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Coffea eugenioides S. Moore and *Coffea stenophylla* G. Don

Distribution, botany, agronomic traits and growing areas

Maarten van Zonneveld, Bioversity International

William Solano, CATIE

Acknowledgements

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Synthesis

This report aims to describe the distribution, botany, agronomic traits and growing areas of two wild coffees: *Coffea eugenioides* S. Moore and *C. stenophylla* G. Don. The report was commissioned by the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). The report presents information on the basis of four sources: i) a literature review; ii) an ecogeographic analysis of wild coffee distribution under current, future and past climate conditions; iii) Ecocrop modelling to identify suitable growing areas for each of the two species; iv) a survey was sent to eight experts for information on agronomy and phenology, which was not found in literature.

The distribution of species is the basic information to develop conservation strategies to maintain genetic resources *in situ* and to target germplasm collection for breeding and *ex situ* conservation. *Coffea eugenioides* occurs in a wide environmental range from lowland dry savannah up to tropical alpine conditions around the great lake in East and Central Africa. *Coffea stenophylla* has a restricted distribution in Western Africa with isolated populations, which are highly threatened to deteriorate under climate change. The results of this report suggest that urgent conservation actions are required for *Coffea stenophylla.*

Botany encompasses species reproductive biology and propagation which is relevant in production and in the development or plant material and biotechnology. Botany also includes systematics, genetic diversity studies and crossing experiments between species to assess the species' potential as for breeding programs of the same species or as gene source with cultivated coffee species. *Coffea eugenioides* is genetically similar to the commercially most important cultivated species *C. arabica* and crosses well with another cultivated species *C. liberica*. The species also crosses well with its wild relatives, *C. kapakata* and *C. sessiflora*. *Coffea stenophylla* crosses well with the cultivated species *C. liberica and C. canephora.* The species also crosses well with its wild relative *C. C. humilis*. *Coffea stenophylla* populations require a taxonomic revision because of the morphological and genetic differences observed between the populations as well as the isolation of these populations from each other.

Agronomic traits are relevant to assess the species´ potential for production and in intra-specific and interspecific breeding programs. *Coffea eugenioides* seeds have low caffeine content whereas *C. stenophylla* seeds have high caffeine content. *Coffea eugenioides* has a deep root system to adapt to drought. *C. eugenioides* reports high resistance to coffee borers (*Hypothenemus hamper*) and *Mycena citricolor.* Resistance to coffee berry disease (*Colletotrichum kahawae*) and coffee rust (*Hemileia vastatrix*) is variable across populations. *Coffea stenophylla* has high resistance to leaf miner (*Perileucoptera coffeella*) but no clear results or information was found on this species related to the other plagues and diseases.

No yield data could be found in literature for either species. However it can be anticipated that both *C. eugenioides* and *C. stenophylla* produce less than the three cultivated species *C. arabica*, *C. canephora* and *C. liberica.* This is because of the small fruit size of *C. eugenioides* and *C. stenophylla* compared to the cultivated species and the little breeding efforts made for *C. eugenioides* and *C. stenophylla*. It can be anticipated that *C. eugenioides* produces less than *C. stenophylla* because the former species has a smaller fruit size than the latter.

The ecological potential of growing areas for coffee production depends to which extent environmental site conditions and environmental species requirements match with each other. Ecocrop crop modelling predicts that *Coffea eugenioides* produces better in tropical dry and tropical alpine climates than *C. stenophylla*. Vice versa *C. stenophylla* producers better in warm moist areas.

The agronomy, reproduction and phenology of both species are under researched. Two of the eight experts who were consulted were not able to provide detailed information on the inquiries related to these issues. This confirms the lack of existing knowledge related to these issues. The other six experts did not respond or suggested to contact another expert. The existing gaps suggest big research opportunities in agronomy and breeding for *C. eugenioides* and *C. stenophylla*.

Distribution

Native distribution

Coffea eugenioides occurs naturally in the mountains of the Congo- Nile Ridge in a disjointed distribution and around Lake Victoria. The species occurs in gallery forests as well as dense mountain forests in a subalpine habitat occurring between 1,000 – 3,000 m (Chevalier 1946; Davis et al. 2006). The species also occurs in seasonally dry, evergreen forest and to a lower degree in lowland savanna woodland and scrubland (Davis et al. 2006). In the Ugandan Kibalu forest reserve it is a common but scattered understory shrub (Kasenene 1998). This study recompiled and checked 40 unique georeferenced locations of *C. eugenioides* wild populations (Figure 1; 2; Annex 1). These locations originate from Congo DRC, Kenya, Tanzania, Uganda and Rwanda. Following the GRIN database, natural populations of *C. eugenioides* occur further in in Sudan and Burundi (U.S. National Plant Germplasm System 2016).

Coffea stenophylla occurs in the tropical forests of Western Africa between 150-700 m (Anonymous 1896; Davis et al. 2006; Slow Food 2016). The species is reported to grow in a wild state as an understory species in the gallery forests , which border rivers (Chevalier 1946). In these forests, the species is generally restricted to drier areas, such as exposed slopes and ridges at a height of about 200m above sea level and where *C. stenophylla* may co-occur with *C. canephora* and *C. liberica* (Davis et al. 2006). This study recompiled and checked 11 unique georeferenced locations of *C. stenophylla* wild populations from Cote d'Ivoire, Guinea and Sierra Leone (Figure 1; 3; Annex 2). Chevalier (1946) also reports the existence of wild populations in Mali.

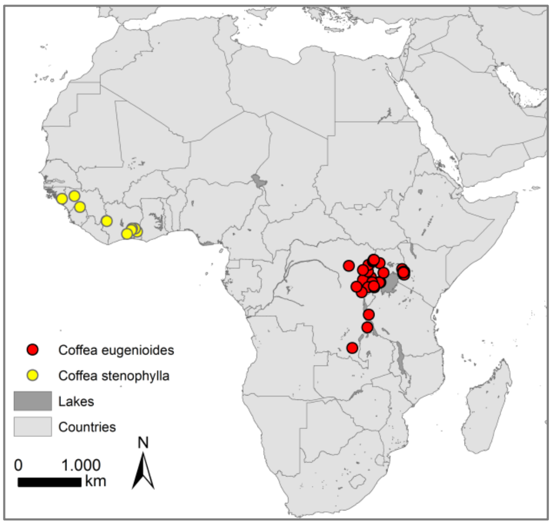

Figure 1. Sampled distribution of *C. eugenioides* and *C. stenophylla* in their native range.

Modelled distribution under current climate conditions

Maxent niche modelling was applied to identify the potential geographic areas where the two species occur naturally under current climate conditions (see method description in Annex 3).

Coffea eugenioides has not yet been confirmed to occur in several modelled areas of occurrence; nor has any germplasm been collected yet in those areas (Figure 2). The modelling results suggest occurrence of *C. eugenioides* in Burundi but not in Sudan.

Coffea stenophylla: The modelling results suggest that this taxum has a restricted distribution of isolated populations (Figure 3). The results don´t support the existence of *C. stenophylla* in Mali. The results should be taken with caution because of the low number of georeferenced locations that were found in this report. For modelling it is better to have more location points.

Modelled distribution under future climate conditions

The climate niche developed for both species is also used to assess the impact of climate change by the 2050s on the distributions of the two species (see method description in Annex 3).

Coffea eugenioides: Populations affected by climate changes are likely to occur in Uganda, Burundi and the border region of Congo DRC (Figure 4 & 5). Even though a considerable area is threatened by climate change, still a relatively large distribution area remains suitable according to the modelling exercise (Figure 4 & 5).

Coffea stenophylla: The native distribution range of this species is highly threatened by climate change (Figure 6 & 7). Niche modelling with both climate models under two scenarios of global warming suggest that all populations of this species will deteriorate heavily by the 2050s. The results suggest that urgent conservation actions are required to save the genetic resources of this species.

Population genetics and origin

No detailed population genetic studies exist for *C. eugenioides* or *C. stenophylla* to determine geographic patterns of species´ genetic diversity and their centres of origin or diversity. This is relevant to maximize the amount of genetic resources in conservation and breeding actions. The nine coffee molecular diversity studies review in this report include less than five accessions of *C. eugenioides* or *C. stenophylla*, or both (Annex 4)

With Maxent niche modelling, potential areas of distribution were modelled in the Last Glacial Maximum (LGM) 23,000 years ago. This allows to identify potential refugia, which are areas with a suitable climate for populations under current and past climate conditions (Vinceti et al. 2013). Following the modelling assumptions, populations have maintained themselves in these areas during the last glacial period and were seed sources for expansion afterwards. Because of the high population size through time, these areas are likely to maintain high levels of genetic diversity and should therefore be prioritized for conservation and screening because they are likely to maintain many traits.

Several potential refugia of *C. eugenioides* can be identified around the Lake Victoria and in the Democratic Republic of Congo (Figure 8). The large lost area modelled in the centre of the Democratic Republic of Congo coincides with the potential refugia from which *Coffea* species are thought to have dispersed to west and east Africa during the last major arid phase (18,000 years BP) (Anthony et al. 2010). The potential refugia areas overlap with the areas that are threatened by climate change. As a consequence the populations in these potential refugia areas are in danger to deteriorate. These populations require therefore urgent conservation actions.

For *Coffea stenophylla*, the results suggest that the species occurred more widely 23,000 years ago than the identified small rainforest refugia in Western Africa during the last major arid phase (Figure 9; Anthony et al. 2010). In Ivory coast two distinct populations of *C. stenophylla* can be distinguished on the basis of morphological characteristics and isozyme markers; an eastern and a wester population (Charrier & Berthaud 1985). This suggests a strong geographic genetic structure with populations that are isolated from each other without interchange of genes. One western population showed clear bottleneck effect, suggesting the limiting number of only five founding parents (Charrier & Berthaud 1985). The genetic makeup of other populations was not reported.

Conservation status

Both species have a IUCN red listing status of Least Concern (Davis et al. 2006). The modelling results suggest that populations of *C. eugenioides* are affected by climate change in 2050 but also show several remaining distribution areas with low climate change impact (Figures 4 &5). Some potential refugia areas of *C. eugenioides* are threatened by climate change. Targeted conservation actions are required to maintain the genetic resources in these putative hotspots of species' genetic diversity of *C. eugenioides.*

Coffea stenophylla occurs in a restricted distribution with isolated populations and is highly threatened by climate change (Figures 6 &7). The modelling results suggest that the natural populations of this species are in danger to extinct by 2050. The results suggest labelling this species as vulnerable or as in danger of extinction. Urgent conservation actions are required to save the genetic resources of this species.

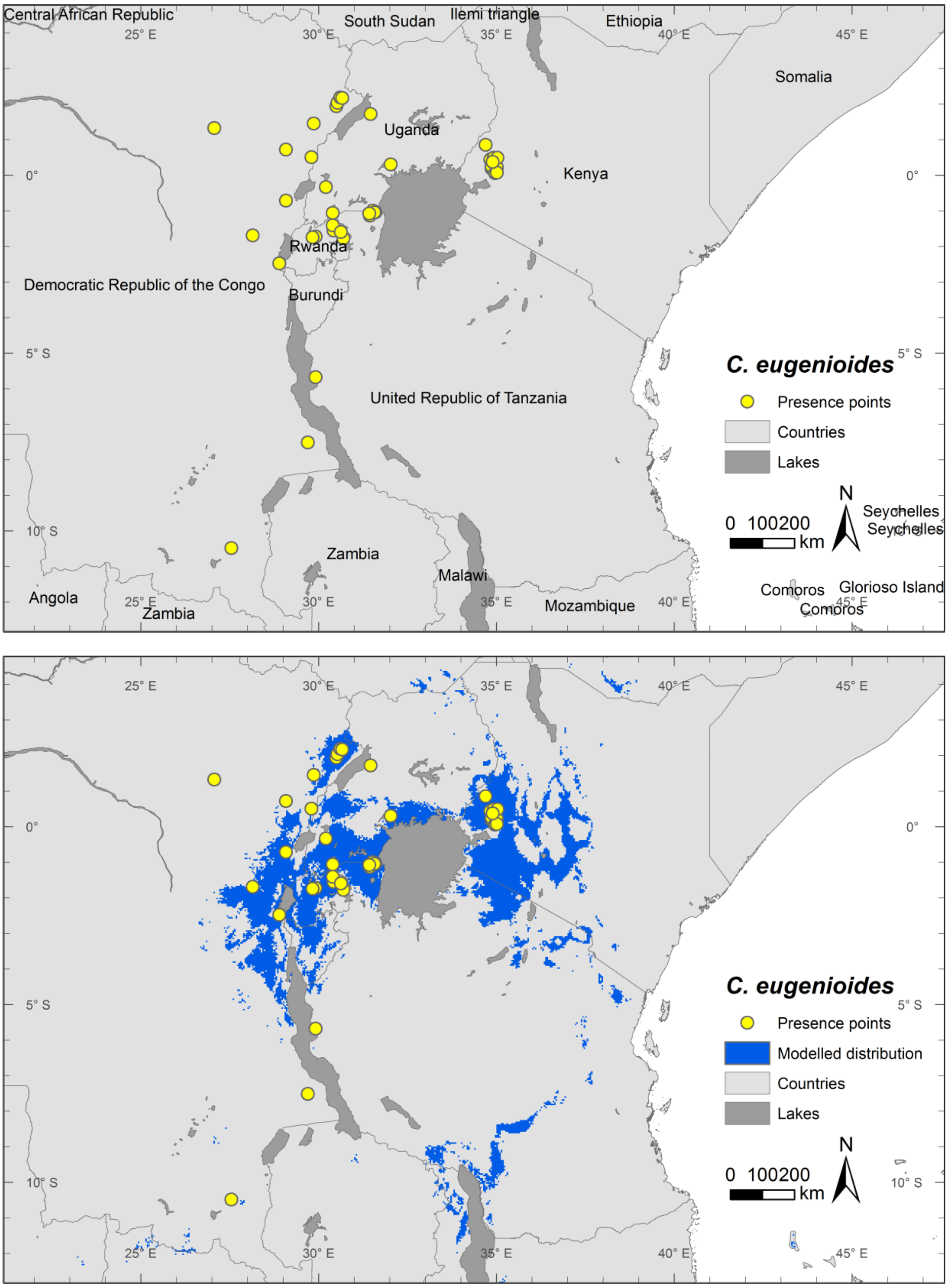

Figure 2. Native distribution of *Coffea eugenioides*. Upper graph: Sampled distribution of *Coffea eugenioides* in its native range. Lower graph: Modelled distribution of *Coffea eugenioides* in its native range.

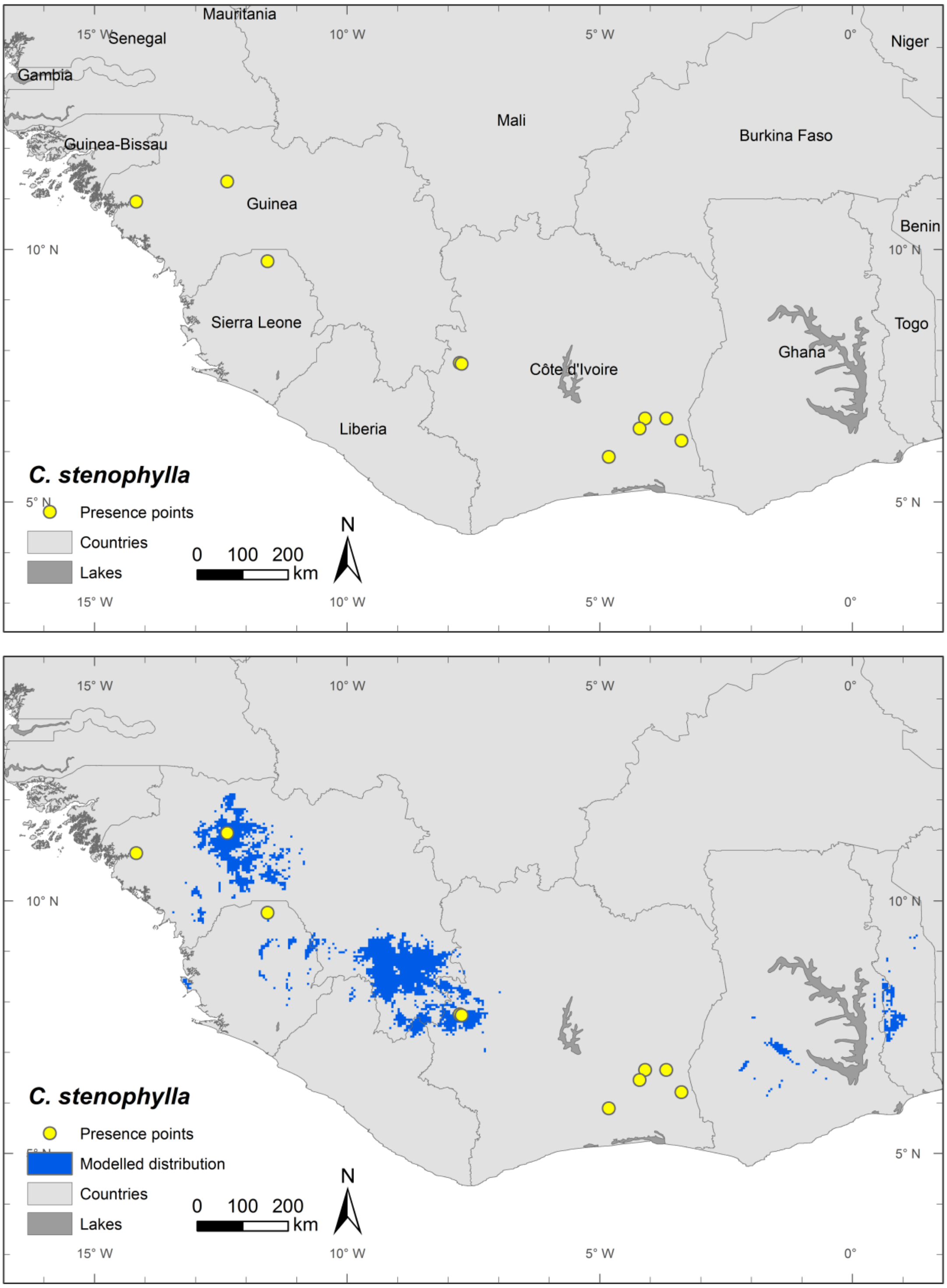

Figure 3. Native distribution of *C. stenophylla*. Upper graph: Sampled distribution of *Coffea eugenioides* in its native range. Lower graph: Modelled distribution of *Coffea eugenioides* in its native range.

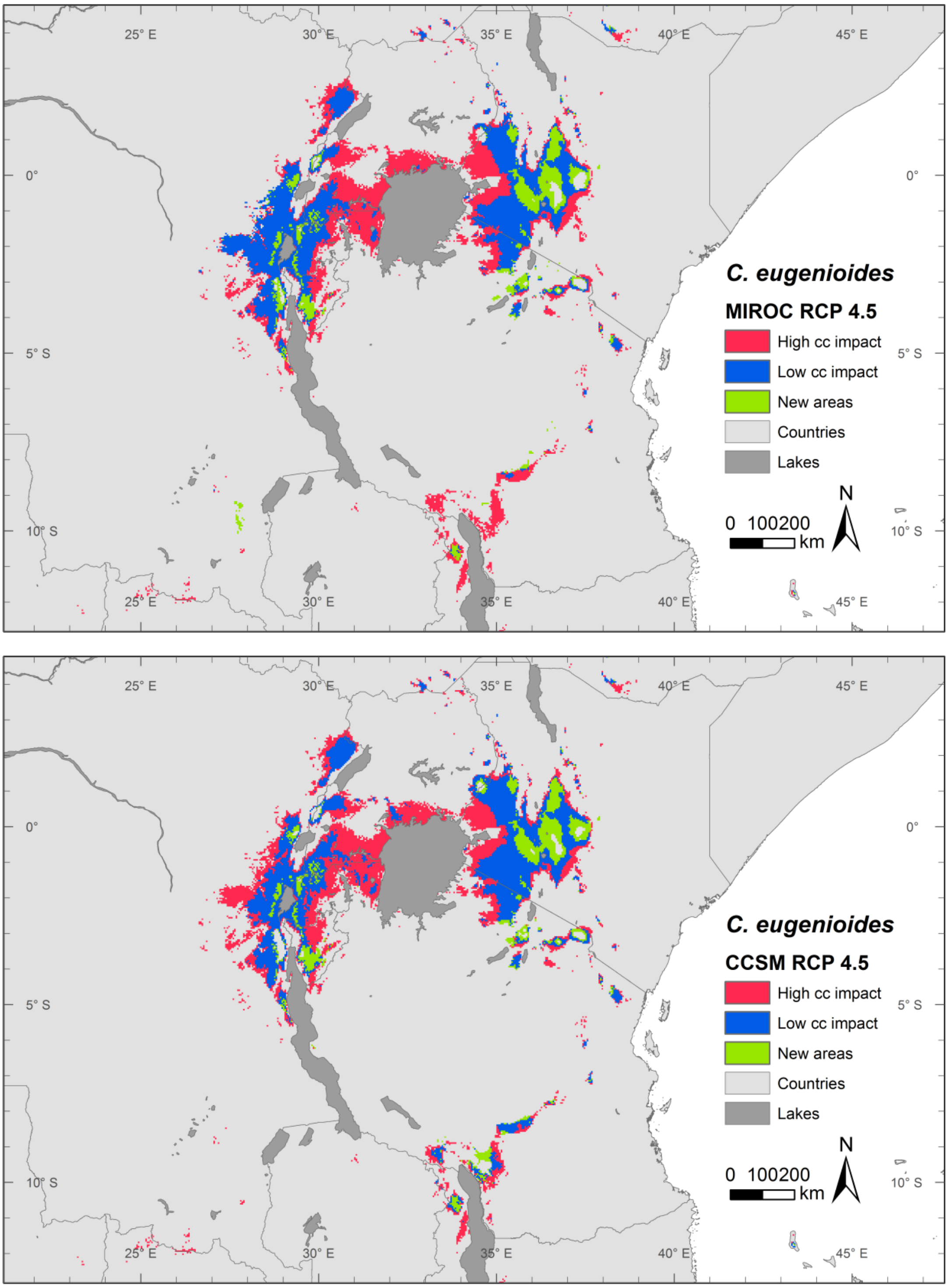

Figure 4. Climate change impact on the distribution of *C. eugenioides* by the 2050s according to two climate models under the 4.5 Representative Concentration Pathway (RCP). Red distribution areas are predicted to be negatively impacted by climate change; **Blue** distribution areas are predicted to have a low impact; **Green** distribution areas are but are predicted to become suitable by the 2050s.

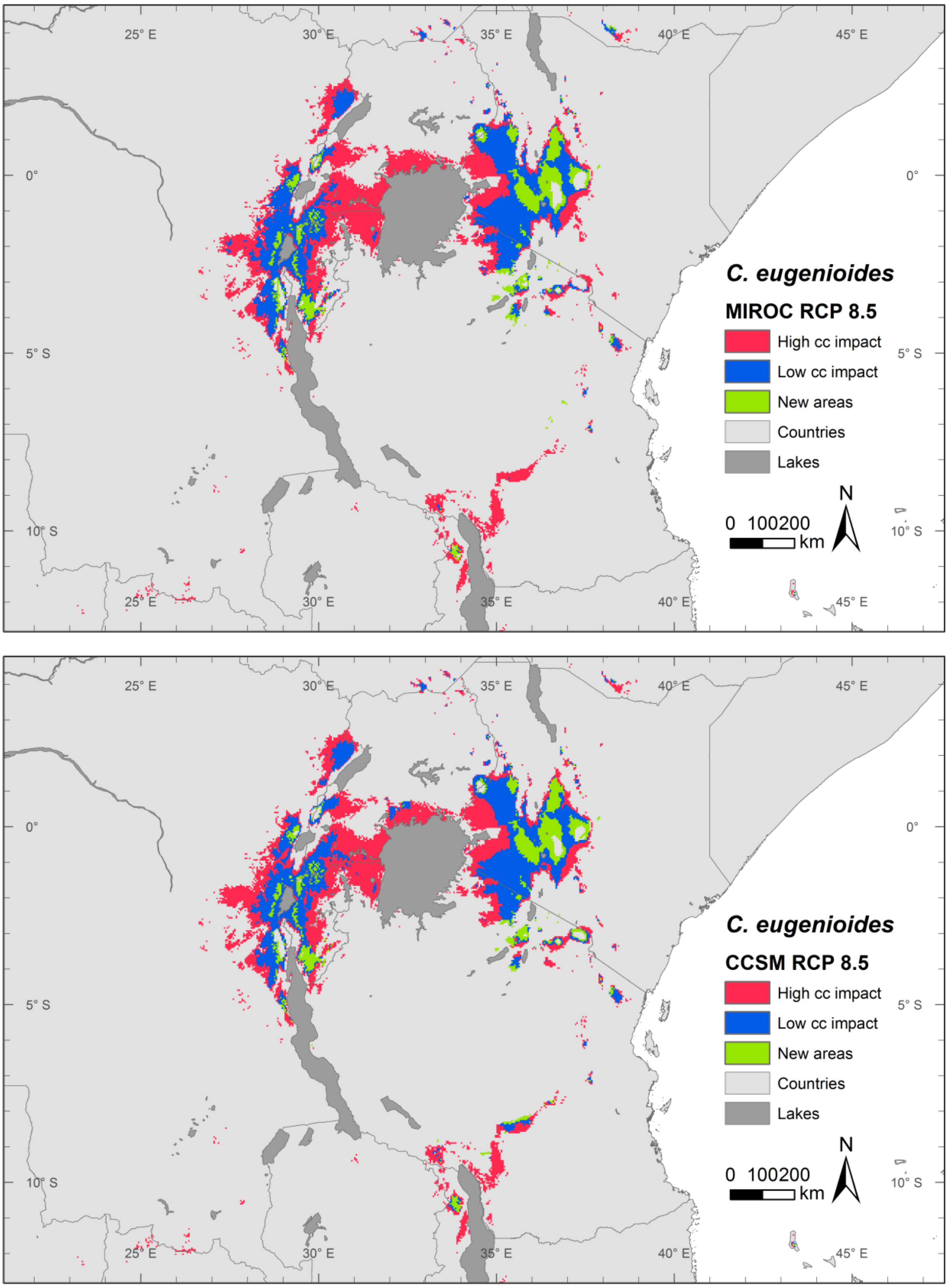

Figure 5. Climate change impact on the distribution of *C. eugenioides* by the 2050s according to two climate models under the 8.5 Representative Concentration Pathway (RCP) as described in figure 4.

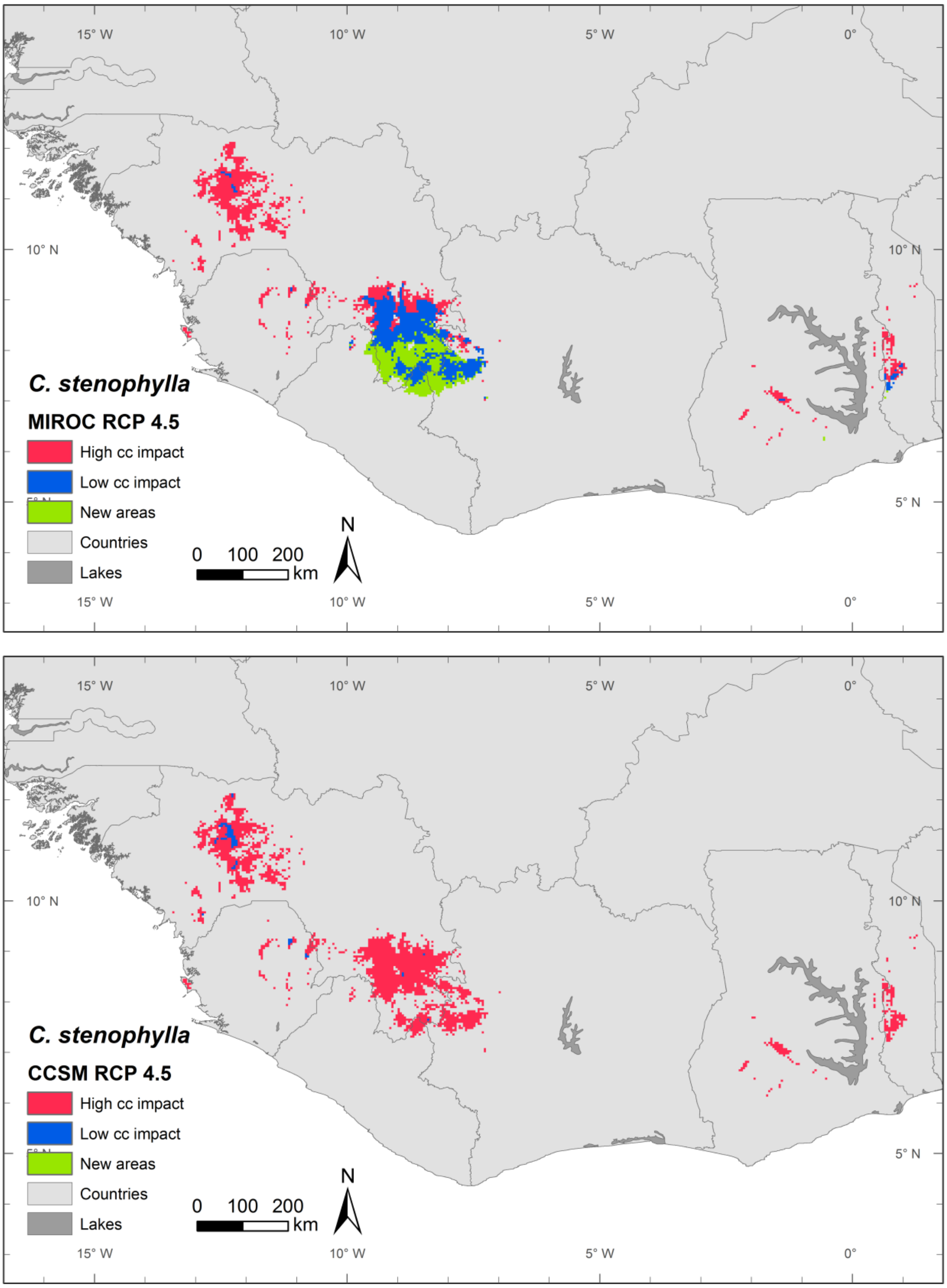

Figure 6. Climate change impact on the distribution of *C. Stenophylla* by the 2050s according to two climate models under the 4.5 Representative Concentration Pathway (RCP) as described in figure 4.

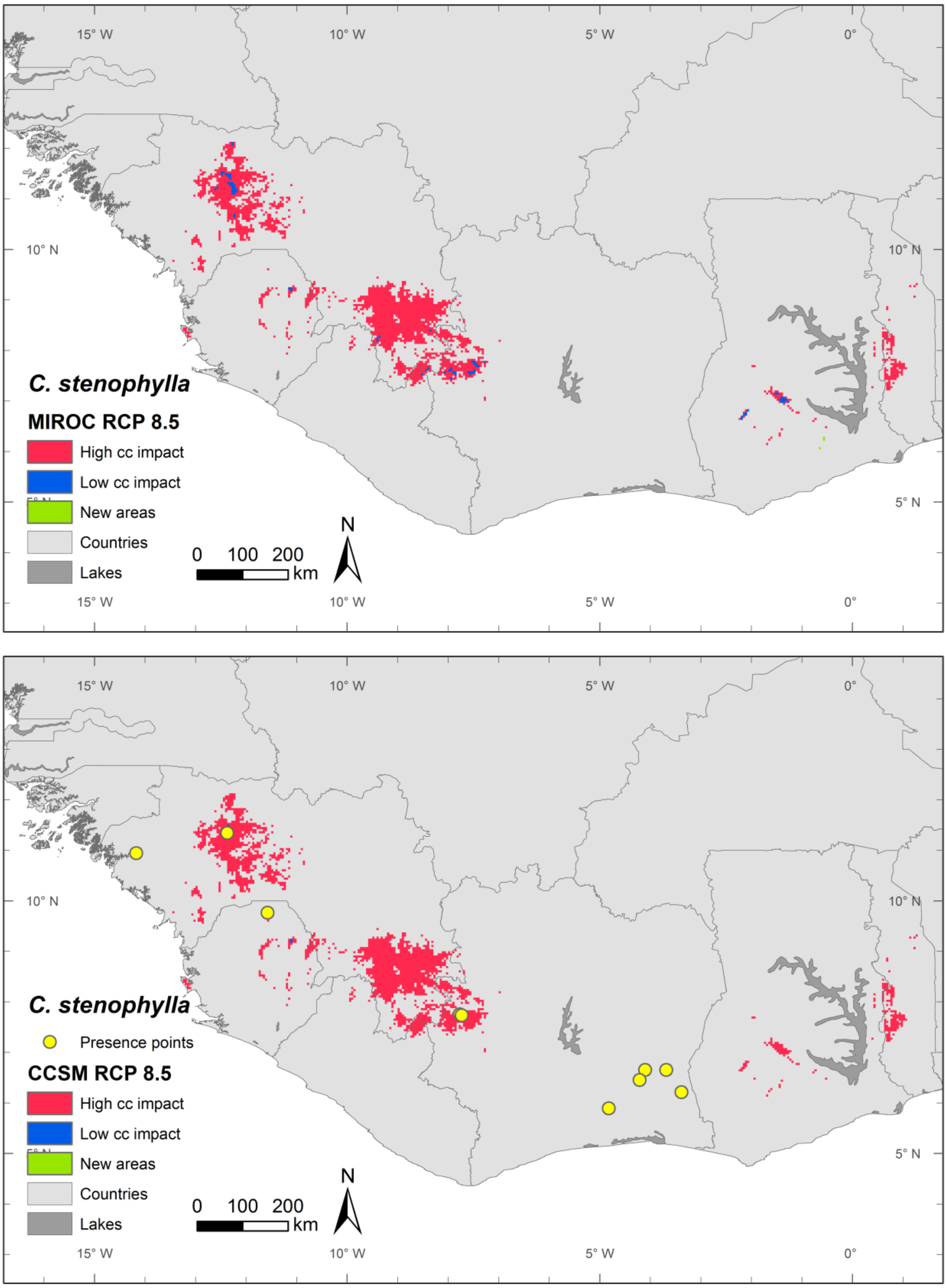

Figure 7. Climate change impact on the distribution of *C. stenophylla* by the 2050s according to two climate models under the 4.5 Representative Concentration Pathway (RCP) as described in figure 4.

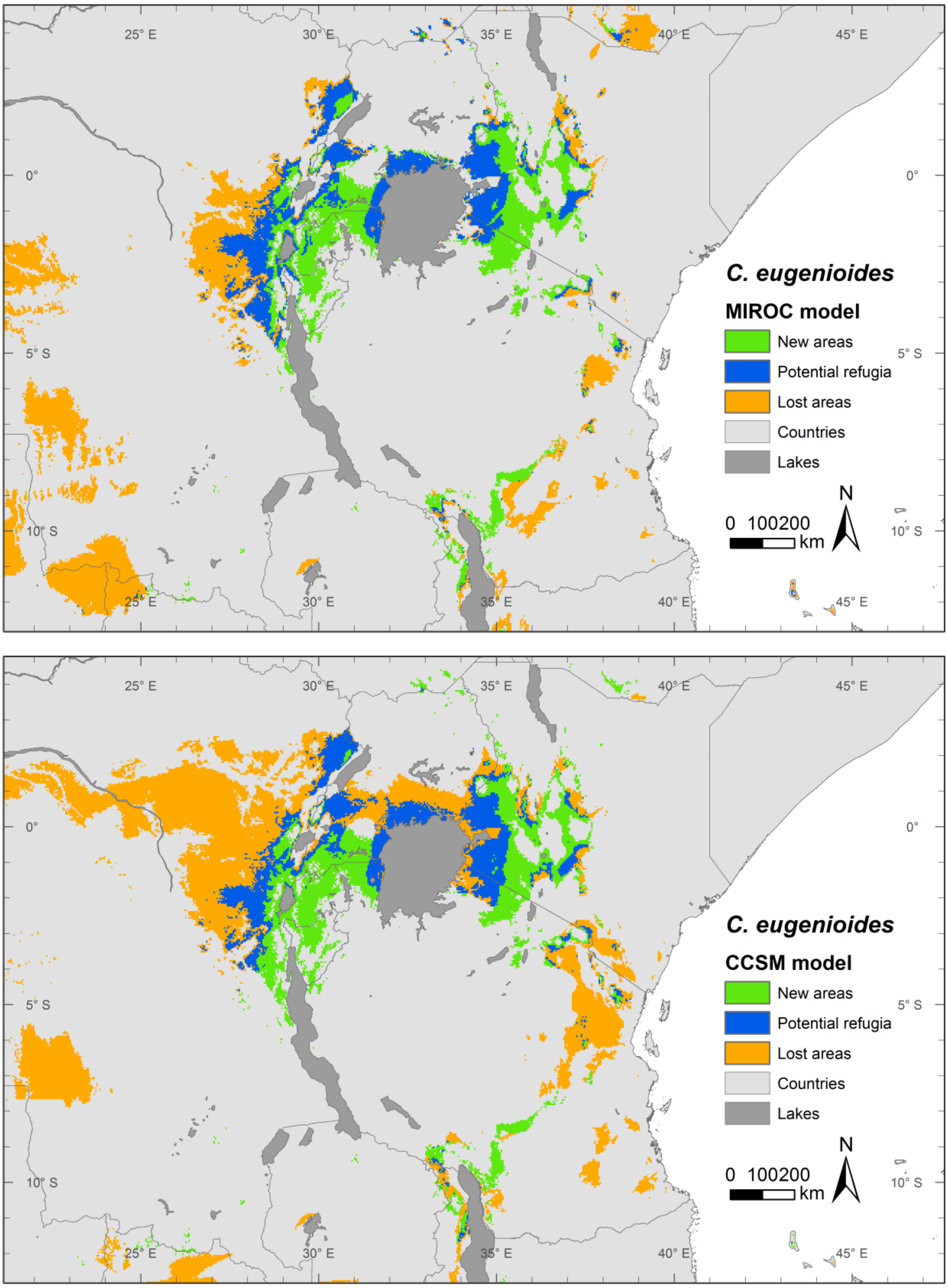

Figure 8. Potential refugia areas of *C. eugenioides* from the Last Glacial Maximum, 23,000 years ago, according to two paleontological climate models. Blue distribution areas are potential refugia; **Orange** distribution areas are lost areas where the species used to occur; **Green** distribution areas indicate expansion areas after the Last Glacial Maximum.

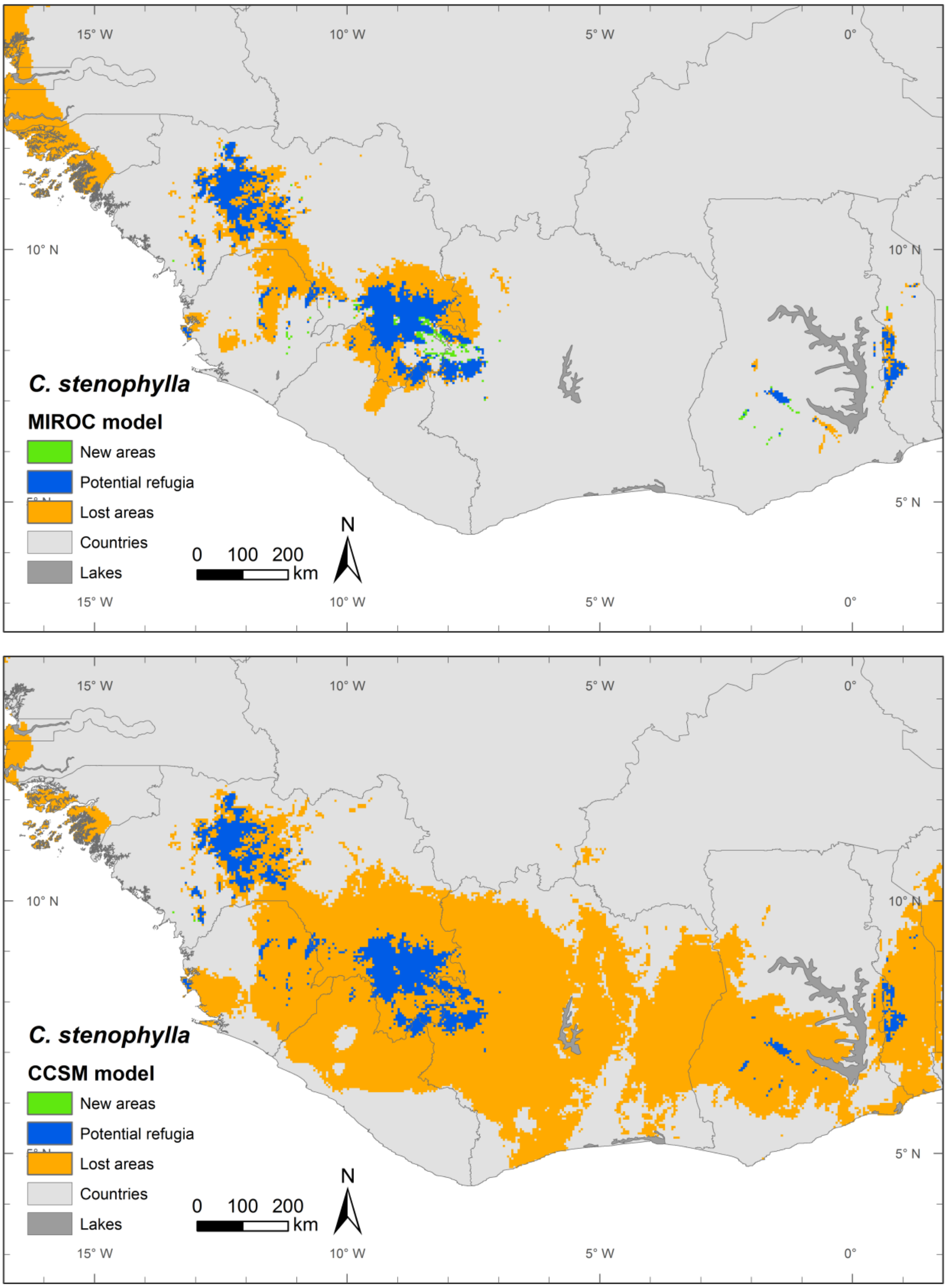

Figure 9. Potential refugia areas of *C. stenophylla* from the Last Glacial Maximum, 23,000 years ago, according to two paleontological climate models as described in figure 8.

Botany

Taxonomy

The Plant list is followed in *Coffea* spp. taxonomy (the Plant list 2016).

Systematics and breeding gene pools

Both species are diploid (n = 2 x 11) (Charrier & Berthaud 1985). The species are part of the genus *Coffea* comprising 103 species (Davis et al. 2006). Recent studies distinguish six clades[1] in the *Coffea* genus: i) Upper Guinea clade; ii)Lower Guinea/ Congolian clade; iii) East-Central Africa clade; iv) East Africa clade; v) Madagascan species; vi) Mascarene clade (Maurin et al. 2007). Although several botanical classifications and phylogenetic studies exist for coffee (Chevalier 1946; Charrier & Berthaud 1985; Maurin et al. 2007), the gene pools have not been identified for both species. A gene pool classification is relevant to understand i) the species' classification as cultivated plant species or its relative; ii) the species´ potential to hybridize with other species; iii) the species´ potential as gene source for other species (Harlan & de Wet 1971). This report presents the genepools of both species in Figure 10 on the basis of a literature review of genetic similarity and reproductive compatibility (Annex 4).

Coffea eugenioides is grouped in the East-Central Africa clade together with *C. anthonyi* and *C. kivuensis* (Lashermes et al. 1997; Maurin et al. 2007). *Coffea eugenioides* is also genetically close to the commercially important *C. arabica* and to *C. kapakata* from the Lower Guinea/ Congolian clade (Figure 10; Annex 4). Finally, *C. eugenioides* crosses well with *C. liberica* and *C. sessiliflora* compared to the crossing rates with other species (Figure 10; Annex 4).

On the basis of phylogenetic studies, *C. stenophylla* is grouped in the Upper Guinea clade together with *C. humilis* and *C. togoensis* (Maurin et al. 2007). *Coffea stenophylla* is also genetically close to *C. liberica* from the Lower Guinea/ Congolian clade (Figure 10; Annex 4). One study identifies close genetic relationships with *C. racemosa*; another study with *C. eugenioides* and the commercially important *C. arabica* (Figure 10; Annex 4). Finally, C. *stenophylla* crosses well with *C. canephora*, *C. liberica* and *C. humilis* compared to the crossing rates with other species (Figure 10; Annex 4).

Chevalier (1947) grouped *C. stenophylla* in the subgroup Melanocoffea with *C. affinis* De Wild. and *C. carissoi* Chev. on the basis of several morphological characteristics. The leaves and fruits of the morphologically similar species *C. affinis* are larger than those of C. stenophylla (Chevalier 1946). *Coffea carissoi* is an unresolved species (Chevalier 1946; The Plant List 2016). The nine molecular marker studies reviewed in this study did not include *C. affinis* and *C. carissoi.* This requires further taxonomical studies.

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[1] A clade is a cluster of species that includes a common ancestor and the living and extinct descendants of that ancestor (http://evolution.berkeley.edu).

Similarly, the taxonomy of *C. stenophylla* needs to be reviewed (Aaron Davis, Kew´s Botanical Garden, Personal communication). Three observations suggest that *C. stenophylla* distribution consists of genetically distinct populations: i) the fragmented distribution of this species; 2) the geographic genetic structure found between the populations of this species; and iii) the morphological differences between the populations of this species.

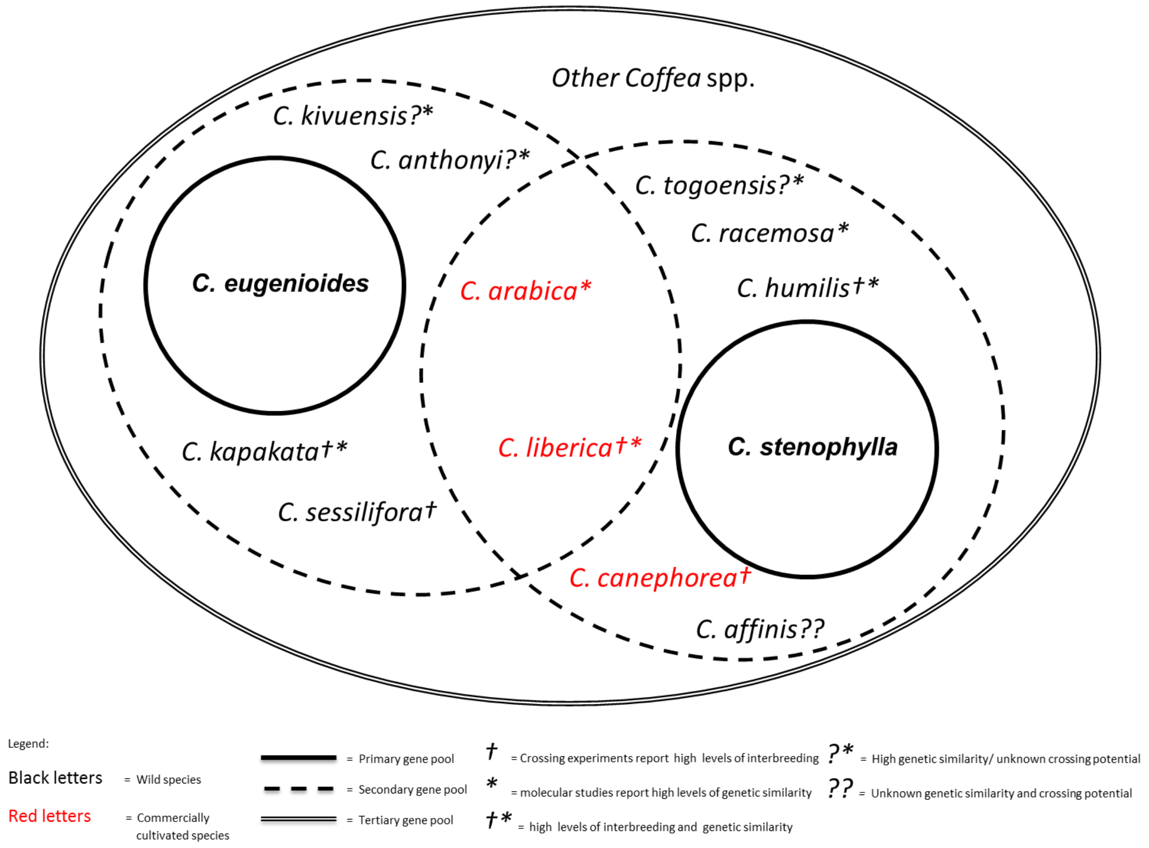

Figure 10. Genepools of *C. eugenioides* and *C. stenophylla.*

Primary, secondary and tertiary genepools for breeding with *C. eugenioides* and *C. stenophylla* are defined on the basis of a literature review (Annex 4). The structure of the framework is adapted from (Zonneveld et al. 2015).

Coffea eugenioides and *C. stenophylla* cross both well with *C. liberica* but *C. stenophylla* is genetically more similar to *C. liberica* than *C. eugenioides* is. *Coffea eugenioides* and *C. stenophylla* are genetically similar according to one of the nine molecular marker studies reviewed in this study.

Coffea arabica is a tetraploid species and therefore is not included in the crossing experiments reviewed, which were between diploid species. In other studies, *Coffea arabica* has been crossed with *C. eugenioides* (Mazzafera & Carvalho 1991; Romero et al. 2010). But no studies were found with crossings between *C. arabica* and *C. stenophylla*. This suggests that *C. arabica* is genetically closer to *C. eugenioides* than to *C. stenophylla*. Molecular studies support the close relationship between *C. arabica* and *C. stenophylla*. One molecular study shows a close relationship between *C. arabica* and *C. stenophylla*.

Coffea affinis is morphologically close *to C. stenophylla* (Chevalier 1946) but this species has not been included yet in crossing experiments or molecular genetics studies to confirm its genetic similarity. *Coffea canephora* and *C. liberica* are commercially cultivated species but also occur in the wild.

Propagation

Reproductive biology

Both species are predominantly outcrossing (Davis et al. 2006).

Coffea eugenioides has a gametophytic self-incompatible system with individual S-alleles (Santa Ram & Sreenivasan 1984). Coffee shrubs are characterized by bi-ovulated and hermaphrodite flowers but no specific references were found for *C. eugenioides* and *C. stenophylla* (Noirot et al. 2016). Coffee species can be pollinated by wind or insects. The species therefore benefit from maintaining a large insect community at agroecosystem level. The importance of each pollen vector differs per species and is influenced by local environmental conditions (Noirot et al. 2016).

The main pollinators for *Coffea stenophylla* are wild bees but are not the exclusive insect pollinators of this species (Slow Food 2016).

Somatic embryogenesis

Induction and selection of somaclonal variation can be done with a wide range of coffee species including *C. stenophylla and C. eugenioides* using callus cultures (Sondahl et al. 1995).

For *Coffea eugenioides*, a species-specific protocol of somatic embryogenesis has been reported with the use of callus culture of leaf expants (Marques 1993).

Coffea stenophylla was reported to obtain rapid cell proliferation in callus cultures from fruit tissue (Santos-Briones & Hernández-Sotomayor 2006).

Interspecific hybridization

Two studies reviewed in this study reported on the potential of hybridization of *Coffea eugenioides* and *Coffea stenophylla* (Annex 4).

Coffea eugenioides crosses well with *C. liberica*, C. *kapakata* and C. *sessilifora* (Figure 10; Annex 4). Less successful crossings have been made between *Coffea eugenioides* and *C. canephora* with 5 % of successful hybrids between *C. canephora* mothers and *C. eugenioides* fathers and 1.7 % of successful hybrids between *C. canephora* fathers and *C. eugenioides* mothers (Louarn 1976). Nevertheless the hybrids produced were evaluated as vigorous with high production with a grain weight of 18g per 100 dry seeds, moderate caffeine content of 1.2 to 1.5 % and resistance to coffee rust (Louarn 1979).

Coffea stenophylla successfully hybridizes with *C. liberica*, *C. humilis*, *C. liberica* and *C. canephora* (Figure 10; Annex 4).

Phenology

Coffee species have in general the following phenological characteristics (Dussert et al. 2000) :

- Flowers will develop only after one or two dry months;
- Flowering is induced by the first abundant rainfall after the dry season; and
- The number of days between the inducing rainfall and flowering is genetically controlled and varies from 6 to 9 days, depending on the species.

Coffea eugenioides

Coffea eugenioides has a long fruit development cycle similar to other coffee species in Central Africa (Anthony 1992). There is a great heterogeneity in the fruit ripening time, both within one population and between different populations (Berthaud et al. 1980). Flowering under natural conditions sets in 7 days after the start of the rains (Noirot et al. 2016). The following experimental evaluation data from Ivory Coast are known: under experimental station condition, the species is reported to induce flowers 9 to 11 days after rain (Dussert et al. 2000). Flowering after the first year of plantation has been observed in in Divo Kenya under forest cover (Berthaud et al. 1980).

The average number of months of seed development among 20-40 genotypes from 4 populations until maturity is 7.8 months on the basis of experimental evaluation data according to (Dussert et al. 2000). The water content at which 50% of initial viability was lost is 0.110 (Table 1). This figure is similar to that of *C. arabica.* This is an indicator of the number dry months until seed shedding. This is for both *C. arabica* and C. *eugenioides* about 4- 5 months (Dussert et al. 2000).

Dussert and Chabrillange (2000) cite (Thomas 1944) who reported that *C. eugenioides* withstands drought better than *C. canephora* and *C. liberica* do since ‘it is restricted to the higher slopes where there is a rapid percolation through the stony soils’ and ‘all the plants are wilted during the dry seasons’. This author reported that, in some localities, *C. canephora* and *C. eugenioides* were found close to each other; however, *C. eugenioides* grew only in the drier areas near forest edges while *C. canephora* was limited to humid areas in the forest (Dussert et al. 2000).

Coffea stenophylla

It takes nine years for this species to reach maturity and yield fruit (Slow Food 2016). This is one of the main limitations for commercial production. According to an experiment in Ivory Coast (Dussert et al. 2000), the average number of months of seed development among 20-40 reproductive genotypes from 4 populations until maturity is: 8.5 months. Other reference report shorter seed development cycles: 6.7 – 7.8 months (Slow Food 2016).

The water content at which 50% of initial viability was lost is 0.150 (Table 1). This is higher than that of *C. eugenioides* and *C. arabica.* This suggests that the coffee species s more susceptible to drought in its seed development stage compared to *C. eugenioides* and *C. arabica*.

That said, two observations suggest that this species is drought tolerant. First, one study reported 33% less stomata across leaf length compared to Arabic coffee 2/cm vs. 2.9/cm (Filho et al. 1987). Second, in its natural habitat , this species is observed to occur in drier higher areas compared to other coffee species, *C. canephora* and *C. liberica*, in the same area, which are restricted to lower areas (Berthaud 1986; Dussert et al. 2000).

Coffea stenophylla can flower all year (Cramer 1957) but during the dry season flower buds enter a dormant state (Slow Food 2016). When rains starts, plants re-hydrate and blossom and resume their vegetative growth. After pollination, fruits grow slowly for 6-8 weeks. After this initially period, they grow rapidly in volume and weight, and their water content increases up to 85%. About 30-35 weeks (7.5-8.5 months) after blooming, fruits complete their growth and the ripening stage begins.

For coffee production with *C.stenophylla*, the ripe berries are dried in the sun for 2-3 weeks immediately after harvest. Then, the dried casing is mechanically removed. Alternatively, they can be immersed in water and mechanically processed to remove the outside casing. The next stage is fermentation, which lasts several days and is followed by drying.” (Slow Food 2016).

Table 1. Seed development duration and seed water content for nine coffee species

Species	SDD (months)*	WC_m**	WC_{50}***
C. arabica	6.9	1.05	0.109
C. brevipes	10.5	1.39	0.203
C. canephora	10.6	0.97	0.170
C. eugenioides	7.8	0.91	0.110
C. humilis	8.9	1.09	0.382
C. liberica	10.6	0.99	0.288
C. poesii	2.1	1.23	0.153
C. pseudozanguebariae	2.3	0.84	0.056
C. stenophylla	8.5	no data	0.158

Data derived from Dussert and Chabrillange (2000)
*Seed development duration (SDD);
**Seed water content at maturity (WC_m) in grams of water per gram of dry weight; and
***Water content at which 50% of initial viability was lost (WC_{50}) in grams of water per gram of dry weight.

Seed, fruit and flower morphology

IPGRI 1996 developed thirty-two key descriptors to morphologically characterize coffee species and varieties (Annex 5). However no study was found during the literature review where *C. eugenioides* or *C. stenophylla,* or both were systematically characterized following these descriptors. Even though several studies report on the morphology of these two species and detailed botanical descriptions have been made (Figures 11 & 12), their appears to be no standardized system yet to morphologically characterize these two species as well as other wild coffee species.

Coffea eugenioides

Leaves: 7-8 cm in length and up to 3 cm in width, lanceolate-acuminate shaped, slightly leathery (Figure 13; 14; Romero et al. 2010). Foliar area is 21.2 ± 3.5 cm^2 compared to *C. arabica* (76.9 ± 16.2) and *C. liberica* (298 ± 80.4) (Romero et al. 2010). Adaptation of *C. eugenioides* individuals to higher elevation can lead to broader leaves (Berthaud et al. 1980).

Inflorescence and flowering: Their inflorescences are axillary and flowers are small and white with 4-6 flowers sepals (Figure 11; 14; Romero et al. 2010).

Fruits: 1 cm in width 1.2 cm in length (Figure 11; 15; Romero et al. 2010).

Coffea eugenioides can be easily distinguished from other species, even though it is a morphologically variable species. Some taxonomic keys overlap with other species (Bridson 1982). *Coffea eugenioides* shares its long fruit cycle and red fruits with coffee species in Central Africa and its small leaves and small berry with East African species (Anthony 1992). Bridson (1982) summarizes the variation by the following taxonomic keys A C (-D) F H (-G) I-K L-M N-O P (-Q):

A. Flowers not precocious; leaves usually well-spaced along the branches.
C. Very young stems always glabrous or **D.** Very young stems sparsely pubescent to pubescent or puberulous.
F. Stipules acute to acuminate or aristate.
H. Leaves with 4-7 main pairs of lateral nerves or **G.** Leaves with 8-17 main pairs of lateral nerves.
I. Lower bracteoles with spathulate to subfoliaceous lobes.
K. Lower bracteoles unlobed or shortly lobed.
L. Scale-like bracteoles absent on pedicel.
M. Scale-like bracteoles present on pedicel.
N. Up to three flowers per axil, usually borne individually.
O. 4-50 flowers per axil, usually borne in one or more fascicles.
P. Domatia absent or **Q.** Domatia present, glabrous to pubescent

Coffea stenophylla

Leaves: Leaf shoots are pink. Leaves are oblong or elliptical (Cramer 1957). They are 3 cm width and between 9 and 15 cm long (Figure 12; 16; 1896; Cramer and Wellman 1957). They grow one to one and are densely clustered (Anonymous 1896; Cramer 1957). Leave colour is bright, dark green and glossy above, paler beneath ; nerves, six to ten pairs, with small glands at the axils, which are white, and perforated on the upper surface (Cramer 1957; Berthaud 1986).

Inflorescence and flowering: Flowers have 5 petals and 8 or more corolla lobes. They are white, star-shaped, and fragrant. Width is 2.5 to 3.8 cm across the corolla lobes (Cramer 1957; Berthaud 1986; Slow Food 2016). They appear on the terminal branch ends and are widely occurring in the outer crown surface (Cramer 1957). Flower shapes differ between native populations in the Ivory Coast; western populations have oblong, round flowers; flowers in the eastern populations are oblong, oval-shaped (Table 2).

Fruits: Fruits have a globose shape and have a size of about 1.25 cm (Figure 12; 1896; Chevalier 1946). They have a black peal when they are mature; some authors report violet berries (Chevalier 1946; Slow Food 2016). The skin is thin and the beans can be pressed out easily (Cramer 1957).

Seeds: Seeds are hemispheric, with a narrow ventral furrow (Figure 12; 1896). The parchment skin is thin and greyish white. The silver skin has a thickened line on the back of the seed where a slight groove in the seed is located (Cramer 1957). Sometimes, one of the two coffee beans in the coffee berry dies. In this case, the remaining one develops and takes on a rounded shape, and is called 'peaberry' (Slow Food 2016).

Table 2. Morphological characteristics of western and eastern *C. stenophylla* populations in the Ivory Coast

Observed character	Western morphotype	Eastern morphotype
Branching habit (descriptor 6.1.6)	Numerous secondary branches	Very numerous secondary branches
Leaves	Very small	Very small
Flowers per fascicle (descriptor 6.2.5)	2	1
Flower shape	Oblong	Globulous
Fruit colour (descriptor 6.3.2)	Black	Black

Derived from (Charrier & Berthaud 1985)

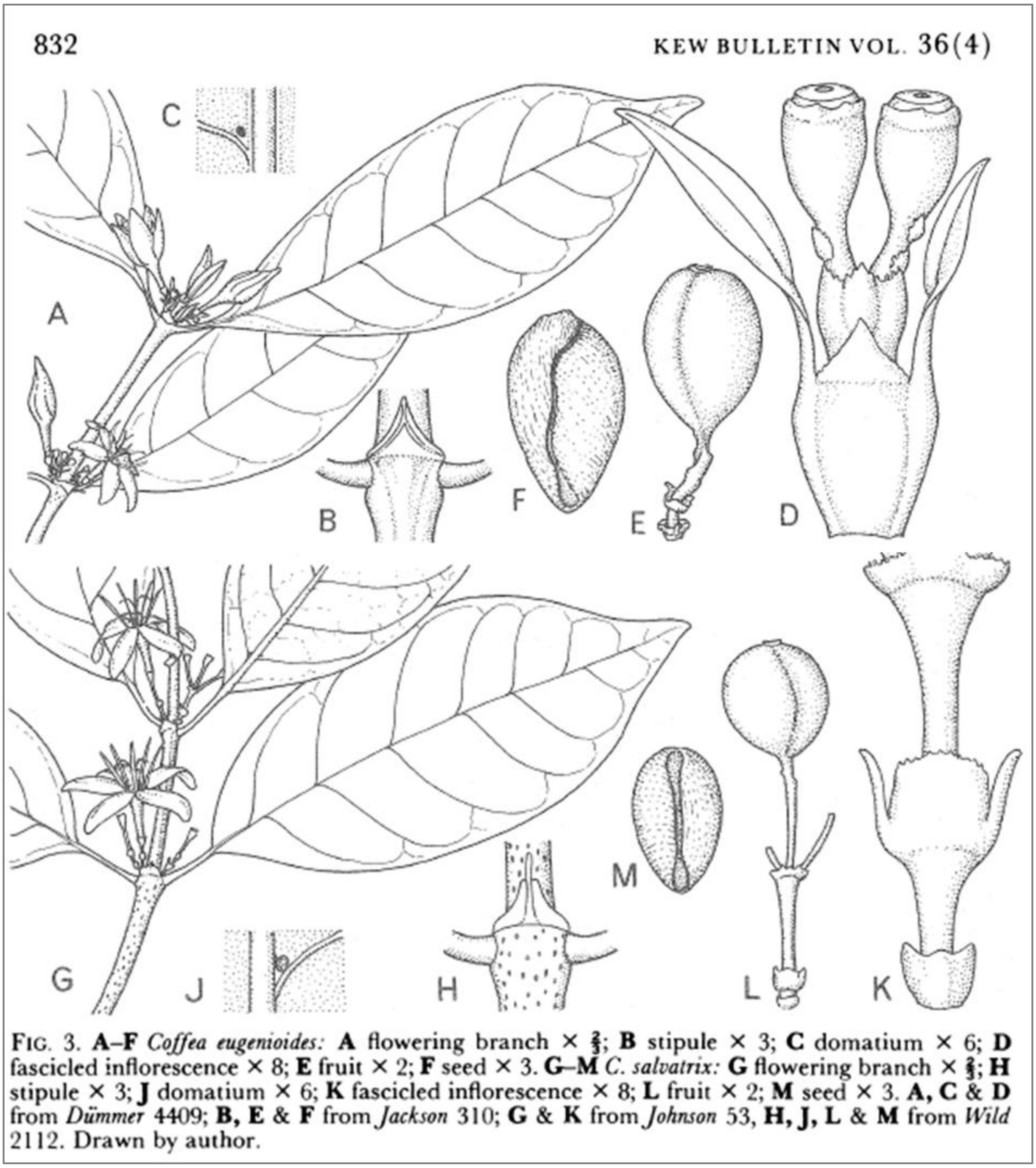

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FIG. 3. **A–F** *Coffea eugenioides:* **A** flowering branch × $\frac{2}{3}$; **B** stipule × 3; **C** domatium × 6; **D** fascicled inflorescence × 8; **E** fruit × 2; **F** seed × 3. **G–M** *C. salvatrix:* **G** flowering branch × $\frac{2}{3}$; **H** stipule × 3; **J** domatium × 6; **K** fascicled inflorescence × 8; **L** fruit × 2; **M** seed × 3. **A, C & D** from *Dümmer* 4409; **B, E & F** from *Jackson* 310; **G & K** from *Johnson* 53, **H, J, L & M** from *Wild* 2112. Drawn by author.

Figure 11. Botanical illustration and description of *Coffea eugenioides*. Copied from (Bridson 1982).

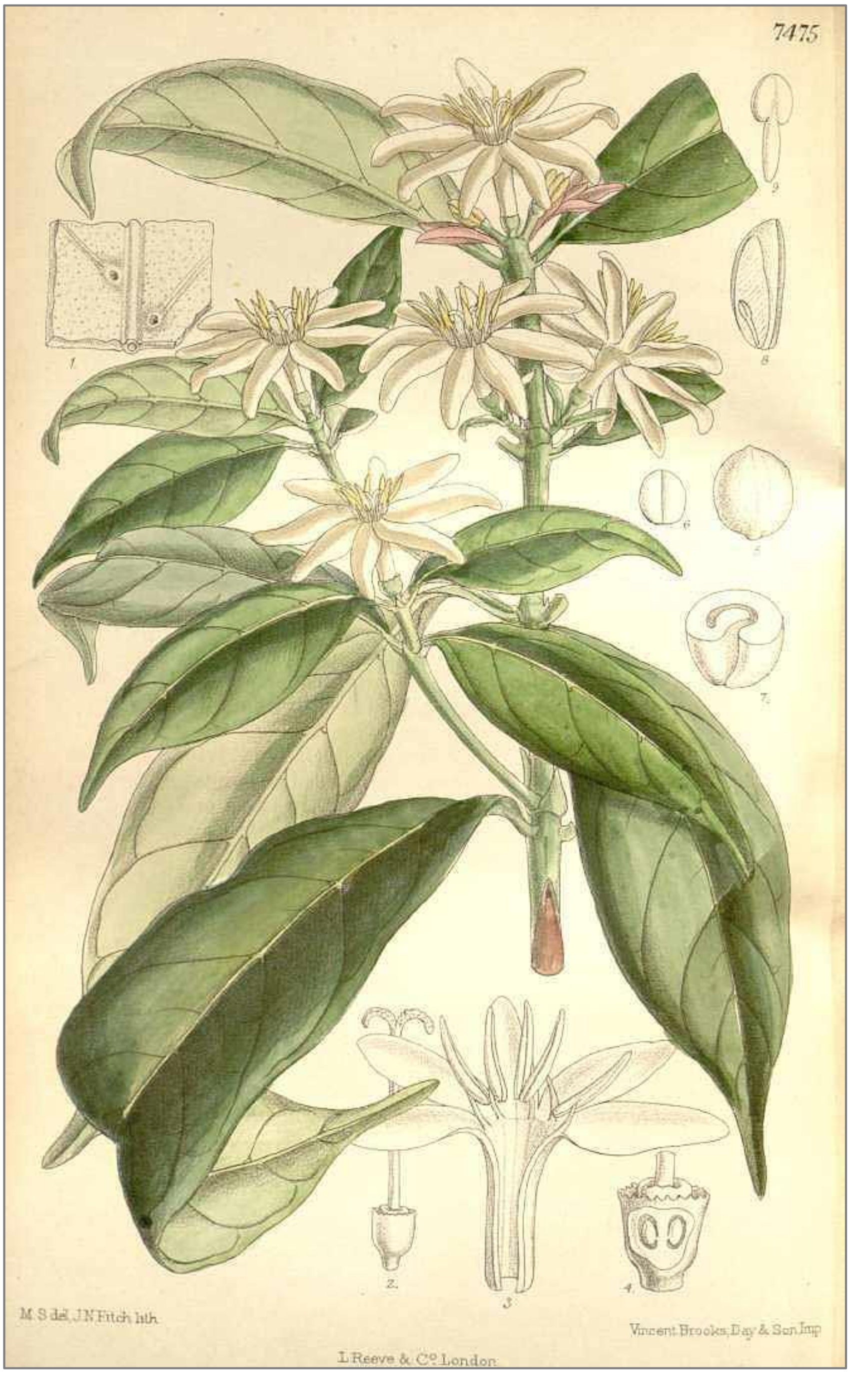


Figure 12. Botanical illustration of Coffea stenophylla from (Anonymous 1896) **http://plantillustrations.org/illustration.php?id_illustration=4989**

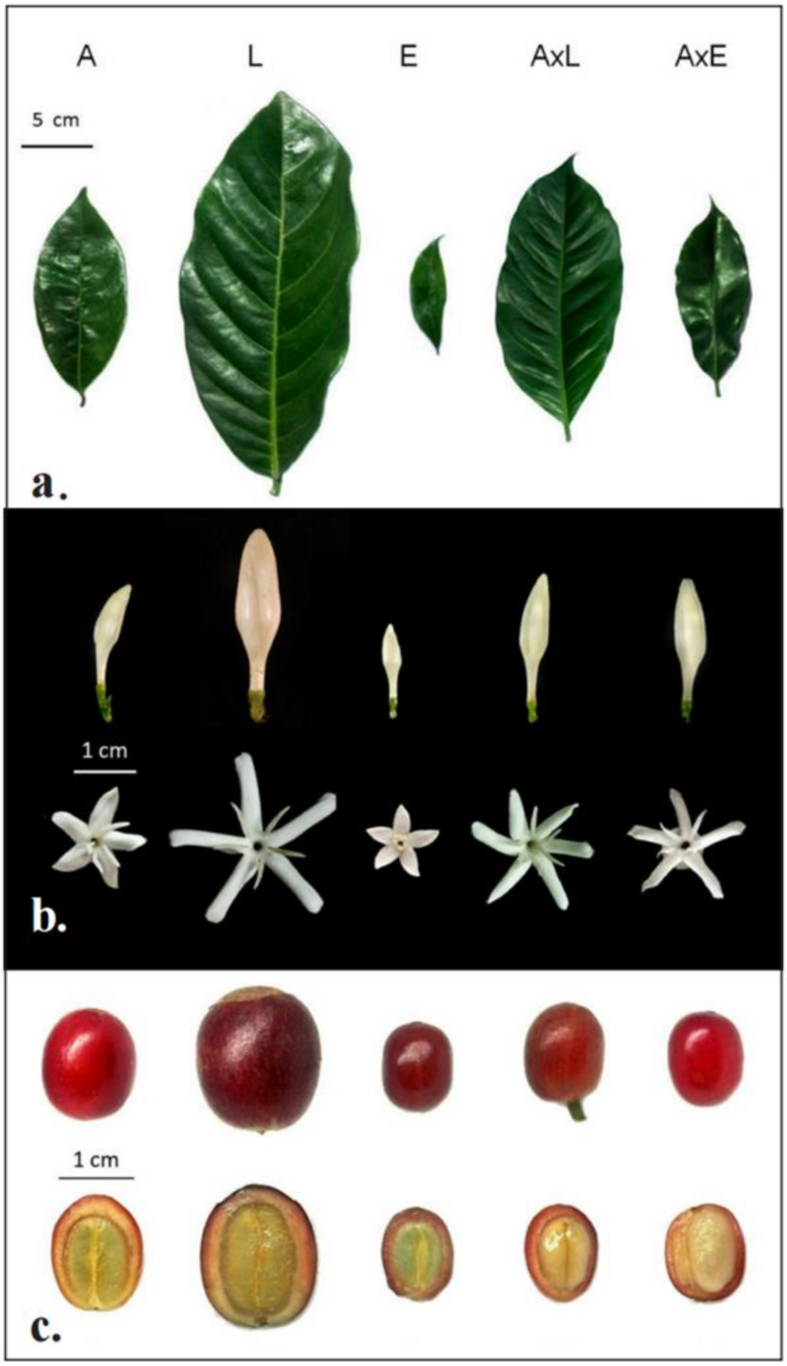


Figure 13. Morphological differences between leaves (a), flowers (b), and fruits (c) of C*. arabica* (A), *C. eugenioides* (E) and *C. liberica* (L). Copied from (Romero et al. 2010).

Figure 14. *C. eugenioides* leaves. Upper photo: *Coffea eugenioides* branch with leaves, fruits and leave shoots. Lower photo: *Coffea eugenioides* leaves compared to *C. arabica* leaves of neighbouring *C. arabica* accessions. The leaves of these surrounding *C. arabica* accessions are infested by *Mycena citricolor* whereas the leaves of *C. eugenioides* don't show any damage by this fungus. This suggest that *C. eugenioides* is resistant to this pathogen. Location: CATIE coffee collection, Turrialba; Date: October 2016; Author: Maarten van Zonneveld.

Figure 15*. Coffea eugenioides* berries. Unripe *Coffea eugenioides* berries (right) compared with unripe *C. arabica* berries (left). Location: CATIE coffee collection, Turrialba; Date: October 2016; Author: Maarten van Zonneveld.

Figure 16. *Coffea stenophylla* leaves. Upper photo: *Coffea stenophylla* leaves (left) compared *to C. Arabica* leaves (right).Lower left photo: *Coffea stenophylla* young leaves. Lower right photo: *Coffea stenophylla* leaves. Location: CATIE coffee collection, Turrialba; Date: October 2016; Author: Maarten van Zonneveld.

Agronomic traits

Yield

Coffea eugenioides

No data for yield (g/plant) for this species was found. But the seed and fruit weights of *C. eugenioides* suggest low productivity compared to *C. arabica*, *C. liberica*, and *C. canephora*. The weight of a hundred seeds of *C. eugenioides* is 2 a 3 grams in contrast to *C. canephora* (18 to 21 grams) (Louarn 1979). Romero et al. (2010) reported a fruit weight is 0.8 ± 0.1 g compared to C. arabica (2 ± 0.1 g) and C. liberica (3.3 ± 0.1 g).

Coffea stenophylla

No data for yield-related data was found. However fruit size of *C. stenophylla* (1.25 cm by 1.25 cm) suggest higher productivity than *C. eugenioides* (1 by 1.2 cm), almost similar to that of C. arabica (1.5 by 1.3 cm) and smaller than *C. liberica* (1.8 by 2 cm) (Figure 13; Romero et al. 2010).

Caffeine content

Coffea eugenioides has a low caffeine content like many other east-African coffee species (Anthony 1992). A synthesis of six studies suggests that this species has a low content compared to other species (Table 3).

C. stenophylla dried seed samples reflected high variability in caffeine content (Anthony et al. 1993). Caffeine content of *C. stenophylla* is higher compared to *C. arabica* and can be similar to that of *C. canephora* (Table 3).

Plant habit

Coffea eugenioides: This species is a conical shrub with numerous thin branches (Romero et al. 2010). In the CATIE collection two plant habits were observed following the IPGRI descriptor 6.1.1: 1) Bush < 5 m without distinct trunk; or 2) Shrub or small tree < 5m with one or more trunks (Figure 17; Annex 5). The length between branch nodes is 3 ± 0.6 cm compared to *C. arabica* (3.1 ± 0.2) and *C. liberica* (6.4 ± 1) (Romero et al. 2010).

Coffea stenophylla : This species grows 3 to 6 m high (Anonymous 1896; Chevalier 1946). This species has two plant habitats according to IPGRI descriptor 6.1.1: 2) Shrub or small tree < 5m with one or more trunks; or 3) Bush >5 m - single trunk (Figure 18; Annex 5). *Coffea stenophylla* has a dense branching habit (Cramer 1957; Charrier & Berthaud 1985).The species is sometimes deciduous in the dry season (Chevalier 1946). Branches are thin and flexible and are similar to *C. arabica* (Cramer 1957).

Root system

Depending on the species and environmental factors, coffee grows as a perennial shrub or small tree, with an extensive root system concentrated on the 0–60 cm soil zone while some roots a grow down to three meters deep (Vieira 2008). *Coffea eugenioides* together with *C. liberica* and *C. excelsa* has deep root systems which allows them to tolerate drought (Sreenivasan 1985).

Disease resistance

Coffee rust (*Hemileia vastatrix*)

This disease is being observed in natural populations of *C. eugenioides* in Kenya, Kambiri forest and Kericho region (Berthaud et al. 1980). Further research is required to understand the levels of resistance in these populations and their use in breeding activities (Berthaud 1986). *Coffea eugenioides* individuals were observed which are fully resistant or fully susceptible to coffee rust (Rodrigues et al. 1975).

Coffea stenophylla individuals were susceptible to coffee rust in Sao Tomé and Príncipe (Lains 1958).

Leaf miner (*Perileucoptera coffeella*)

Coffea eugenioides demonstrated medium levels of resistance to leaf miner (Guerreiro Filho et al. 1999).

Coffea stenophylla demonstrated highest resistance levels to leaf miner among studied *Coffea* species to date (Medina-Filho et al. 1977; Guerreiro Filho et al. 1999; Sera et al. 2010). Eggs were observed on the leaves of *C. stenophylla* but no damage was reported in contrast to Arabic coffee, *C. canephora* or hybrids between *C. stenophylla* and *C. arabica* (Cardenas & Orozco n.d.; Filho et al. 1987). At least two recessive genes control resistance to leaf miner in *C. stenophylla* (Sera 2001).

Coffee borer (*Hypothenemus hamper*)

Coffea eugenioides is resistant to this pest compared to *C. arabica*, *C. canephora*, *C. congensis* and *C. dewevrei*. This resistance was observed at epicarp level but not at grain level (Sera et al. 2010). The reasons for resistance are not clear. Caffeine is not correlated to resistance (Filho & Mazzafera 2003).

No information was found on *C. stenophylla* resistance or tolerance to this pest.

Coffee berry disease (CBD) (*Colletotrichum kahawae*)

This disease seem to have originated from *C. eugenioides* populations in the mountain forests in western Kenya and Uganda (Illy and Viani 200S). This disease is being observed in the native distribution of *C. eugenioides* in Kenya, in Kimilili and Malava (Berthaud et al. 1980). These populations may possess individuals with resistance or tolerance.

No information found on *C. stenophylla*.

Mycena citricolor

This pathogen is a fungus producing leaf damage to coffee plants. *Coffea eugenioides* accessions in the coffee collection of the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) are resistant to this disease compared to infested *C. arabica* accessions in the surround areas (Maarten van Zonneveld; personal observations).

Other diseases

For *C. stenophylla*, the following diseases were observed in natural populations: *Spegazzinia meliolae* and witch broom (*Zukalia* sp.) (Dade 1940).

Figure 17.Plant habit of two *C. eugenioides* accessions. Upper foots: First accession with a forked stem. Lower foots: Second accession with a single stem. Location: CATIE coffee collection, Turrialba; Date: October 2016; Author: Maarten van Zonneveld.

Figure 18. Plant habitat of *Coffea stenophylla*. Location: CATIE coffee collection, Turrialba; Date: October 2016; Author: Maarten van Zonneveld.

Table 3. Grain caffeine content

Species	% dry material of the grain	Number of individuals	Reference
C. pseudozanguebariae	0.00–0.00	4	(Campa et al. 2005)
C. humblotiana	0.00-0.00	4	(Campa et al. 2005)
C. salvatrix	0.01–0.06	4	(Campa et al. 2005)
C. eugenioides	**0.2-0.4**	**Not reported**	(Louarn 1979)
C. eugenioides	**0.3-0.5**	**Not reported**	(Anthony 1992)
C. eugenioides	**0.34-0.64**	**14**	(Berthaud et al. 1980)
C. eugenioides	**0.4-0.5**	**2**	(Mazzafera & Carvalho 1991)
C. eugenioides	**0.44–0.60**	**4**	(Campa et al. 2005)
C. zanguebariae	0.46	1	(Berthaud et al. 1980)
C. Arabica	0.62-1.21	9	(Mazzafera & Carvalho 1991)
C. kapakata	0.72	1	(Mazzafera & Carvalho 1991)
C. salvatrix	0.72	1	(Mazzafera & Carvalho 1991)
C. eugenioides*	**0.76**	**1**	(Mazzafera & Carvalho 1991)
C. racemosa	0.83	1	(Mazzafera & Carvalho 1991)
C. heterocalyx	0.86–0.99	4	(Campa et al. 2005)
C. racemosa	0.86–1.25	4	(Campa et al. 2005)
C. liberica	0.94-1.24	4	(Campa et al. 2005)
C. Arabica	0.96	1	(Berthaud 1986)
C. kapakata	1.04–1.39	4	(Campa et al. 2005)
C. poessi	1.04–1.71	4	(Campa et al. 2005)
C. congensis	1.08–1.83	4	(Campa et al. 2005)
C. liberica	1.21-1.36	2	(Mazzafera & Carvalho 1991)
*C. salvatrix**	1.38	1	(Mazzafera & Carvalho 1991)
C. canephora	1.51–3.33	4	(Campa et al. 2005)
C. stenophylla	**1.65**	**1**	(Mazzafera & Carvalho 1991)
C. humilis	1.67–2.27	4	(Campa et al. 2005)
C. canephora	1.71-2.36	2	(Mazzafera & Carvalho 1991)
C. canephora	1.9-2.3	Not reported	(Louarn 1979)
C. stenophylla	**2.05–2.43**	**4**	(Campa et al. 2005)
C. congensis	2.04	1	(Mazzafera & Carvalho 1991)
C. brevipes	2.36–2.96	4	(Campa et al. 2005)

*double chromosome pairs due to colchicine treatment

Growing areas

Environmental conditions

Little information exists on optimal environmental conditions for growing these two species apart from its occurrence and environment in their native distribution areas. In general, wild coffee species require one or two dry months. This is necessary to induce floral buds (Dussert et al. 2000; Slow Food 2016).

Coffea stenophylla

The cultivation of *C. stenophylla* is limited to a few tropical areas in western Africa, especially in Sierra Leone, where it has been cultivated locally (Anonymous 1896; Slow Food 2016). Literature suggests that *Coffea stenophylla* grows well in hills from 150 to 700 meters a.s.m.l. on gneissose or granitic soil (Anonymous 1896; Slow Food 2016). The species prefers well-drained fertile, neutral to slightly acid soils (Fern 2014).

Ecocrop

Ecocrop modelling predicts that *Coffea eugenioides* produces better in tropical dry and tropical alpine climates than *C. stenophylla*. Vice versa *C. stenophylla* producers better in warm moist areas. (Table 4; Figure 19). Ecocrop is a simple mechanistic model for plant species to predict under which climate conditions they can grow well (Figure 19; Annex 6). This model is useful when no information exist on suitable environmental conditions for the cultivation of a plant species. Minimum and maximum rainfall and temperature ranges were identified for marginal and optimal growth. This was done on the basis of the georeferenced locations recompiled in this study, which come from wild populations, experimental stations and botanical gardens. For both species, an average growing season of 270 days was assumed, and which encompass nine months. This assumption was made on the basis of the number of months for the production cycle of *C. arabica* according to Ecocrop (www.ecocrop.org).

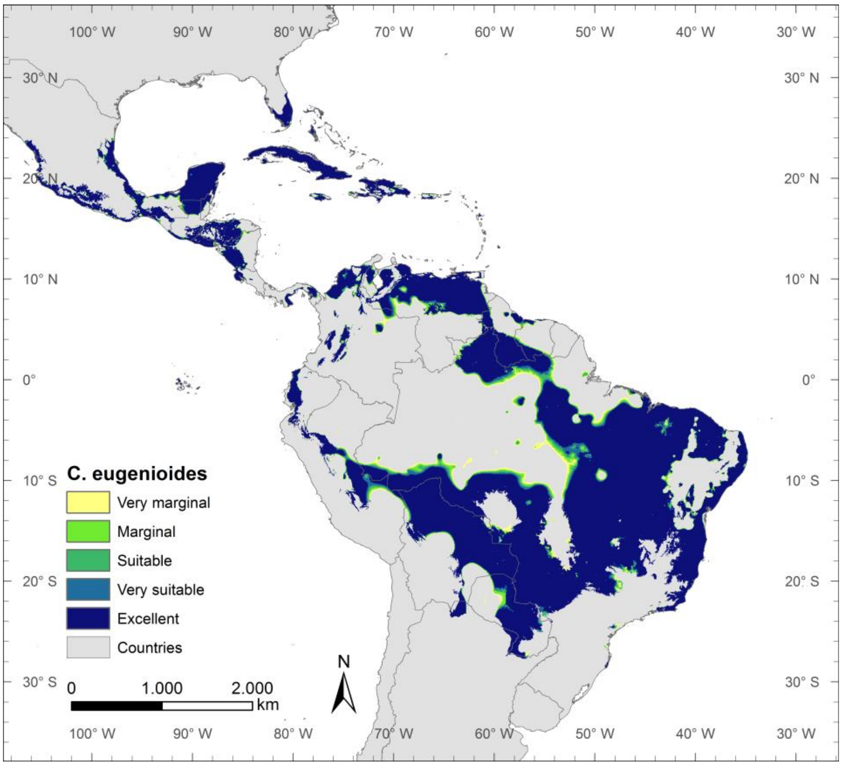
Table 4. Results Ecocrop models

Ecocrop model *Coffea eugenioides*

- Minimum length growing season: 210 days
- Maximum length growing season: 330 days
- Average length growing season: 270 days
- Killer temperature: 9.6 degrees Celsius
- Minimum temperature marginal growing areas: 10.1 degrees Celsius
- Minimum temperature optimal growing areas: 11.4 degrees Celsius
- Maximum temperature optimal growing areas: 28.6 degrees Celsius
- Maximum temperature marginal growing areas: 29 degrees Celsius
- Minimum rainfall (270 days) marginal growing areas: 658 mm
- Minimum rainfall (270 days) optimal growing areas: 701 mm
- Maximum rainfall (270 days) optimal growing areas: 1371 mm
- Maximum rainfall (270 days) growing areas: 1509 mm

Ecocrop model *Coffea stenophylla*

- Minimum length growing season: 210 days
- Maximum length growing season: 330 days
- Average length growing season: 270 days
- Killer temperature: 13 degrees Celsius
- Minimum temperature marginal growing areas: 16 degrees Celsius
- Minimum temperature optimal growing areas: 17.7 degrees Celsius
- Maximum temperature optimal growing areas: 31.9 degrees Celsius
- Maximum temperature marginal growing areas: 33.7 degrees Celsius
- Minimum rainfall (270 days) marginal growing areas: 845 mm
- Minimum rainfall (270 days) optimal growing areas: 979 mm
- Maximum rainfall (270 days) optimal growing areas: 1623 mm
- Maximum rainfall (270 days) growing areas: 2172 mm



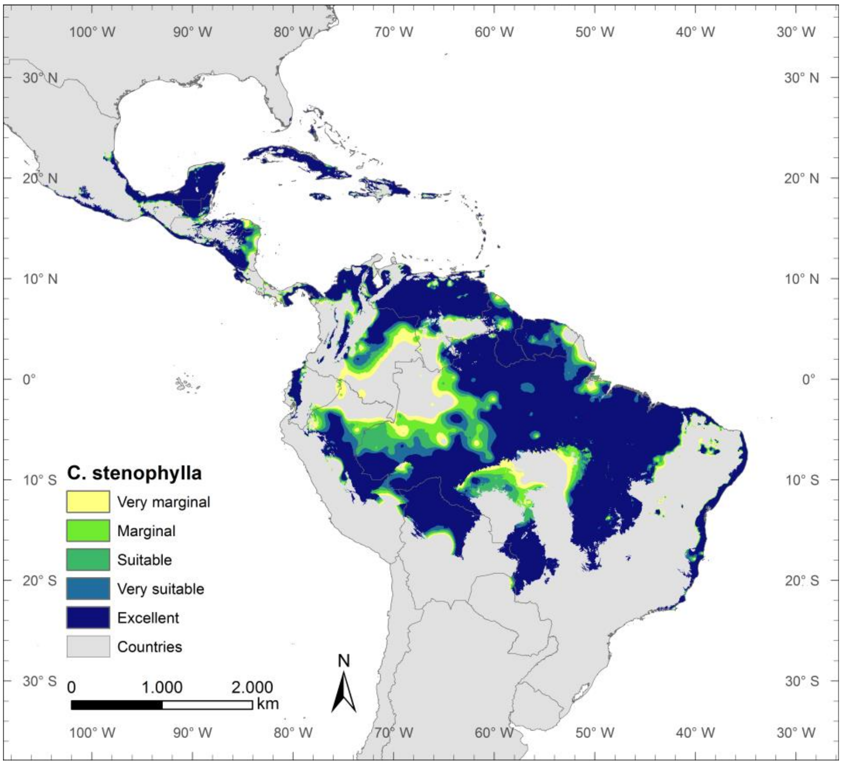


Figure 19. Suitable areas for production of *C. eugenioides* and *C. stenophylla* in Latin America and the Caribbean according to the Ecocrop models for these species.

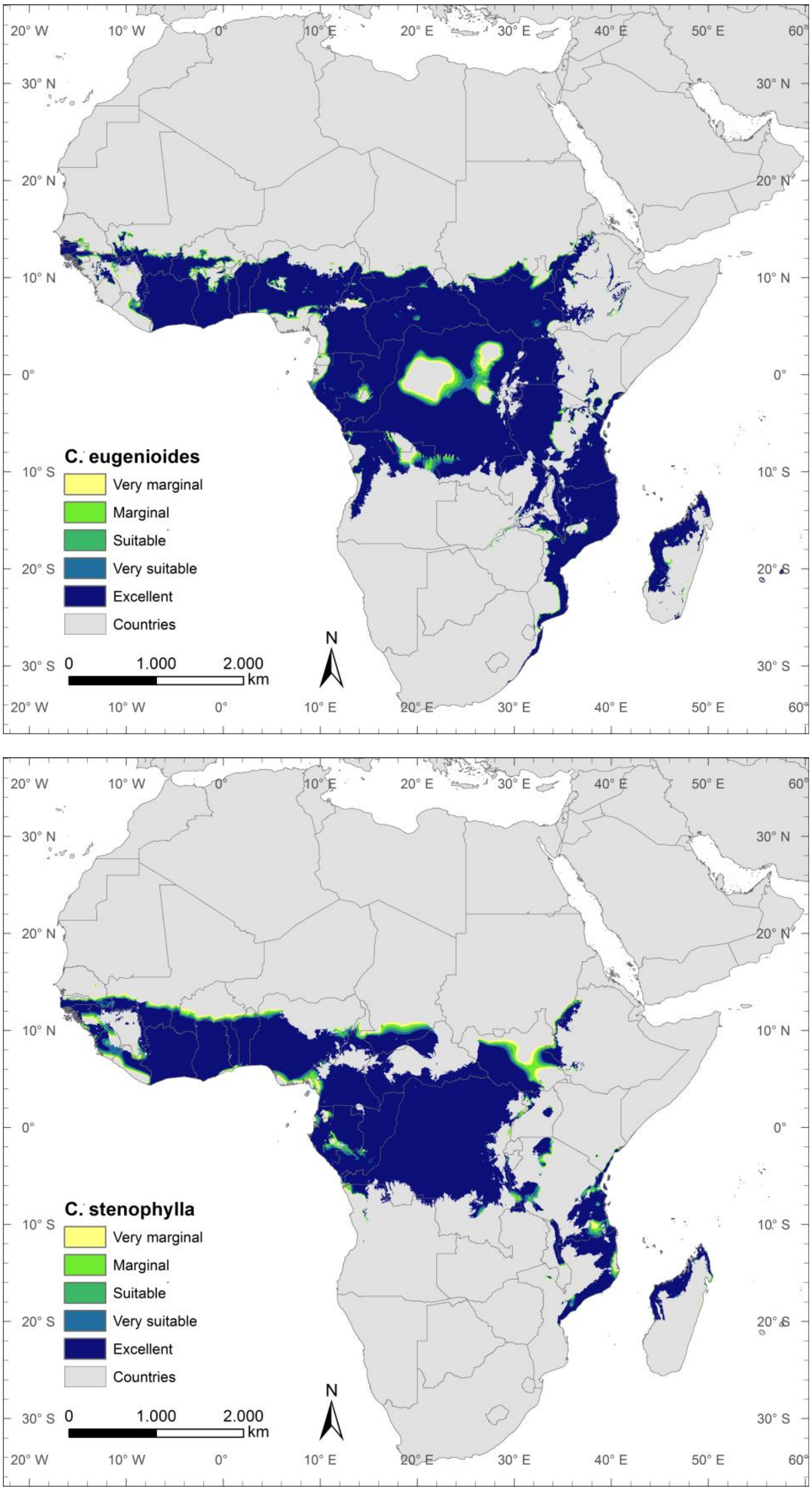


Figure 20. Suitable areas for production of *C. eugenioides* and *C. stenophylla* in Africa according to the Ecocrop models developed for these species.

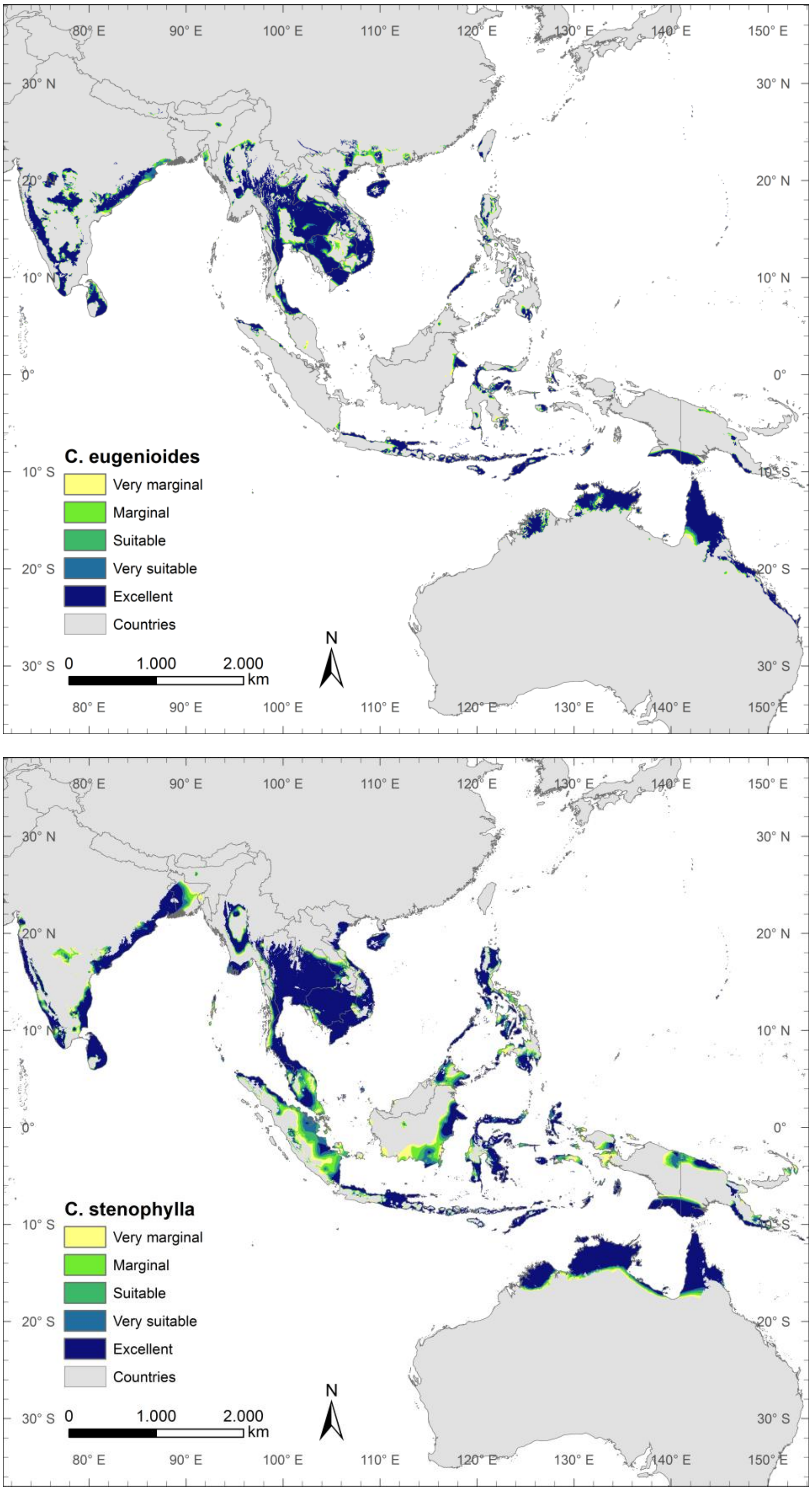


Figure 21. Suitable areas for production of *C. eugenioides* and *C. stenophylla* in Africa according to the Ecocrop models developed for these species.

Conclusions

This report aimed to describe the distribution, botany, agronomic traits and growing areas of two wild coffees: *C. eugenioides* and *C. stenophylla*.

Coffea eugenioides occurs in a wide environmental range from lowland dry savannah up to tropical alpine conditions around the great lake in East and Central Africa. *Coffea stenophylla* has a restricted distribution in Western Africa with isolated populations, which are highly threatened to deteriorate under climate change. The results of this report suggest that urgent conservation actions are required for *Coffea stenophylla.*

Coffea eugenioides is genetically similar to the commercially most important cultivated species *C. arabica* and crosses well with another cultivated species *C. liberica*. The species also crosses well with its wild relatives, *C. kapakata* and *C. sessiflora*. *Coffea stenophylla* crosses well with the cultivated species *C. liberica and C. canephora.* The species also crosses well with its wild relative *C. C. humilis*. *Coffea stenophylla* populations require a taxonomic revision because of the morphological and genetic differences observed between the populations as well as the isolation of these populations from each other.

Coffea eugenioides seeds have low caffeine content whereas *C. stenophylla* seeds have high caffeine content. *Coffea eugenioides* has a deep root system to adapt to drought. *C. eugenioides* reports high resistance to coffee borers (*Hypothenemus hamper*) and *Mycena citricolor.* Resistance to coffee berry disease (*Colletotrichum kahawae*) and coffee rust (*Hemileia vastatrix*) is variable across populations. *Coffea stenophylla has* high resistance to leaf miner (*Perileucoptera coffeella*) but no clear results or information was found on this species related to the other plagues and diseases.

No yield data could be found in literature for either species. However it can be anticipated that both *C. eugenioides* and *C. stenophylla* produce less than the three cultivated species *C. arabica*, *C. canephora* and *C. liberica.* This is because of the small fruit size of *C. eugenioides* and *C. stenophylla* compared to the cultivated species and the little breeding efforts made for *C. eugenioides* and *C. stenophylla*. It can be anticipated that *C. eugenioides* produces less than *C. stenophylla* because the former species has a smaller fruit size than the latter.

Ecocrop crop modelling predicts that *Coffea eugenioides* produces better in tropical dry and tropical alpine climates than *C. stenophylla*. Vice versa *C. stenophylla* producers better in warm moist areas.

The agronomy, reproduction and phenology of both species are under researched. Two of the eight experts who were consulted were not able to provide detailed information on the inquiries related to these issues. This confirms the lack of existing knowledge related to these issues. The other six experts did not respond or suggested to contact another expert. The existing gaps suggest big research opportunities in agronomy and breeding for *C. eugenioides* and *C. stenophylla*.

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Annexes

Annex 1. Checked and updated *C. eugenioides* locations from herbarium specimens and literature

Species	Longitude	Latitude	Type	Country	State	Source	Institution code	GBIF Key
C. eugenioides	27.55	-10.48333	wild	Congo, RDC	Katanga (Shaba)	GBIF	Naturalis	1137132353
C. eugenioides	27.55	-10.48333	wild	Congo, RDC	Katanga (Shaba)	GBIF	Naturalis	1137149677
C. eugenioides	29.08333	-0.71667	wild	Congo, RDC	NA	GBIF	Naturalis	1138519057
C. eugenioides	30.5	1.93333	wild	Congo, RDC	Orientale	GBIF	Naturalis	1137515331
C. eugenioides	30.5	1.93333	wild	Congo, RDC	Orientale	GBIF	Naturalis	1138290046
C. eugenioides	30.5	1.93333	wild	Congo, RDC	Orientale	GBIF	Naturalis	1140006563
C. eugenioides	30.5	1.93333	wild	Congo, RDC	Orientale	GBIF	Naturalis	1137511829
C. eugenioides	29.6997222	-7.516666	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	28.1497222	-1.7	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6166667	2.13305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	29.8	0.5	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	29.8666667	1.44972222	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	27.0666667	1.31666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.5	1.93305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6666667	2.16666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6666667	2.16666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.5	1.93305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.5	1.93305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.5330556	2.03305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6666667	2.16666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6166667	2.18305556	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6666667	2.16666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	29.0830556	0.71666667	wild	Congo, RDC	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	34.86667	0.18333	wild	Kenya	Western	GBIF	UPS	351830879
C. eugenioides	34.86667	0.25	wild	Kenya	Nyanza	GBIF	Naturalis	1137518481
C. eugenioides	34.86667	0.25	wild	Kenya	Western	GBIF	UPS	351830718
C. eugenioides	34.7	0.85	wild	Kenya	Bugoma	(Berthaud et al. 1980)		
C. eugenioides	34.85	0.45	wild	Kenya	Kakamega	(Berthaud et al. 1980)		
C. eugenioides	34.8333333	0.43333333	wild	Kenya	Kakamega	(Berthaud et al. 1980)		
C. eugenioides	35.0166667	0.21666667	wild	Kenya	Nandi	(Berthaud et al. 1980)		
C. eugenioides	35.0166667	0.21666667	wild	Kenya	Nandi	(Berthaud et al. 1980)		
C. eugenioides	34.9333333	0.48333333	wild	Kenya	Nandi	(Berthaud et al. 1980)		
C. eugenioides	34.9666667	0.05	wild	Kenya	Nandi	(Berthaud et al. 1980)		
C. eugenioides	35.0166667	0.06666667	wild	Kenya	Nandi	(Berthaud et al. 1980)		

C. eugenioides	35.0333333	0.48333333	wild	Kenya	Kericho	(Berthaud et al. 1980)		
C. eugenioides	34.9	0.36666667	wild	Kenya	Kakamega	(Berthaud et al. 1980)		
C. eugenioides	32.03333	0.3	wild	NA	NA	GBIF	K	912046724
C. eugenioides	30.42	-1.56	wild	Rwanda	NA	GBIF	Naturalis	1137393031
C. eugenioides	30.4014	-1.412	wild	Rwanda	Kibungu	GBIF	MO	1258336694
C. eugenioides	30.4014	-1.412	wild	Rwanda	NA	GBIF	Naturalis	1137215384
C. eugenioides	30.4014	-1.412	wild	Rwanda	NA	GBIF	Naturalis	1140858175
C. eugenioides	30.4	-1.06667	wild	Rwanda	Byumba	GBIF	Naturalis	1137141815
C. eugenioides	29.92	-1.73	wild	Rwanda	NA	GBIF	K	912144661
C. eugenioides	29.8330556	-1.75	wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	29.8330556	-1.75	wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	28.8997222	-2.4830555	wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides			wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6997222	-1.783055	wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	30.6330556	-1.6	wild	Rwanda	NA	http://projects.bebif.be/enbi/albertinerift/rubiaceae/		
C. eugenioides	31.53194	-1.00111	wild	Tanzania, URO	Kagera	GBIF	MO	1258935350
C. eugenioides	31.4425	-1.14	wild	Tanzania, URO	Kagera	GBIF	MO	1258937234
C. eugenioides	31.59833	-1.04972	wild	Tanzania, URO	Kagera	GBIF	MO	1258621127
C. eugenioides	31.57111	-1.04916	wild	Tanzania, URO	Kagera	GBIF	MO	1258609303
C. eugenioides	31.4275	-1.08222	wild	Tanzania, URO	Kagera	GBIF	MO	1258621958
C. eugenioides	29.91667	-5.68333	wild	Tanzania, URO	NA	GBIF	Naturalis	1137361263
C. eugenioides	31.46666	1.71666	wild	Uganda	Western	GBIF	MO	1258496307
C. eugenioides	30.2103	-0.3375	wild	Uganda	NA	GBIF	NBDB	1098629394
C. eugenioides	28.15	-1.7	NA	Congo, RDC	Nord-Kivu	GBIF	Naturalis	1137424553
C. eugenioides	28.81667	-2.26667	NA	Congo, RDC	Sud-Kivu	GBIF	Naturalis	1137454227
C. eugenioides	-7.64	7.45	NA	Côte d'Ivoire	Man	GBIF	MO	1258336702
C. eugenioides	34.86667	0.73333	NA	Kenya	NA	GBIF	Naturalis	1138146608
C. eugenioides	34.91667	0.18333	NA	Kenya	NA	GBIF	Naturalis	1137190892
C. eugenioides	34.89	-19.8	NA	Mozambique	NA	GBIF	Naturalis	1141406382
C. eugenioides	30.22306	-5.92944	NA	Tanzania; URO	Kigoma	GBIF	MO	1257514740
C. eugenioides	32.875	-18.375	NA	Zimbabwe	NA	GBIF	SANBI	461730589
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090569170
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090557550
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090553648
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090547185
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090547182
C. eugenioides	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090547187

C. eugenioides	-52.8731	-10.8339	cultivated	Brazil	NA	GBIF	F	1228368318
C. eugenioides	0	0	cultivated	Costa Rica	Cartago	GBIF	MNCR	44719946
C. eugenioides	-4.03	5.32	cultivated	Côte d'Ivoire	Abidjan	GBIF	MO	1258336683
C. eugenioides	-7.55	7.4	cultivated	Côte d'Ivoire	Man	GBIF	MO	1258336715
C. eugenioides	47.86397	-21.38239	cultivated	Madagascar	Fianarantsoa	GBIF	TEF	345130417
C. eugenioides	47.86389	-21.3825	cultivated	Madagascar	Fianarantsoa	GBIF	MO	1257748855
C. eugenioides	47.86397	-21.38239	cultivated	Madagascar	Fianarantsoa	GBIF	TEF	1212472623
C. eugenioides	37.23333	-3.25	cultivated	Tanzania, URO	NA	GBIF	W	1230544639

Annex 2. Checked and updated *C. stenophylla* locations from herbarium specimens and literature

Species	Longitude	Latitude	Type	Country	State	Source	Institution code	GBIF Key
C. stenophylla	-7.76667	7.75	wild	Côte d'Ivoire	Man	GBIF	MO	1258336961
C. stenophylla	-7.76667	7.75	wild	Côte d'Ivoire	Biankouma	GBIF	Naturalis	1137518484
C. stenophylla	-4.82	5.89	wild	Côte d'Ivoire	NA	(Chevalier 1946)		
C. stenophylla	-4.21	6.45	wild	Côte d'Ivoire	NA	(Chevalier 1946)		
C. stenophylla	-4.1	6.65	wild	Côte d'Ivoire	NA	(Chevalier 1946)		
C. stenophylla	-3.68	6.65	wild	Côte d'Ivoire	NA	(Chevalier 1946)		
C. stenophylla	-3.38	6.21	wild	Côte d'Ivoire	NA	(Pierrès et al. 1989)		
C. stenophylla	7.73	-7.73	wild	Côte d'Ivoire	NA	(Berthaud 1986)		
C. stenophylla	-14.17	10.94	wild	Guinea	NA	(Pierrès et al. 1989)		
C. stenophylla	-12.37	11.34	wild	Guinea	NA	(Chevalier 1946)		
C. stenophylla	-11.573	9.761	wild	Sierra Leone	NA	GBIF	K	912104635
C. stenophylla	-12.16987	8.34095	wild	Sierra Leone	NA	GBIF	K	912104601
C. stenophylla	6.55	0.23333	NA	Sao Tome and Principe	São Tomé	GBIF	IICT	813351601
C. stenophylla	-47.07717	-22.87025	NA	Brazil	São Paulo	GBIF	IAC	1090569189
C. stenophylla	-47.07717	-22.87025	NA	Brazil	São Paulo	GBIF	IAC	1090557568
C. stenophylla	-13.67729	9.53795	NA	Guinea	NA	GBIF	Naturalis	1139077281
C. stenophylla	-11.79192	8.56028	NA	Sierra Leone	NA	GBIF	NHMUK	1056519049
C. stenophylla	14.8342	-9.97685	cultivated	Angola	Cuanza Sul	GBIF	IICT	813353518
C. stenophylla	-47.07717	-22.87025	cultivated	Brazil	São Paulo	GBIF	IAC	1090549201
C. stenophylla	18.32	0.05	cultivated	Congo, DRC	NA	GBIF	BR	209967650
C. stenophylla	-10.75	10.08	cultivated	Guinea	NA	(Chevalier 1946)		
C. stenophylla	-10.1	9.18	cultivated	Guinea	NA	(Chevalier 1946)		
C. stenophylla	-76.74954	18.02343	cultivated	Jamaica	NA	GBIF	US	888494660

Annex 3. Method description Maxent niche modelling

Maxent niche modelling was used to predict suitable areas under current climate conditions, 2050s projections and climate conditions under the Last Glacial Maximum (LGM) about 23,000 years ago. Version 3.3.3k in the R Dismo package was used (Hijmans et al.; Phillips et al. 2006). Niche models can be used to develop predictive models that make inferences about species' geographic distributions, and are therefore considered a useful tool to overcome the lack of complete distribution data. This kind of modelling technique defines a species' ecological niche to predict areas of potential species occurrence. This is done on the basis of environmental data obtained for occurrence sites where a species has been observed and from sites where it is absent. Because absence points are difficult to obtain, therefore in our study randomly generated background points are used as an alternative to discriminate less suitable environments from more suitable environments in areas where the species has been observed.

Presence points were derived from literature (Chevalier 1946; Berthaud 1986; Pierrès et al. 1989) and from the Global Biodiversity Information Facility:

- Coffea eugenioides: GBIF.org (20th June 2016) GBIF Occurrence Download http://doi.org/10.15468/dl.pszz78
- Coffea stenophylla: GBIF.org (20th June 2016) GBIF Occurrence Download http://doi.org/10.15468/dl.qk0hjh

In total 18 and 10 unique locations for respectively C. eugenioides and C. stenophylla were georeferenced for the modelling exercise.

The environmental layers that were used in Maxent algorithm were selected from 19 bioclimatic variables. All climate layers had a 2-5 minutes resolution. Data was obtained from the Worldclim database (www.worldclim.org):Current climate data from interpolated weather station data. Climate reconstructions in the LGM constructed by two climate models: MIROC and CCSM. Future downscaled projections from 2 General Circulation Models (GCMs) for 2050s (2040-2069) under the Representative Concentration Pathways (CRP) 4.5 and 8.5 that were used in the fifth Assessment IPCC report (Pachauri et al. 2014). These are MIROC – ESM and CCSM. To avoid collinearity in the climate modelling, six climate variables were selected for each species separately from the 19 bioclimatic variables.

To select these variables the clustering approach of van Zonneveld et al. (2009) was followed. For each model run, the climate values at the growing sites were used as input and climate values from 1,000 random background points within a buffer around the growing sites. This buffer comprised 10% of the largest extent of the growing sites. The selected bioclimatic variables were used as environmental layers. The modelled suitable areas were distinguished from non-suitable areas at the probability value of maximum training sensitivity plus specificity (Liu et al. 2005). All analyses were carried out in R version 2.15.2(R Development Team 2014) and with the use of several packages (Bivand and Rundel; Hijmans et al.; Lemon 2006; Hijmans and Etten 2012; White and Gramacy 2012; Bivand et al. 2013; Urbanek 2013; Bivand and Lewin-Koh 2014). Maps were edited in DIVA-GIS.

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Annex 4. Overview genetic studies, which include *C. eugenioides* and/ or *C. stenophylla*

Genetically similar species	Other species included	Method	Marker	Reference
Coffea eugenioides				
Molecular analysis				
C. kivuensis Lebrun and *Coffea anthonyi* Stoff. & F.Anthony	85 *Coffea* spp. and other relatives	Strict consensus tree generated from combined molecular (plastid–ITS) analysis	ITS sequences of nuclear ribosomal DNA + nuclear plastid DNA	(Maurin et al. 2007)
C. kivuensis and *C. Anthonyi*	*C. arabica* L.., *C. bertrandii* A.Chev, *C. brevipes* Hiern, *C. canephora* Pierre ex A.Froehner, *C. congensis* A.Froehner, *C. costatifructa* Bridson, *C. ebracteolata* (Hiern) Brenan, *C. farafanganensis* J.-F.Leroy, *C. humilis* A.Chev, *C. kapakata* (A.Chev.) Bridson, *C. liberica* Hiern, *C. mannii* (Hook.f.) A.P.Davis, *C. millotii* J.-F.Leroy, *C. perrieri* Drake ex Jum. & H.Perrier,, *C. pseudozanguebariae* Bridson, *C. racemosa,* Lour. *C. resinosa* (Hook.f.) Radlk., *C. salvatrix,* Swynn. & Philipson, *C. sakarahae* J.-F.Leroy, *C. sessiliflora* Bridson, *C. stenophylla, C. travancorensis* Wight & Arn.		ITS sequences of nuclear ribosomal DNA	(Lashermes et al. 1997)
C. arabica	*C. arabica x liberica, C. canephora, C. congensis, C. kapakata, C. liberica, C. neoleroyi* A.P.Davis, *C. salvatrix, C. stenophylla*	Single shortest tree	Chloroplast SSRs	(Geletu 2006)
C. arabica, C. Anthonyi	*C. bertrandii, C. brevipes, C. canephora, C. congensis, C. costatifructa, C. ebracteolata C. eugenioides, C. humblotiana* Baill., *C. humilis, C. kapakata, C. liberica, Coffea manni, C. millotii, C. perrieri, C. pseudozanguebariae, C. racemosa, C. salvatrix, C. sessiliflora, C. stenophylla, Gardenia jasminoides* J.Ellis	Parsimonious tree	chloroplast DNA sequences	(Cros et al. 1998)
C. anthonyi	*C. bertrandii, C. brevipes, C. humilis, C. liberica, C. millotii, C. pseudozanguebariae, C. racemosa, C. salvatrix, C. sessiliflora, C. stenophylla*	Joined neighbouring analysis	Nuclear SSRs	(Cubry et al. 2008)
Ethiopian *C. arabica* landraces	*C. kapakata, C. liberica, C. canephora, C. congensis*	Principal coordinate analysis	Nuclear SSRs	(Moncada & McCouch 2004)
C. kapakata	*C. arabica, C. canephora,C. congensis, C. liberica, C. racemosa, C. stenophylla*	Dendrogram based on Dice similarity coefficients	ISSRs	(Ruas et al. 2003)

		using the UPGMA method		
C. kapakata	*C. canephora, C. arabica, C. ebracteolata, C. congensis, C. heterocalyx* Stoff., , *C. liberica, C. racemosa, C. stenophylla*	Dendrogram based on Jaccard genetic distance using the UPGMA method	RAPD	(Silvestrini et al. 2008)
C. arabica	*C. canephora, C. brevipes, C. liberica, C. congensis, C. humilis, C. pseudozanguebariae, C. racemosa, C. sessifolia, C. stenophylla*	Dendrogram of coffee accessions based on single cluster analysis	RAPDs and chloroplast and mitochondrial genome specific sequence tagged sites (STS).	(Orozco-Castillo et al. 1996)
Crossing experiments				
C. liberica, C. kapakata	*C. canephora, C. congensis, C. brevipes, C. humilis, C. milloti, C. racemosa, C. salvatrix, C. stenophylla, C. zanguebariae* Lour.	More than 19 hybrids per 100 flowers		(Louarn 1993)
C. kapakata, C. sessilifora	*C. canephora, C. congensis, C. humilis, C. liberica, C. stenophylla, C. pseudozanguebari, C. racemosa, C. salvatrix,*	Polinator viability of F1 hybrids (17-19%)		(Louarn 1982)
Coffea stenophylla				
Molecular markers				
C. humilis, *C. togoensis*	85 *Coffea* spp. and other relatives. *Coffea affinis* and *Coffea carissoi* are not included	Strict consensus tree generated from combined molecular (plastid–ITS) analysis	ITS sequences of nuclear ribosomal DNA + nuclear plastid DNA	(Maurin et al. 2007)
C. liberica	*C. anthonyi, C. arabica, C. bertrandii, C. brevipes, C. canephora , C. congensis, C. costatifructa, C. ebracteolata, C. farafanganensis*, *C. humilis, C. kapakata, C. kivuensis , C. liberica, C. mannii, C. millotii, C. perrieri, C. pseudozanguebariae, C. racemosa, C. resinosa, C. salvatrix, C. sakarahae, C. sessiliflora, C. stenophylla, C. travancorensis*		ITS sequences of nuclear ribosomal DNA	(Lashermes et al. 1997)
C. humilis	*C. anthonyi, C. bertrandii , C. brevipes, C. canephora, C. congensis, C. costatifructa, C. ebracteolata C. eugenioides, C. humblotiana, C. humilis, C. kapakata, C. liberica, C. mannii, C. millotii, C. perrieri, C. pseudozanguebariae, C. racemosa, C. salvatrix, C. sessiliflora, C. stenophylla, , Gardenia jasminoides*	Parsimonious trees	chloroplast DNA sequences	(Cros et al. 1998)

C. humilis and *C. liberica*	*C. anthonyi, C. bertrandii , C. brevipes, C. eugenioides, C. milloti, C. pseudozanguebariae, C. racemosa, C. salvatrix, C. sessiliflora*	a joined neighbouring analysis	Nuclear SSR	(Cubry et al. 2008)
C. racemosa	*C. arabica, C. canephora, congensis, C. kapakata, C. liberica, C. stenophylla*	Dendrogram based on Dice similarity coefficients using the UPGMA method	ISSRs	(Ruas et al. 2003)
C. arabica, C.eugenioides	*C. canephora, C. brevipes, C. liberica, C. congensis, C. humilis, C. pseudozanguebariae, C. racemosa, C. sessifolia, C. stenophylla*	Dendrogram of coffee accessions based on single cluster analysis	RAPDs and chloroplast and mitochondrial genome specific sequence tagged sites (STS).	(Orozco-Castillo et al. 1996)
Crossing experiments				
C. liberica, C. canephora	*C. congensis, C. humilis, C. kapakata, C. pseudozanguebari, C. racemosa, C. salvatrix, C. sessilifora*	Pollinator viability of F1 hybrids (27 - 60%)		(Louarn 1993)
C. humilis, C. liberica, C. canephora	*C. congensis,C. brevipes, C. kapakata, C. millotii, C. racemosa, C. salvatrix, C. zanguebariae*	More than 19 hybrids per 100 flowers		(Louarn 1982)

Annex 5. Key coffee descriptors (IPGRI 1996)

Vegetative

6.1.1 Plant habit (1 Bush (< 5 m - without distinct trunk); 2 Shrub or small tree (< 5m – one or more trunks; 3 Bush (>5 m - single trunk))

6.1.4 Vegetative development (1 Monopodial; 2 Sympodial)

6.1.6 Branching habit (1 Very few branches (primary); 2 Many branches (primary) with few secondary branches; 3 Many branches (primary) with many secondary branches; 4 Many branches (primary) with many secondary and tertiary branches)

6.1.8 Stipule shape (1 Round; 2 Ovate; 3 Triangular; 4 Deltate (equilaterally triangular); 5 Trapeziform; 6 Other)

6.1.9 Stipule arista (length [mm] Average of five well-developed stipule arista)

6.1.11 Leaf shape (1 Obovate; 2 Ovate; 3 Elliptic; 4 Lanceolate; 5 Other)

6.1.12 Leaf apex shape (1 Round; 2 Obtuse; 3 Acute; 4 Acuminate; 5 Apiculate; 6 Spatulate; 7 Other)

6.1.13 Leaf length ([mm] Average of five mature (> node 3 from the terminal bud) leaves, measured from petiole end to apex)

6.1.14 Leaf width ([mm] Average of five mature (> node 3 from the terminal bud) leaves, measured at the widest part)

6.1.15 Leaf petiole length ([mm] Average of five one-year leaves, measured from the base to the insertion with the blade)

6.1.22 Domatia pilosity (Observed with portable lens or binocular lens: 3 Sparse; 5 Intermediate; 7 Dense)

Inflorescence and flowering

6.2.1 Number of days from rainfall to flowering

6.2.2 Inflorescence position (1 Axillary; 2 Terminal)

6.2.4 Number of flowers per axil (Average of 10 axils, randomly selected from different nodes)

6.2.5 Number of flowers per fascicle (Average of 10 fascicles, randomly selected from different nodes)

6.2.6 Number of fascicles per node (Average of 10 nodes, randomly selected from different branches)

6.2.7 (Inflorescence stalk length [mm] Average of five inflorescences, randomly selected from different nodes)

6.2.8 Corolla tube length [mm] (Average of five flowers, randomly selected from different nodes)

6.2.9 Number of petals per flower (Average of 10 flowers, randomly selected from different nodes) 6.2.10 Anther insertion (1 Excluded; 2 Included)

Fruit

6.3.2 Fruit colour (Observed on mature fruits: 1 Yellow; 2 Yellow-orange; 3 Orange; 4 Orange-red ; ; 5 Red; 6 Red-purple; 7 Purple; 8 Purple-violet; 9 Violet; 10 Black; 11 Other).

6.3.3 Fruit shape (Average of five normal (not caracoli) mature fruits: 1 Roundish; 2 Obovate; 3 Ovate; 4 Elliptic; 5 Oblong; 6 Other)

6.3.4 Absence/presence of fruit ribs (0 Absent; 1 Present)

6.3.5 Endocarp texture (1 Coriaceous; 2 Subcoriaceous; 3 Other)

6.3.6 Fruit-disc shape (The fruit-disc shape is positioned at the end of the coffee cherry: 1 Not marked; 2 Marked but not prominent; 3 Prominent (cylindrical); 4 Beaked (apex constricted into bottleneck shape))

6.3.7 Calyx limb persistence (0 No; 1 Yes).

6.3.8 Fruit length ([mm] Average of five normal mature green fruits, measured at the largest part Characterization)

6.3.9 Fruit width ([mm] Average of five normal mature green fruits, measured at the widest part) 6.3.10 Fruit thickness ([mm] Average of five normal mature green fruits, measured at the thickest part)

Seed

6.4.1 Seed length ([mm] Maximum length average of five normal mature seeds)

6.4.2 Seed width ([mm] Average of five normal mature seeds, measured at the widest part)

6.4.3 Seed thickness ([mm] Average of five normal mature seeds, measured at the thickest part)

Annex 6. Method Ecocrop models

An Ecocrop model was developed for *C. eugenioides* and for *C. stenophylla,* to identify the suitable climate niche for these species and suitable growing areas for each of the two species. Ecocrop is a simple mechanistic model on to identify the climate niche in which a crop produces well. The model requires data on minimum and maximum temperatures and rainfall values in marginal and optimal growing areas. Once the climate niche is determined, geographic areas with a suitable climate can be identified, for example with GIS spatial analyses.

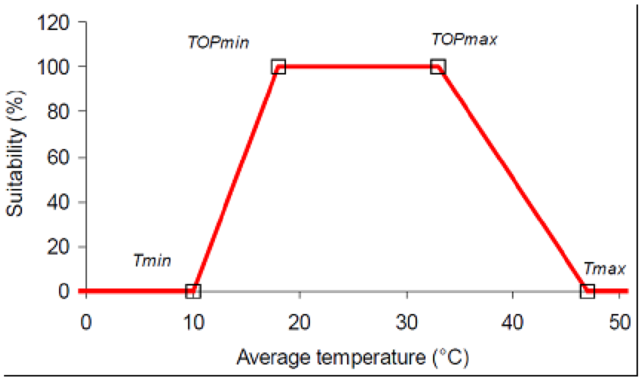

Figure 7. Representation of Ecocrop suitability model for temperature values

http://download.cassandralab.com/suitability/suitability_help/lib/NewItem11.png

An Ecocrop model was developed for each species on the basis of the climate data at the locations of the species´ presence in their natural habitat, experimental stations and botanical gardens. Ramirez et al. (2013) was followed to determine temperatures and rainfall values in marginal and optimal growing areas. Worldclim data with a resolution of 2-5 minutes (about 5 km around the equator) was used as climate data input (worldclim.org).

For each data, point 12 growing seasons were developed of nine subsequent months (270 days) and four growing seasons with nine random months; 16 growing seasons in total. Climate data was collected from the following variables: minimum and maximum temperature per month and rainfall per month.

For each growing season and each data points, mean minimum and mean maximum temperature over the nine months growing season were calculated. Kernel density curves were developed for the resulting climate data sets. On the basis of these density curves, the mode was calculated for the three datasets. This mode was used as a reference to identify marginal and optimal climate ranges.

- The minimum killer temperature was as the 95% class value to the left of the minimum temperature mode;

- Minimum and maximum temperatures in marginal growing areas were assigned as the 80% class values to the left and right of the corresponding modes;
- Minimum and maximum temperatures in optimal growing areas were assigned as the 40% class values to the left and right of the corresponding modes;
- Minimum and maximum rainfall (nine months/ 270 days) in marginal growing areas were assigned as the 80% class values to the left and right of the corresponding modes; and
- Minimum and maximum rainfall (nine months/ 270 days) in optimal growing areas was assigned as 40% of the class values to the left and right of the rainfall mode.

References

Ramirez-Villegas. J., Jarvis, A. & Läderach, P. (2013). Empirical approaches for assessing impacts of climate change on agriculture: the EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology,* 170, 67-78.

Annex 7. Eleven questions on *C. eugenioides* and *C. stenophylla*

These questions were sent to eight wild coffee experts. Two of the eight experts were so kind to respond to the survey. However their response were either very general, like low yield, or confirming that the knowledge no exists yet.

Phenology

1. Which environmental conditions trigger flowering in these two species?
2. In which months do *Coffea stenophylla* and/or *Coffea eugenioides* flower in their native range?
3. In which months are the fruits of these species mature and ready for harvest in their native range?
4. How long does the growing period of the berries of these species take until their maturity?

Propagation

5. Which biological technologies do you know of to propagate and multiply these species (sexual and/or vegetatively)?

Tolerance

6. Which are the three most important diseases for which *Coffea stenophylla* and/or *Coffea eugenioides* have shown resistance or high tolerance?

7. To which abiotic stresses (drought, flooding, temperature, frost, and wind) are these species tolerant? Could you indicate the traits that enable them tolerating these stresses?

Morphological traits

8. How can the root systems of these two species be described?

Yield

9. Do you have an estimation of the yield (dry seed weight) per plant of these two species?

10. Do you know geographic areas where these species return high yields?

Management

11. Under which production system conditions can these species be grown (for example shade or open sun)?

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