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. We are currently in the process of assessing the vegetation status across our reserves and we will make these reports available in the coming months and years

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 active restoration efforts result in the recovery of specific ecosystem processes. These initiatives have been spearheaded by Dr. Anna Carbonell (Director of Restoration and Research, Plant-for-the-Planet Mexico; *start date:* October 2020) and Dr. Leland Werden (Director of Science, Plant-for-the-Planet Foundation; *start date:* March 2021).

Building restoration capacity in 2021:

Since the start of the year we have focused on shifting our practices to increase the impact and effectiveness of our restoration work in the region. To do so we have been:

- **Building a team of staff Ecologists** with specializations in botany, GIS, research and team management, and community outreach.
- **Creating a seed collection program** to increase the number of native species available for plantings (especially early-successional and flood-tolerant species), improve the genetics of planted species, and build a GIS database of mother trees for future seed collection. Our seed collection efforts in the next year will focus on increasing the number of mother trees that seeds are collected from to increase the genetic variability of seeds collected and ensure diverse communities of species are planted across the landscape.
- **Increasing the number of native tree species available for active planting from 8 to >30 species** by working with our partner nursery to grow a more diverse mix of species, and by periodically delivering collected seeds to the nursery. Our broader aim is to shift our focus away from primarily planting tree species typically used in a forestry context.

Plant-for-the-Planet Restoration Plans – 2021

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 fire that burned through the area in 2019. INIFAP has developed a detailed restoration plan for their site which is available on request.

Restoration area for 2021 (Americas 7):

For 2021 we are focusing our efforts on restoring 377 hectares of deforested pasture. This area has two distinct 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 the site (Figure 1). Accordingly, we are taking these edaphic and topographical gradients into account and designing 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**." Below we outline the main components of our management plan and design for Americas 7.

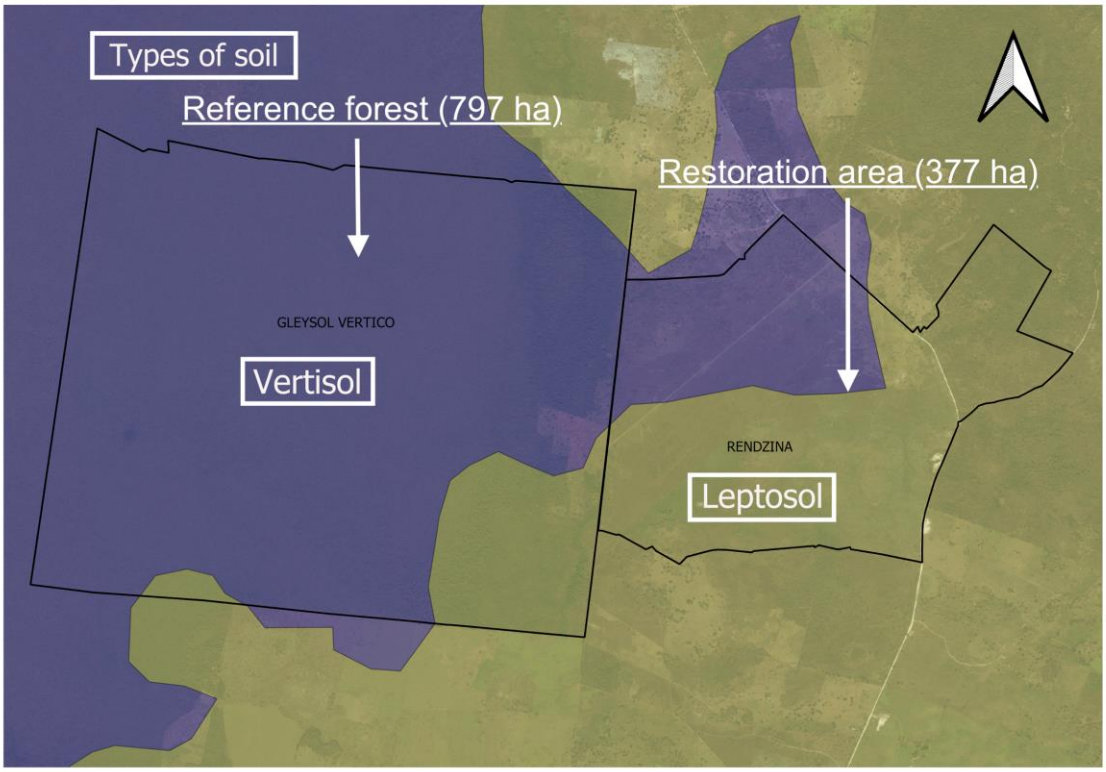

Figure 1. Management units of Americas 7: Restoration area (completely deforested except for a few remnant trees) and reference forest (some degree of disturbance but mostly forested) and soil type (Vertisol = Blue; Leptosol = Green). The Vertisols in this area typically host a flooded forest vegetation type, and the Leptosols are at a slightly higher elevation and do not flood seasonally.

Management units (Figure 1):

- *Restoration area (377 ha):* We will be actively planting the restoration area with two tree species mixes, one for each soil type (Figure 2), which will be finalized in June depending on availability of plants from our partner nursery (*see* Table 1 for available species). The two soil types and current conditions are as follows:
  - **Vertisols** (~200 hectares): 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** (~177 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 will lead to higher seedling establishment and growth rates. We will also clear all vegetation in some small 0.25 ha plots to assess how much clearing all the existing tajonal affects growth rates, and if clearing has a negative impact on seedling growth rates as assumed.

- *Reference forest (797 ha):* This area is primarily flooded forest and will serve as a target reference forest for the Vertisol restoration area. We have initial floristic surveys for this area, and noted some selective harvesting (Figure 3), and we will work on determining the extent of the disturbance. We will define a reference forest for the Leptosol restoration area soon, but we have already made floristic lists (available on request; leland.werden@plant-for-the-planet.org) of secondary forests on our reserves that are on this soil type to help guide our species selection.

Figure 2. *Left panel:* Seasonally flooded Vertisol area. This area is actively grazed by cattle which will be removed by early June. *Right panel:* Leptosol area of Americas 7. Note the presence of scrubby vegetation (tajonal; *Viguiera dentata*) which can become dominant in disturbed pastures.

<u>Immediate restoration goals in the "Restoration area":</u>
We have two main restoration goals to start, focusing on re-establishing vegetation structure and reassembling the plant community at this site. 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.

<u>Site-preparation, long-term maintenance, and minimizing the impact on natural regeneration:</u>
We will clear grasses and scrub vegetation from the area to increase establishment and growth rates of planted tree seedlings. However, we have noted that certain tree species that naturally occur in these areas are naturally regenerating in the Vertisols (*e.g.*, *Caesalpinia vesicaria*, *Haematoxylum campechianum*). Therefore, we are training our field crews to avoid cutting these tree species to not hinder the natural regeneration that is already occurring. All clearing will be conducted by hand with machetes. We will not be using heavy machinery (*i.e.*, tractors) in

Vertisols as this approach compacts the soil. After trees are planted the vegetation around them will be cleared for at least two years to release planted seedlings from competition.

Figure 3. Americas 7 "Reference forest" - flooded forest that will serve as a reference forest for the Vertisol soils. *Left panel:* Plant-for-the-Planet Seed Program coordinator Marcos Escobar conducting initial survey of the area. *Right panel:* Evidence of selective harvests by the previous landowner in the area.

<u>Restoration approach and planting densities</u>:

- *Planting dates 2021:* Planting will begin at the onset of consistent rains (~July) and we will be working with a team of >50 restoration technicians + field crew leaders, our GIS database manager, and our ecologist team to set up a grid across the site so that plantings are implemented systematically. 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 ~2.1 million trees across the 377-hectare restoration area in Americas 7, plus an additional ~100,000 seedlings for an additional density manipulation experiment (*see* <u>Experimental work</u> below).
    - We will use an approach 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 2 or 4 seedlings in clusters every 1-3 m. Seedlings in each cluster will all be the same species so that seedling survival and growth can easily be monitored. Planting the same species in each cluster will also decrease logistic challenges in the field.
    - 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.
        - **Vertisols:** We anticipate low survival rates of planted seedlings in Vertisols, which has been observed by us and others (~20-30%; Dekers et al., 2001; Werden et al., 2018, 2020), due to the shrink swell cycles observed in this type of soil. As such we will plant four seedlings per cluster in the Vertisols, assuming that one out of four seedlings will survive. Others have noted the importance of planting seedlings at high densities in flooded forest restoration as well (Vázquez-Benavides et al. 2020)

        - **Leptosols:** We anticipate higher survival rates of planted seedlings in this soil type (~50%) so we will plant two seedlings per cluster assuming one will survive.
- *Planting densities:* We will plant at two densities in each soil type, either spacing planting rows every 3 m (forestry standard) or every 2 m. Evaluating the outcomes of these two planting densities will help us to decide on the ideal density for future active restorations. For the two soil types we will split up the planting areas into ~10 hectare areas randomly distributed across the restoration areas and plant trees at low and high densities:
    - **Vertisols**: *low density* - 3×3 m spacing with 4 seedlings per cluster = 4,356 seedlings/ha (100 ha · 4,356 seedlings/ha = 435,600 trees total) // *high density* - 2×2 m spacing with 4 seedlings per cluster = 10,000 seedlings/ha (100 ha · 10,000 seedlings/ha = 1 million trees total).
    - **Leptosols**: *low density* - 3×3 m spacing with 2 seedlings per cluster = 2,312 seedlings/ha (89 ha · 2,312 seedlings/ha = 205,768 trees total) // *high density* - 2×2 m spacing with 2 seedlings per cluster = 5,000 seedlings/ha (88 ha · 5,000 seedlings/ha = 440,000 trees total).
- *Species richness per hectare:* At least 10 flood tolerant species (Table 1), out of a pool of 13 will be planted into the Vertisols per hectare. There are also some additional candidate species that also persist on this soil type. In the Leptosols we have a potential species pool of 22 species, and we will aim to plant at least 15 species per hectare. Across the planting site we will experiment with different species mixes that will be finalized in the coming months after the nursey delivery schedule is finalized. Having different species mixes planted in different areas across the site will ensure that plantings result in heterogeneous communities of trees planted across the site, rather than simply having the same species mix planted everywhere. These species mixes will be developed with specific ecological concepts in mind that will improve overall outcomes of restoration efforts (e.g., augmentation of growth rates when nitrogen-fixing tree species are planted alongside non-fixers).

Experimental work: In addition to the large-scale plantings we will also be establishing two experiments at the site this year 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 will be dispersed randomly across each soil type. We are currently developing a monitoring protocol for this work.
- *Assessing effectiveness of the Miyawaki restoration method:* The Miyawaki method has been effective at rapidly re-establishing forest canopy cover in many different ecosystems (Schirone et al. 2011). The main tenants of this method are that trees are planted at very high densities (~20,000-40,000 seedlings per hectare), trees are regularly maintained, and that organic mulch is placed around the base of planted seedlings. We will apply this method in 12 0.25-ha plots in each soil type (n = 12 plots per soil type = 24 0.25-ha plots total) to assess the effectiveness of this approach.

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Monitoring outcomes:

Across our restoration area and our reference forests, we will be establishing monitoring plots that will use simple indicators to track vegetation recovery (*e.g.*, canopy cover development, natural recruitment of seedlings, decrease of tajonal and grass cover). We will also be quantifying the growth and survival of planted seedlings. Additionally, we are also currently building a digital elevation model for our site so we can use drone imagery to track recovery of vegetation across our restoration areas. These data collection efforts will give us the ability to monitor the outcomes of the active restoration efforts in Americas 7 and future sites. We are currently building our monitoring program and we look forward to presenting it to the public in the near future.

Future initiatives

After discussions with our Restoration Expert Supervision Board we identified on a few additional aspects that we will focus in the coming months and years to improve our communications efforts and connections with local communities.

- **Improving science communication:** We will work on improving our explanations of how forest succession and forest-self thinning occur both on our website and in general communications to the public. These efforts will help the general public to understand that not every planted tree will survive, which is a very natural aspect of forest recovery. We will also focus our future communications efforts on emphasizing that the end goal of our work is a functioning forest that will be present for future generations, moving away from a focus on individual trees planted.
- **Improving connections with local communities:** We are currently working to connect with local communities by building relationships with surrounding Natural Protected Areas as well as local researchers. Additionally, we will make an effort to involve surrounding communities (e.g., ejidos) directly in the restoration planning process for 2022. We will also add a social scientist to our team sometime in 2021 to not only help us communicate lessons learned from our restoration efforts to key stakeholders, but also to better connect with surrounding communities.

Q2 2021 Restoration Plan Approval – Restoration Supervision Expert Board

I have reviewed the updated 2021 restoration plan and agree that the Plant-for-the-Planet restoration team sufficiently considered and integrated all suggestions made during the Q2 2021 Board meeting on May 28th, 2021.

Dr. Pilar Angélica Gómez-Ruiz	June 28th, 2021 Date
Zahawi DN: cn=Rakan Zahawi, o, ou, email=rakan.zahawi@fcdarwin.org.ec, c=EC Dr. Rakan A. (Zak) Zahawi	June 29, 2021 Date
Dr. Joachim Hamberger	June 30, 2021 Date
Joachim Elsässer	June 29, 2021 Date

Table 1. List of 33 species available for the 2021 Plant-for-the-Planet restoration season. Species that are known to tolerate seasonal flooding are indicated with **bold text**. Species collected by the Plant-for-the-Planet seed collection program are indicated with "*".

Family	Genus/specific epithet	common name
Fabaceae	***Acacia gaumeri****	Kaatsim negro
Annonaceae	*Annona reticulata**	Anonillo
Moraceae	*Brosimum alicastrum*	Ramón
Burseraceae	***Bursera simaruba***	chakaj
Leguminosae	*Caesalpinia mollis*	Chacté Viga
Fabaceae	***Caesalpinia vesicaria****	Fierrillo
Fabaceae	***Caesalpinia yucatanensis****	Taa k'in che'
Meliaceae	*Cedrela odorata*	Cedro
Malvaceae	*Ceiba pentandra*	Ceiba
Rhamnaceae	*Colubrina arborescens**	Tatuán
Boraginaceae	***Cordia dodecandra***	Ciricote
Bignoniaceae	***Crescentia cujete***	Luuch/jicara
Fabaceae	*Enterolobium cyclocarpum*	Pich
Fabaceae	***Gliricidia sepium***	Madre de cacao
Malvaceae	***Guazuma ulmifolia***	Pixoy
Fabaceae	***Haematoxylum campechianum***	Palo de tinte
Bignoniaceae	*Handroanthus chrysanthus*	Guayacan amarillo
Fabaceae	***Havardia albicans****	Chukum
Malvaceae	*Heliocarpus mexicanus**	Corcho
Fabaceae	*Leucaena leucocephala*	Waxim
Fabaceae	*Lonchocarpus longistylus*	Balche
Fabaceae	***Lonchocarpus rugosus****	K'anasín
Malvaceae	*Luehea speciosa**	K'an kaat
Fabaceae	*Lysiloma latisiliquum*	Tzalam
Sapotaceae	***Manilkara zapota***	Chicozapote
Fabaceae	***Mimosa bahamensis****	Káatsim blanco
Fabaceae	*Piscidia piscipula*	Jabín
Fabaceae	*Platymiscium yucatanum**	Granadillo
Fabaceae	*Senna racemosa**	K'an lool
Simaroubaceae	*Simarouba glauca*	Passak
Meliaceae	*Swietenia macrophylla*	Caoba
Bignoniaceae	*Tabebuia rosea*	Maculis
Meliaceae	*Trichilia hirta**	Cabo de hacha

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