diversity

MDPI

**Supplementary material for**

# Assessing biodiversity conditions in cocoa fields with a rapid assessment method: Outcomes from a large-scale application in Ghana

## 2. Materials and methods

### *2.4. Data analysis*

a) Tree density

This indicator results from the extrapolation of the number of non-cocoa trees (plants above 10 cm dbh, including fruit trees) counted in the sample plots within each cocoa field. Certification bodies, such as Rainforest Alliance, recommend a minimum of 18 trees per ha, specifically shade trees, since the Sustainable Agriculture Standards of 2014 [29]. Above this threshold, the number of trees is considered adequate to maintain biodiversity and as such, this minimal threshold was adopted. Moderate levels of tree density were defined between 6-17 trees/ha and <5 trees/ha was defined as low and inadequate. Although the certification criteria refer specifically to shade trees, the inclusion of fruit trees in this estimation derives from their use for shade to younger cocoa trees and their widespread cultivation to provide food and additional income to the household [47, 56].

b) Species richness

This indicator was calculated with the Evans estimator [32]. It is based on the number of different tree species, of at least 10 cm dbh, found in the sample plots in each cocoa field. The number recorded results from visual observation, without retrieving individual species name and only counting additional new species not recorded on previous plots of the same field. Oil palm trees and fruit trees are included. This option ensures the applicability of the method at large scale, with minimum resources and without the need of expert knowledge to identify each tree species [28]. The thresholds for species richness were based on previous findings in cocoa farms in West Africa [1,31,42,46]. The Standards for Sustainable Agriculture [29] recommended a minimum of 12 different species per ha, on average, particularly native ones, for maintaining a suitable biodiversity level.

c) Shade cover

The assessment of shade focused specifically on the extrapolation of the number of trees that are taller than mature cocoa trees, therefore having a dbh above 30 cm. This threshold was based on previous results for West Africa; in Cameroon, Sonwa [31] found that trees between 5-10 m height, which are taller than mature cocoa trees, had an average dbh of 22 cm, and trees between 10-20 m height had an average dbh of 47 cm. For cocoa productivity, shade should be kept at moderate levels [42,57], thus the recommended level of shade was set between 14 and 25 trees/ha. Other thresholds, for example by Rainforest Alliance encourage a minimum of 18 permanent shade trees on farm, to obtain 30-40% shade level (estimated by 18 trees/ha) and to maximize the ecosystem services, as well as cocoa productivity [29]. Above the threshold of 25 trees/ha, it is considered heavy shade and can impact negatively on cocoa productivity of cocoa trees [45], whereas below 14 trees/ha means insufficient levels of shade. No shade (full sun or the total absence of shade trees on the cocoa field) is considered unsustainable and not supportive of biodiversity.

d) Vegetation structure

Vegetation structure indicates the presence of trees of different sizes and the existence of varied canopy levels within the cocoa field, representing a similar structure to the

one found in natural forests [35]. The assessment of vegetation structure was based on tree size (dbh), by analysing the distribution of the number of trees by the different dbh ranges and the number of banana/plantain. The dbh value per individual tree is obtained with the middle value of the range where the tree was recorded within the survey form. Banana/plantain are considered the same stratum as mature cocoa and all trees above 10 cm dbh correspond to strata above cocoa canopy (disregarding age/height differences), divided in two levels: 10-30 cm and above 30 cm dbh.

Guided by the criteria defined for certification by Rainforest Alliance, the threshold for categorisation as ideal was established by the identification of at least 2 canopy levels (strata) above cocoa trees [29]. If trees from only one dbh class are found, only 1 stratum above cocoa is recorded and the cocoa farm is below ideal. If there are trees from two classes, the cocoa field has the recommended vegetation structure. If no other trees, or only banana/plantain are found on farm, only cocoa stratum is considered and vegetation structure is far from the recommended level.

e) Above-ground carbon stock on non-cocoa trees

Agroforestry systems provide the opportunity to increase carbon stocks and potentially be used or even sold as carbon offset [47,60]. Carbon stock was estimated from above-ground biomass values of existing non-cocoa trees. The dbh values, recorded as a tally in pre-defined ranges, were inserted in an allometric formula based on studies by Sonwa (2004), which applied the Brown allometric approach [31] for the moist life zones. Biomass of cocoa trees was not taken into account, as the focus of this study was the benefits of associated non-cocoa trees; banana/plantain and oil palm were also excluded from this analysis, since the allometric formula presented does not apply to these species. The final value of biomass was estimated as an average for all types of trees and was not differentiated by species, although variations may exist [30]. Therefore, the carbon values represent an approximate estimation of the minimum potential carbon existing in the farm.

An estimated desirable minimum value was calculated using the average dbh (60-70 cm on a mature farm) of the 18 trees recommended for tree density, with the above-ground biomass of each tree being calculated as:

$$Y = 42.69 - 12.800(65)^{*} + 1.242(65^{2})^{*}$$

$$Y = 4458.14 \text{ kg tree}^{-1}$$

* considering the middle value of the dbh range = 65 cm.

The above-ground biomass available in 18 trees would be 4458.14 kg x 18 trees = 80246.52 kg/ha. Based on this value, and assuming that the carbon stock corresponds to 45% of the tree biomass [33], the minimum recommended carbon stock level was estimated as 36 Mg/ha (Megagram or tonne per hectare). Sonwa [31] has found that in fields with high density of cocoa trees the carbon stock was 39 Mg/h, which is consistent with our threshold. Following this calculation, the farms that reach 36 Mg/ha or above are at the recommended level, whereas below 10 Mg/ha is considered very low, with intermediate levels found between 10 and 35 Mg/ha. As the dbh of the trees cannot be directly extrapolated, contrary to what was done for tree density, only the trees found within the sample plots were measured and accounted for in the calculation of carbon stock.

f) Tree succession potential

In a natural forest, an inverted J-shape is found, with smaller trees dominating the system to ensure its sustainability [34]. To estimate succession potential, the proportion of trees in two different dbh categories (10-30 cm; above 30 cm) was calculated and 3 classes were defined, based on the proportion of younger trees (10-30cm dbh as proxy) in relation

to older trees (above 30cm dbh). Good succession potential results from at least 50% presence of smaller trees (10-30 cm dbh); a moderate level corresponds to a proportion of smaller trees between 35 and 50% of the total; a low level was attributed when the smaller trees correspond to less than 35% of the total number of trees. A minimum of 2 trees measured in the sample plots is required, otherwise succession potential cannot be determined. If the number of trees in the lowest dbh ranges (10 cm to 30 cm) is lower than the number of trees of larger size, then succession is undermined.