Plant-for-the-Planet Mexico – 2022 Restoration Plan

Project summary and current aims:

Plant-for-the-planet Reserves on the Yucatán Peninsula, Mexico:

The Plant-for-the-Planet restoration and conservation reserves comprise >20,000 hectares of seasonally dry semi-evergreen tropical forest surrounding Constitución, Campeche, Mexico (general location: https://bit.ly/3wEiTf8). This area is classified as a tropical dry forest following Holdridge et al. (1971). In this region there is an average annual rainfall of 1313 mm, with a 4-5 month dry season with occasional rainfall events (Mardero et al., 2020). This occasional precipitation sustains a high proportion of evergreen species. As a result, there is always some canopy cover during the dry season in intact forests. Across our reserves the forest spans a wide range of successional stages, from degraded pasture devoid of trees to mature forest.

Redefining our forest restoration goals:

Starting in late 2020 we have been making a significant effort to shift our restoration foci on the Yucatán Peninsula from a traditional forestry approach using native tree species (*i.e.,* "reforestation") towards a more holistic forest "restoration" approach. Specifically, we are working to not only target our tree planting to sites where natural recovery is slow, but also to evaluate how our assisted restoration efforts result in the recovery of specific ecosystem processes. These initiatives have been spearheaded by Dr. Leland Werden (Director of Science, Plant-for-the-Planet Foundation; *start date:* March 2021).

Scaling-up restoration capacity in 2022:

- **Increasing our ability to plant diverse species mixes at scale** by working more closely with our long-term partner nursery and developing a partnership with a new nursery who will produce ~20% of our seedlings this year. This will give us the ability to plant diverse species mixes with more balanced abundances per species that we were able to in 2021.
- **Building an on-site nursery** that will specialize in the production of native tree species not typically grown by forestry-focused nurseries, and the development of protocols for the collection, storage, germination, and production of these species. Our new nursery will produce at least 20,000 seedlings this year, and potentially up to 200,000, which will give us the ability to produce seedlings on our timeline and refine production procedures.
- **Refining our seed collection program** to serve as a model for the collection of native tree species across the peninsula. In 2022 we will use all the seeds we collect in our restoration program, but our goal is to make excess seeds available to other restoration and conservation organizations starting in 2023.

Ongoing management of restoration areas:

Removing the original factors that led to forest deforestation and damage is incredibly important and we have therefore taken major steps to decrease the chance that a fire will damage our restoration areas. In 2021, we cleared firebreaks at least 3 meters wide around all of our sites, which are regularly re-cleared once a year. This helps to reduce the pressure of external fires. We have also had external organizations come in to give fire training courses (one in 2021, one in 2022) and we now have a procedure in place, and a specific firefighting brigade, in case a fire threatens our restoration areas.

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Planting goals for 2022:
In total we plan to use assisted restoration approaches to plant **~3.8 million trees** in 2022. ~3.1 million trees will be planted in our home base in Constitución, Campeche. The remaining ~700k trees will be planted in Bacalar in collaboration with INIFAP.

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Continued collaboration with INIFAP in Bacalar:
We are working at a satellite site (location: https://bit.ly/3oDtgO8) owned by a governmental organization (INIFAP; Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias; https://bit.ly/3bE044c) to perform enrichment planting focused on specific late successional species (e.g., *Brosimum alicastrum, Manilkara zapota*) that were impacted by a significant unnatural fires that burned through sites in 2019 and 2020. We have developed a restoration plan in collaboration with INIFAP that is available on request.

Restoration areas for 2022 (Americas 7, 7.1, 7.2, 9, 11):
For 2022 we are focusing our efforts on restoring 373 hectares of deforested pasture across four sites in and around Constitución, Campeche. The vegetation type and degradation status of the new sites (Americas 7.1, 7.2, 9, and 11) is similar to Americas 7, which we described last year. In brief, these sites encompass two vegetation types: semi-evergreen flooded forest and semi-evergreen forest that does not seasonally flood. These distinct vegetation types are present due to topography and the two soil types present at sites (see example for Americas 7 in Figure 1). Following the approach we used last year, we have taken these edaphic and topographical gradients into account to design tree species mixes targeted to each soil type based on literature reviews and local knowledge.

Hereafter, we refer to these distinct sections of the "restoration area" as "**Vertisols**" and "**Leptosols**." Our general restoration plans for all sites around Constitución are the same as they have similar vegetation status and the same two soil types. We therefore use examples from Americas 7 throughout as they are applicable to all sites. Below we outline the main components of our management plan and design for Americas 7, 7.1, 7.2, 9, and 11:

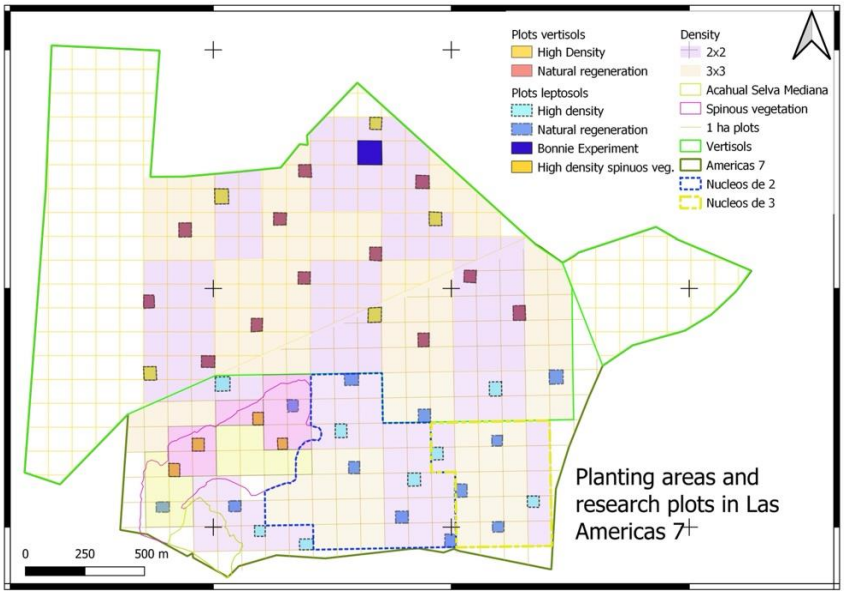

Figure 1. Management units and ongoing experiments in the Americas 7 restoration area: The restoration area is completely deforested except for a few remnant trees and the soil types are designated as follows: Vertisol = outlined in green at the top of the site; Leptosol = bottom of site outlined in black. The Vertisols at all sites typically host a flooded forest vegetation type, and the Leptosols are at slightly higher elevations and do not flood seasonally.

Management units (example for Americas 7 in Figure 1):

- *New restoration plantings (373 ha total):* We will be planting all restoration areas with two tree species mixes, one for each soil type (Figure 2), which will be finalized in June (*see* Table 2 for tentative plan). The total restoration area and the total number of seedlings we plan to plant in each site can be found in Table 1. In total we plan to plant **3,132,500** seedlings in these areas in 2022 (*see* Restoration approach and planting densities below for an extended description of the approach). The two soil types, current conditions, and the total area to be restored in each soil type are as follows:
    - **Vertisols** (~160 hectares): As a reminder, these soils with high shrink-swell clay content that can seasonally flood in the wet season and develop large cracks in the dry season. This flooding and cracking cycle becomes more prominent the more degraded the soil is. Most of this area is currently grazed so only minimal clearing of grasses and herbaceous vegetation will be necessary.
    - **Leptosols** (~200 hectares): Well-drained soils with a very thin organic layer and high stone content. This area has been colonized by tajonal (*Viguiera dentata*), an Aster species that can dominate disturbed areas. This vegetation will be cleared prior to planting, but only in narrow rows so that the existing vegetation can act to improve the microclimatic conditions for planted seedlings. This approach worked very well in 2021.
- *Replanting of some 2021 areas (13 ha)*: We will be replanting some areas that were planted late in the growing season that experience high seedling mortality in the Vertisols (~10

hectares) and Leptosols (~3 hectares). Planting densities will be much lower in these areas and are described below. In total we plan to replant **32,500** seedlings in 2022.

Figure 2. *Left panel:* Seasonally flooded Vertisol area. *Right panel:* Leptosol area of Americas 7. Note the presence of scrubby vegetation (tajonal; *Viguiera dentata*) which can become dominant in disturbed pastures. All sites we are restoring this year have a similar vegetation status to what is pictured in the two panels based on the soil type present.

Table 1. Total assisted restoration plantings planned for restoration sites in and around Constitución, Campeche in 2022.

Site	Soil type	Total planting area (ha)	Total Replanting area (ha)	Total planting plan (# seedlings)
Americas 7	Vertisol	120	10	1,225,000
Americas 7	Leptosol		3	7,500
Americas 7.1	Leptosol	30		225,000
Americas 7.2	Vertisol	40		400,000
Americas 7.2	Leptosol	80		600,000
Americas 9	Leptosol	20		150,000
Americas 11	Leptosol	70		525,000
			total:	**3,132,500**

Immediate restoration goals in the "Management units":
We have the same main restoration goals as 2021 to start: reestablish vegetation structure and reassemble the plant community at the sites. To address these goals, we will plant native tree species to 1) reestablish a forest canopy at this site to shade out grasses and tajonal; and 2) augment species richness of common canopy dominants that are not naturally recruiting in abundance.

Site-preparation, long-term maintenance, and minimizing the impact on natural regeneration:
We will clear grasses and scrub vegetation from the area to increase establishment and growth rates of planted tree seedlings. However, we noted in 2021 that certain tree species that naturally occur in these areas are naturally regenerating in the Vertisols (*e.g., Caesalpinia vesicaria, Haematoxylum campechianum*). Therefore, our field crews have become adept at avoiding cutting

these tree species to not hinder the natural regeneration that is already occurring. All clearing is conducted by hand with machetes. After trees are planted the vegetation around them will be cleared for at least two years to release planted seedlings from competition.

Restoration approach and planting densities:

- *Planting dates 2022:* Planting will begin at the onset of consistent rains (~July). We will set up a grid across all sites so we can track our progress (see example for Americas 7 in Figure 1). This worked very well in 2021 and facilitates our tracking of all plantings with our TreeMapper app (https://www1.plant-for-the-planet.org/yucatan). We will cease planting at the end of November (~2 months before the end of consistent wet season rains).
- *Total trees planted and planting approach:*
    - In total we plan to plant ~3.1 million trees across the restoration sites (Table 1).
    - We will use the same approach we used in 2021 that attempts to increase the heterogeneity of plantings to better mimic tree spacing in natural forest. In brief, we will plant seedlings in rows at approximate densities per hectare. However, rather than planting one seedling at standard intervals, we will haphazardly plant 3 or 4 seedlings in clusters every 2 m (see example in Figure 3). Seedlings in each cluster will all be the same species so that seedling survival and growth can easily be monitored. This also decreases logistic challenges in the field.

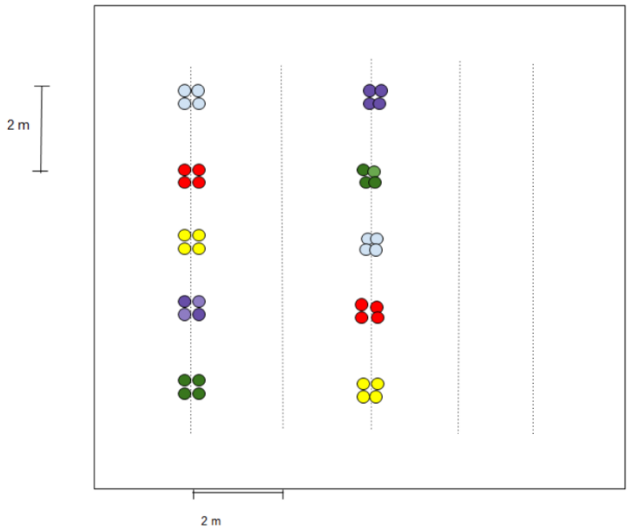

Figure 3. Example of cluster planting approach with four plants per cluster. Difference colors represent species.

    - Using the same approach from 2021, we will plant seedlings in each cluster at abundances tied to expected survival rates in these two soil types, with the goal of minimizing the need for replanting. Our predictions for survival rate in each soil type were very close to what we observed in preliminary survival surveys conducted in December 2021, and results suggest that the approach is working to create a heterogenous planting structure.
        - Preliminary survival data collected at the end of the planting season in December 2021 show that the planted tree survival rates were on average

30-40% overall, which we expect to be closer to 20-30% by the end of the 2022 dry season (~May 2022). This aligns with our expectation that survival rates would be quite low due to the level of degradation present at the site and the difficulty restoring these two soil types (Vertisols in particular; *see* Deckers et al., 2001; Werden et al., 2018, 2020). This also indicates that our high planting density approach (7,500 seedlings/ha in clusters in Leptosols; 10,000 seedlings/ha in clusters in Vertisols) will reach the <2000 seedlings per hectare goal that we had initially and will require little to no replanting in almost all areas.

- *Planting densities:* Based on the 20-30% observed survival rate of planted seedlings, we will plant at a standard density in each soil type, spacing rows every 2m, which will result in a density of <2000 seedlings per ha, similar to natural forests in this region:
    - **Vertisols**: 2×2 m spacing with 4 seedlings per cluster = 10,000 seedlings/ha
    - **Leptosols**: 2×2 m spacing with 3 seedlings per cluster = 7,500 seedlings/ha

- *Species richness per hectare:* At least 10 flood tolerant species (Table 2), out of a pool of 14 will be planted into the Vertisols per hectare. In the Leptosols we have a potential species pool of 20 species, and we will aim to plant at least 11 species per hectare. Across the planting site we will vary the species mixes as much as possible to ensure that plantings result in heterogeneous communities of trees planted across the site.
    - *Approach to design of species mixes in 2022 and beyond:* We have complied life-history trait data (e.g., N-fixation status, leaf habit, seed dispersal syndrome) for all of the 31 species we plant to plant in 2022. We will use this information to design species mixes that have appropriate proportions of these functional groups based on forest inventory data from nearby reference forests that we have collected and are actively colleting. In 2022 we will work to build out our trait database, both through literature review and by collecting functional trait data in the field, so we can start to build more robust species mixes based on community weighted functional trait means of remnant reference forests.
    - *Plans to expand the scope of woody growth forms planted in the future:* Our seed collection team is collecting seeds of many native tree species that are not typically grown in plant nurseries in the region, and that we do plant trees that have short stature and are more like shrubs. However, we will plan to start incorporating other growth forms such as shrubs into species mixes in 2023, especially now that we are building our own nursery to do so. We are also being very careful to plant seedlings with sufficient genetic diversity and that we have worked with our partner nurseries to have them collect data for mother trees and ensure they collect from many trees/populations."
    - *Genetic diversity of species mixes:* To ensure that we are not introducing genetic bottlenecks across the landscape as we make our restoration plantings, we now ensure that seeds are collected from a sufficient number of mother trees and populations of mother trees. We plan to increase this requirement to include more populations and a higher number of mother trees. In our contracts with our external nursery partners, we include the following text (both nurseries have already fully complied with this requirement for 2022):

> "Collected seeds must come from a minimum of four tree populations separated by at least 1 km. The seeds must be collected from a minimum of 20 trees in total (for example, 5 trees from each of the 4 populations = 20 trees in total). GPS locations and images of all mother trees must be collected and shared with and approved by the Plant-for-the-Planet team before any seeds are used to produce seedlings."

Ongoing experimental work: In addition to the large-scale plantings we have also established an experiment in Americas 7 that will help us to improve our restoration plans in the long-term:

- *Quantifying rates of natural regeneration:* In each of the two soil types we will clear existing vegetation and leave at least 12 0.25-ha plots (three hectares total) completely unplanted to observe the rate of natural regeneration over time in these two soil types (n = 12 plots per soil type = 24 0.25-ha plots total). These 12 0.25-ha plots were randomly dispersed randomly across each soil type (Figure 1). We are following standardized vegetation monitoring protocols developed by the Crowther Lab at ETH Zürich to measure the outcomes of this work. We have also developed a collaboration with Restor (www.restor.eco), who will be facilitating the use of some emerging technologies such as bioacoustics and drone-based monitoring to quantify the outcomes of this experiment.
- *Determining ideal planting densities for seedlings:* To have a better sense of what density to plant each of our 31 focal species at, we plan to implement to determine the ideal planting densities for specific species using an approach such as the Nelder wheel design in 2023 (Parrott et al. 2012).

Progress on monitoring outcomes:
Across our restoration area, we have started to establish monitoring plots that will use protocols developed by the Crowther Lab at ETH Zürich to track simple vegetation recovery metrics (*e.g.,* canopy cover development, natural recruitment of seedlings, decrease of tajonal and grass cover). We have also been quantifying the growth and survival of planted seedlings and are currently building functionality into our TreeMapper app to do this (https://a.plant-for-the-planet.org/treemapper/). We will also continue to use traditional survey methods in comparison. We have also been establishing permanent monitoring plots in reference forests adjacent to the sites to have benchmark we can compare our work to. A master's student from ETH Zürich established 10 forest inventory plots on remnant Vertisol sites 2021, and a PhD student from Imperial College London is currently doing extensive seedling recruit surveys and monitoring seed rain in the same areas. These data collection efforts will give us the ability to monitor the outcomes of the assisted restoration efforts in our restoraiton sites. We hired a new monitoring program coordinator in April 2022 with strong botanical knowledge who will oversee this effort. We will give an update about this status of this program later this year.

Summary of our monitoring efforts thus far: We took extensive survival measurements in the Fall of 2021 to look at transplant shock of planted seedlings, and that we will take measurements in May/June to assess survival after the first full dry season. Ideally, we will monitor for at least 10 years, monitoring every two to 5 years depending on how old plantings are, and that for all plantings at least the first two years of survival and growth will be monitored. We are also building

functionality into TreeMapper to facilitate the collection of survival rate, and that we will generate a report on survival and growth for the 2021 plantings sometime later in 2022. In this report we will also assess the outcomes of different planting densities we used in 2021 (2 x 2 m and 3 x 3 m) to inform our future work.

Soon to be released TreeMapper monitoring features: We have built the following functionality into TreeMapper that will facilitate the measurement of the outcomes of our work. (1) We have added the ability create permanent monitoring plots that you can return to and track survival and growth. Additionally, we already used TreeMapper to collect initial diameter and height data for at least 10 seedlings in each planting polygon in 2021 (2) The development team is working to make TreeMapper collected data completely open and easily downloadable.

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Q2 2022 Restoration Plan Approval – Restoration Supervision Expert Board

I have reviewed the updated 2022 restoration plan and agree that the Plant-for-the-Planet restoration team sufficiently considered and integrated all suggestions made during the Q2 2022 Board meeting on April 26th, 2022.

	16/5/2022
Dr. Pilar Angélica Gómez-Ruiz	Date
	11/5/2022
Dr. Rakan A. (Zak) Zahawi	Date
	10/5/2022
Dr. Joachim Hamberger	Date
	20/5/2022
Joachim Elsässer	Date

Table 2. List of 31 species available for the 2022 Plant-for-the-Planet restoration season. Species that are known to tolerate seasonal flooding are indicated with **bold text**. Species collected at least partially by the Plant-for-the-Planet seed collection program are indicated with "*".

Family	Common name	Species
Fabaceae	Balché	*Lonchocarpus longistylus*
Meliaceae	Caoba	*Swietenia macrophylla*
Fabaceae	Catzin negro	***Acacia gaumeri***
Meliaceae	Cedro	*Cedrela odorata*
Leguminosae	Chacté viga	*Caesalpinia mollis*
Burseraceae	Chakaj	***Bursera simaruba***
Sapotaceae	Chicozapote	***Manilkara zapota***
Fabaceae	Chukum	***Havardia albicans****
Boraginaceae	Ciricote	***Cordia dodecandra***
Fabaceae	Fierrillo	***Caesalpinia vesicaria****
Fabaceae	Granadillo	*Platymiscium yucatanum**
Fabaceae	K'aan jabin	*Senna racemose**
Malvaceae	K'aan kaat	*Luehea speciosa*
Fabaceae	Kanasin	***Lonchocarpus rugosus****
Fabaceae	Katzin blanco	***Mimosa bahamensis****
Ehretiaceae	Laurel/Bakalché	*Bourreria mollis*
Bignoniaceae	Luuch/jicara	***Crescentia cujete***
Bignoniaceae	Maculis	*Tabebuia rosea*
Fabaceae	Madre de cacao	***Gliricidia sepium***
Malvaceae	Mahahua	*Heliocarpus mexicanus*
Fabaceae	Palo de tinte	***Haematoxylum campechianum****
Simaroubaceae	Passak	*Simarouba glauca*
Fabaceae	Pich	*Enterolobium cyclocarpum*
Malvaceae	Pixoy	***Guazuma ulmifolia***
Combretaceae	Pucté	***Bucida burseras***
Meliaceae	Quiebrahacha	*Trichilia hirta**
Moraceae	Ramón	*Brosimum alicastrum*
Rhamnaceae	Tatúan	*Colubrina arborescens**
Fabaceae	Tzalam	***Lysiloma latisiliquum****
Fabaceae	Waxim	***Leucaena leucocephala****
Fabaceae	Ya'ax kin ché	*Caesalpinia yucatanensis*

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