A Methodology for the selection and agroecological management of native tree species to enhance carbon sequestration and mitigate climate change in the production of shade-grown coffee.

This methodology was developed as part of the 'Enhancing carbon sequestration and improving livelihoods in shade-grown coffee plantations in the State of Veracruz, Mexico' a collaborative project led by The Royal Botanic Gardens, Kew (RBG Kew) in collaboration with Facultad de Estudios Superiores Iztacala (FESI) of the Universidad Nacional Autónoma de México (UNAM) in alliance with the non-governmental organisation Pronatura Veracruz and funded by UK PACT Mexico.

The methodology here described (Fig. 1) aims to outline the species selection for the conservation, propagation and planting as a shade diversification strategy in shade-grown coffee plantations. Indeed, the selection of tree species for shade diversification, which is able to promote coffee production and preserve biodiversity at the same time, is a fundamental consideration in the agroecological management of coffee. This selection must take into account several factors, i.e., i) conservation of native biodiversity, ii) benefit to local community livelihoods, i.e., local uses, ecosystem services associated to the tree species, iii) carbon capture capacity to help mitigating the effects of climate change. This methodology aims to be replicated in other coffee growing regions in Mexico and the wider Latin America.

Phases of the methodology

1. Preselection and Prioritisation phase
    a. Native Biodiversity
    b. Carbon sequestration attributes
2. Participatory workshop phase
    a. Traditional knowledge
    b. Socio-environmental criteria
    c. Gender Equality and Social Inclusion
3. Field study phase
    a. Benefits to coffee plantations
    b. Morphometric data
    c. Physiologic data
    d. Carbon sequestration
    e. Conservation and Propagation

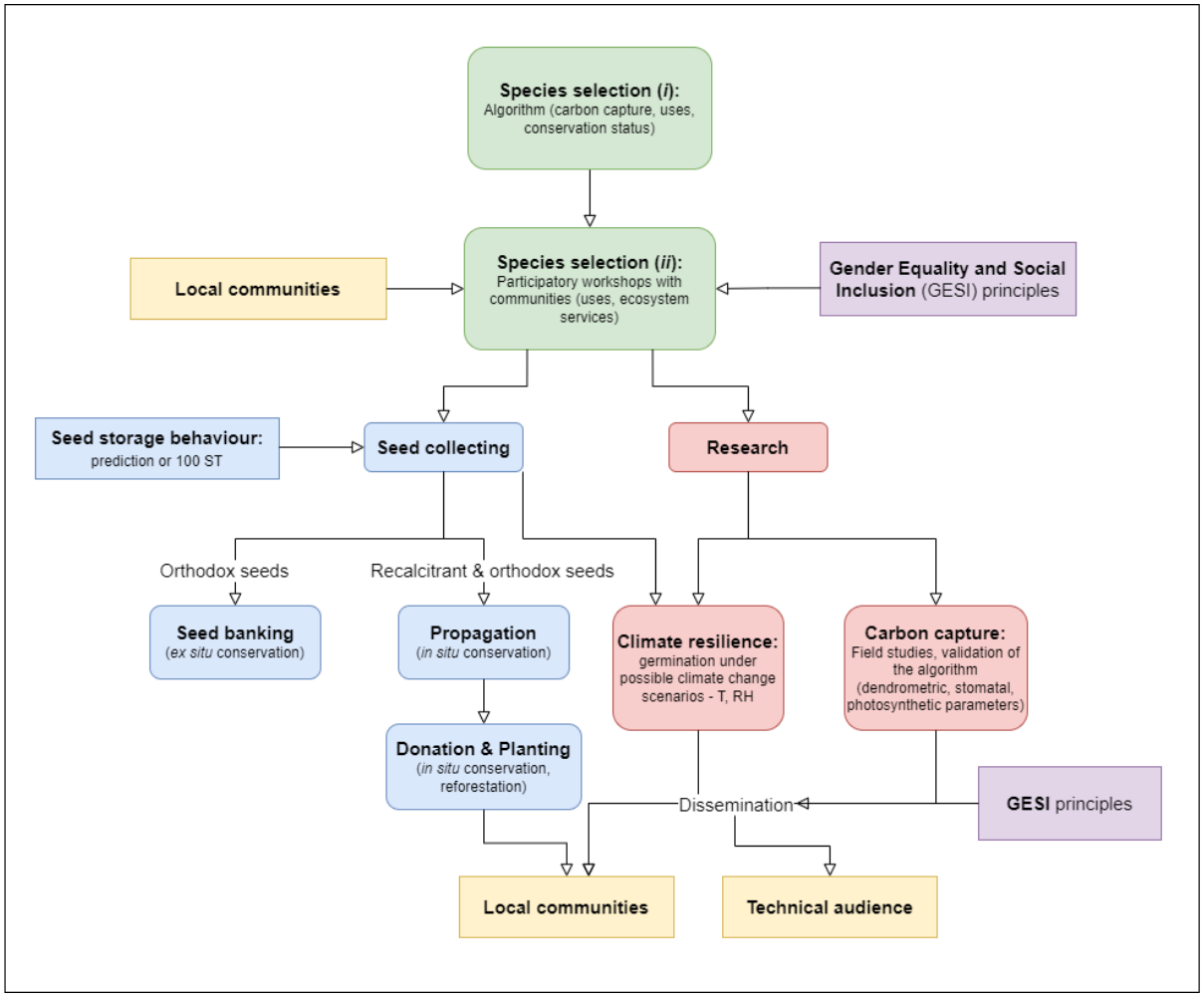

Figure 1: Flowchart of the methodology

1. Preselection and Prioritisation

1.1 Desk-based:

- A list of tree species native to the area was gathered from literature (e.g., Castillo & Luna, 2009, Niembro et al., 2010, Téllez-Valdés et al., 2020).
- The following characteristics were considered:
    - Local distribution
    - Uses:
    - Carbon sequestration capacity:
        - Fast-growing species
        - Long-lived species
        - Large trunks
        - Dense wood
        - Large leaves
    - Other Qualities:
        - Low maintenance needs
        - Resistance to diseases
        - Species that are not used as fuel (to avoid by-products such as greenhouse gases)
- These characteristics were integrated into an algorithm, used to rank the initial list.

1.2 Participatory workshop phase

- The list of 50 prioritised species was presented to the communities through participatory workshops with the local communities. Along with an evaluation of the social, ecological and economic criteria (Fig. 2):

- **Cultural**
  - Medicinal use
  - Customs and traditions
  - Attractive species
- **Species rarity**
  - Distribution limited at the local level
  - Few individuals at the local level
- **Household economy**
  - Food
  - Wood
- **Soil fertilization**
  - Nitrogen and potassium fixation
  - Organic matter
- **Environmental services**
  - Barrier or live fence
  - Flowers attractive to pollinators
  - Food for wildlife
  - Habitat creation for other species
- **Economic services**
  - Fast growing species
  - Timber
  - Production of interest for sale
- **Resilience to climate change**
  - Slope stabilization and erosion control
  - Resistance to drought or bad conditions
  - Resistance to pests
  - Moisture retention in the litter
  - Importance of shade for coffee

Figure 2. Social, economic and ecological criteria (uses, ecosystem services) used to rank species in the participatory workshops).

- Based on the previous exercise, the main socio-ecological criteria were selected and ranked by the attendants. The species list was then analysed and scored based on the criteria.
- A final list of 25 species was produced.
- Among these, the first 7 non-domesticated native tree species were selected for eco-physiological studies in terms of climate resilience and carbon capture capacity (*Inga inicuil* Schltdl. & Cham. ex G.Don, *Inga vera* Willd., *Inga punctata* Willd., *Erythrina americana* Mill., *Psidium guajava* L., *Heliocarpus appendiculatus* Turcz., *Persea schiedeana* Nees)

<u>Considerations for workshops (GESI)</u>

To incorporate and value the perspectives of all workshop participants, it is vital to note that during the workshop exercises, gender equity and social inclusion (GESI) measures must be followed. GESI is a set of principles outlined to help reduce gender bias in the study and to ensure the inclusion of all regardless of disability, gender and socio-economic background. Examples of considerations:

- Ensure that participation among genders and socio-economic background is not biased by factors such as: distance of the location to the farmers' households, transportation to the location, time of the day according to genders' local subdivision of responsibilities (e.g., fieldwork, children day-care etc.), accessibility etc.
- Allow genders to present their selection separately to allow for gender equality in expressing votes/opinions.

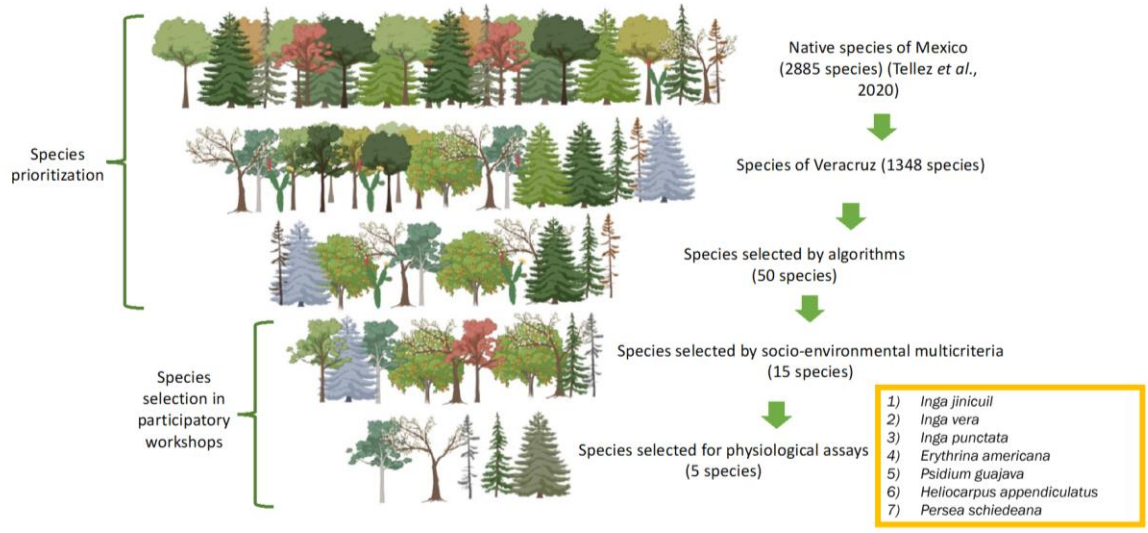

Figure 3. Species selection from literature review to algorithm (carbon capture, uses, distribution), to participatory approach with social, environmental and economic criteria taking into account uses and ecosystem services preferred by local communities.

3. Field Study Phase

Seed storage behaviour

Seed storage behaviour must be considered prior to determine whether *ex situ* conservation (conventional seed banking) is viable for the selected species.

Orthodox behaviour: Seeds survive conventional drying and freezing storage methods.

Recalcitrant behaviour: Seeds do not survive drying and freezing storage methods.

Seed that are considered orthodox and will survive in *ex situ* conservation through drying, freezing as storing are banked in seedbanks as part of *ex situ* conservation. Recalcitrant seeds must be treated differently and should be prioritised for propagation and planting (*in situ*) if other *ex situ* conservation methods are not available (e.g., cryopreservation, *in vitro*).

To predict seed storage behaviour: https://seedcollections.shinyapps.io/seed_storage_predictor/ (Wyse and Dickie, 2018)

To assess seed storage behaviour in the lab: The 100 seed test is a test devised to empirically assess desiccation tolerance, using a reduced number of seeds (Mattana et al., 2020).

Seed collecting & banking

Seeds are collected following the prioritisation obtained through the species selection phases, and the best conservation strategy is selected for each species according to the seed storage behaviour (*ex situ*, seed banking, or *in situ*, propagation and planting, or both).

15 of the prioritised species were then collected in Veracruz for conservation through conventional seed banking at the at the Seed Bank of the Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México (FESI-UNAM). Accessions were then duplicated and stored at The Royal Botanic Gardens, Kew seedbank at Wakehurst, Sussex in the UK.

Seed collecting, Propagation and Planting

After seed collecting, seeds are propagated and plants donated to local communities (e.g., coffee plantations). Priority is given to species with recalcitrant seeds, that must be germinated and propagated immediately to avoid viability loss. Both fresh and banked seeds can be used for the propagation of orthodox species.

Climate resilience

Germination tests

- Randomized germination tests, seeds incubated at different temperatures.
- The germination rates are monitored at fixed intervals (at least once per day), scoring for germinated seeds (radicle at least 2 mm long). At the end of the germination tests cut-tests are performed to adjust the total viability (empty or infested seeds are discarded).
- The data collected is used to produce a thermal time model for the estimation of the width of the thermal range over which seeds of a particular species can germinate. This can be described by cardinal temperatures: optimum temperature (To), base temperature (Tb), and ceiling temperature (Tc).
- This data can then be compared with future projected climate scenarios (e.g., https://www.ipcc.ch/report/emissions-scenarios/) to determine the likelihood of survival and infer future distribution in terms of germination and establishment.

Carbon Capture Assessments

In order to assess the actual carbon capture capacity, the selected trees are then tested in the field.

The study sites:

- At least two different sites to compare shaded and unshaded conditions.
- Sites must be relatively close to one another to ensure little variation of the environmental conditions.

The measurements:

- Dendrometric parameters (to determine the above ground biomass (AGB) for individual trees*)
    - Diameter at breast height (DBH at 1.30m)
    - Height

*this parameter is linked to ecosystem functioning qualities as well as climatic change, due to implications of biomass on carbon cycles. Biomass values were transformed in biomass carbon stock by multiplying AGB by 0.47, the value assigned by the Intergovernmental Panel on Climate Change (IPCC) to the fraction of carbon that corresponds to the calculated biomass; this value relates to the tree's potential to store carbon and its capacity to develop into new cells.

- Photosynthetic parameters (measured on individual tree leaves localized on the first plagiotropic branches near the understory.)
    - Maximum quantum yield (F_v/F_m)
    - Photosynthesis
    - Photosynthetically active radiation (PAR_{out})
- Stomatal parameters (measured on individual tree leaves localized on the first plagiotropic branches near the understory)
    - Stomatal conductance

- Transpiration
- Intercellular CO_2 (C_i)

Findings from *in situ* study

- All tree species and shaded coffee plants have a non-stressed condition compared with unshaded coffee plants.
- Leaf nitrogen levels and therefore carbon absorption rates are higher for shaded coffee plants.

Dissemination of the results

GESI principles must be taken into consideration when designing and distributing the dissemination material, in terms of inclusiveness of the language at all stages, and attention to individual conditions such as, but not limited to, degree of literacy, colour blindness, ability to access to digital *vs* printed materials.

Dissemination is considered as a global public good for different audiences, including local communities, technical audience, scientific community. Based on the audience, different dissemination material is produced. Examples include species leaflets, dissemination on social networks, videos directed to the local communities; scientific papers and technical reports for the technical audience and the scientific community.

All dissemination products were reviewed by an assigned GESI advisor ensuring the accessibility and appropriate representation in all products.

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