubbell, 2001). These observations for this species were confirmed by Dike and Aguguom (2010) in a forest reserve in Nigeria. The work of these authors revealed that the maximum distance of seed dispersal of *G. kola* is 8.42 m. Indeed, the limitation of dispersion results in an aggregated geographical distribution (Condit et al., 2000) often observable for tropical trees species (Seidler and Plotkin 2006). In addition, a study by Mcconkey et al*.* (2015), showed that 'small animals' often consume *Garcinia benthamii* fruits, but their ability to disperse seeds has not been evaluated. In contrast, elephants and gibbons are the main dispersal agents of *G. benthamii* seeds. In the present study, the presence of elephants was not reported, but informal exchanges with landowners confirmed the presence of monkeys in the sampled habitats.

However, the aggregated distribution could result from the scale of observation. Indeed, the spatial extent or scale could influence the observation of the spatial distribution of the species as small or large (Goreaud, 2000; Dungan et al., 2002). Komenan et al*.* (2019) obtained an aggregated distribution of *G. kola* using the Clark and Evans method. However, this method is sensitive to the effect of extent (Kumba et al., 2013), confirmation of the aggregated distribution was made using the T-square sampling procedure.

The study of the diameter structure reveals that trees belonging to the middle stratum dominate in both stands. Modelling of all the trees in each population, divided into diameter classes according to Weibull's law, shows a positive asymmetric or right asymmetric distribution. According to Husch et al. (2003), this distribution is characteristic of populations with low regeneration potential due to exogenous actions especially in small diameter classes. There is thus a problem of recruitment of young individuals in the classes of older individuals (Glèlè et al., 2016). This cannot be interpreted as a good conservation status of *G. kola* stands in its different habitats. Indeed, *G. kola* is subject to anthropogenic pressure, which compromises the viability of the species (Neuenschwander et al., 2011; Goné Bi et al., 2013). This pressure is linked to the fact that *G. kola* is multipurpose. The organs (seeds, roots, bark, branches and wood) are mainly used in pharmacopoeia and food (Guedje and Fankap, 2001).

The low or non-existent regeneration rate of *G. kola* in the wild may also be due to the seed's very hard pericarp, which delays germination (Agyili et al., 2007; Yakubu et al., 2014). The poor regeneration would also be due to the non-contact of the fruits with the soil and the failure to bury the seeds of the species in the soil to facilitate germination. The fruits fall and remain above the dead leaves and eventually rot. Dossa et al. (2019) found similar reasons for compromising natural regeneration in *Detarium senegalense* (Fabaceae) in dense forests. For this reason, there is reportedly a low rate of young individuals in both populations of *G. kola*, which justifies the low density of the species in these populations. This low density of all the trees confirms the precariousness and decline of *G. kola* populations in the areas under consideration and especially in its area of occurrence.

The average diameter and basal area of trees are higher in Affery than in Biankouma. There are several reasons explaining this difference. According to our study, individuals in the upper stratum with a diameter greater than 70 cm are represented in the Affery population, whereas none exist in the Biankouma population. In addition, trees in the Affery population are more in agrosystems and would benefit from protection and maintenance by field owners. However, in the

Biankouma locality, this species would be subject to greater human pressure.

Conclusion

The study of the spatial structure within the two populations showed that *G. kola* is a gregarious species. The structural characterization of two populations of *G. kola* in Côte d'Ivoire showed, on the one hand, a structure in diameter class dominated by trees in the middle stratum and, on the other hand, that the density of this species is very low. Therefore, the safeguarding of the rare individuals of this species is important to ensure their sustainable management. A study on the morphological variability of *G. kola* would help to achieve this objective.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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