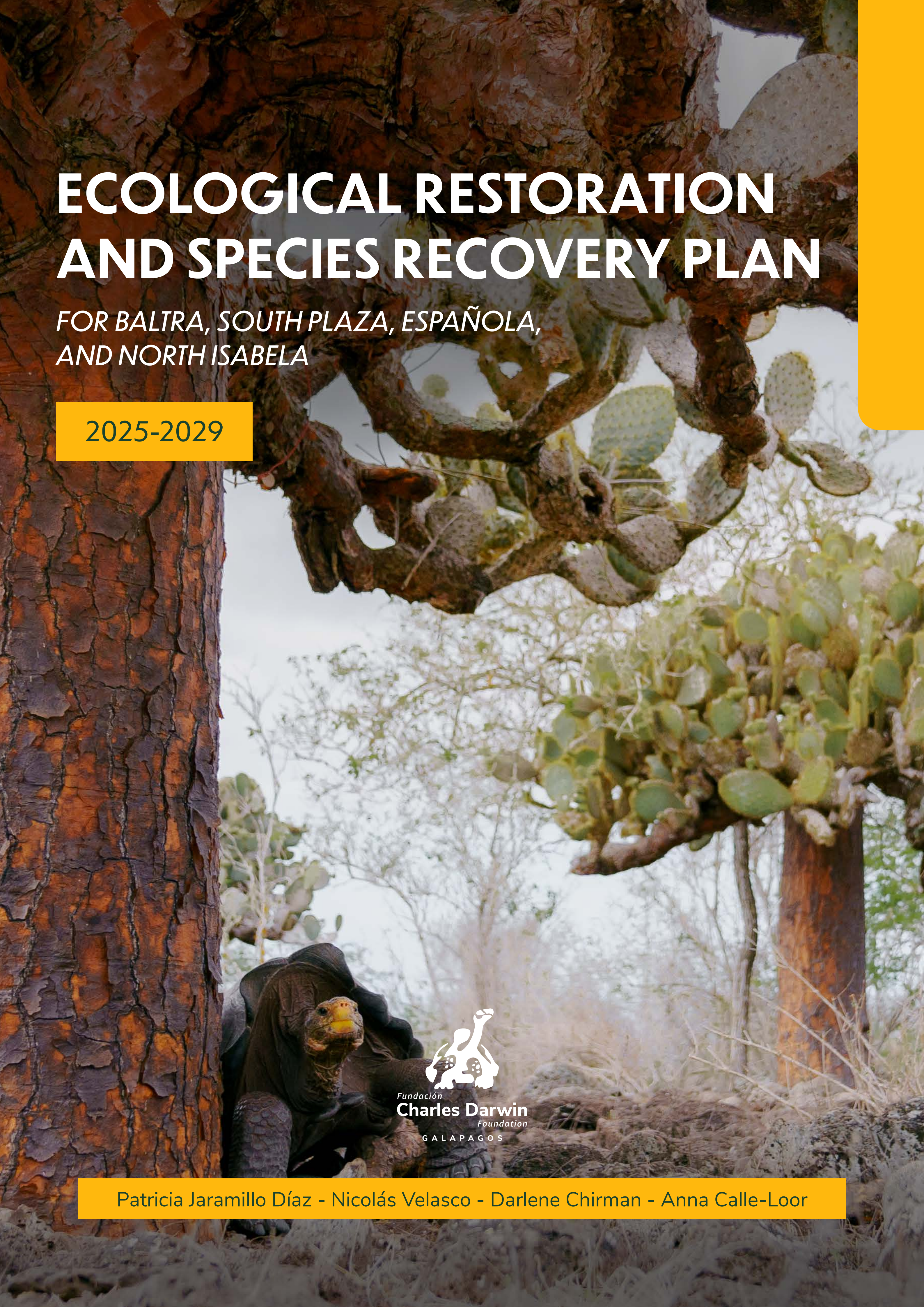

ECOLOGICAL RESTORATION AND SPECIES RECOVERY PLAN

FOR BALTRA, SOUTH PLAZA, ESPAÑOLA, AND NORTH ISABELA

2025-2029

Fundación Charles Darwin Foundation GALAPAGOS

Patricia Jaramillo Díaz - Nicolás Velasco - Darlene Chirman - Anna Calle-Loor

2024
Ecological Restoration And Species Recovery Plan for Baltra, South Plaza, Española, and North Isabela 2025-2029

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"The mission of the Charles Darwin Foundation and its Research Station is to tackle the greatest threats and challenges to Galapagos through scientific research and conservation action, in order to safeguard one of the world's most important natural treasures".

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INTRODUCTION

The Galapagos Verde 2050 Program (GV2050) of the Charles Darwin Foundation (CDF) is publishing this plant Ecological Restoration and Species Recovery Plan, hereafter referred to as the Restoration Plan. This document will offer guidance to practitioners and institutions involved in restoration efforts across the Galapagos Islands.

This plan aims to advance restoration and species recovery efforts in Baltra, South Plaza, Española, and North Isabela over the next five years and was developed in collaboration with the Galapagos National Park Directorate (GNPD), CDF's main collaborator.

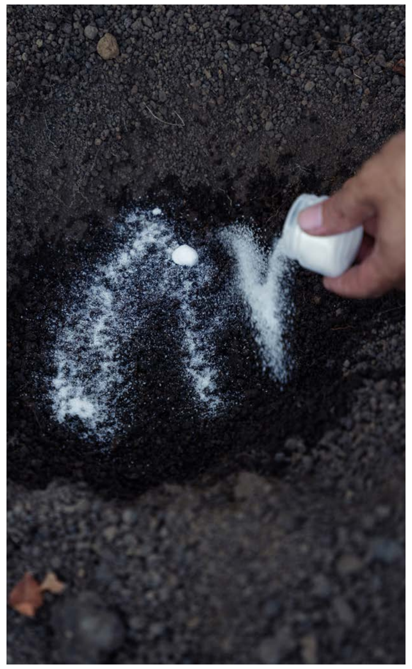
Ecological Restoration And
Species Recovery Plan

NEED FOR A RESTORATION PLAN

While the Galapagos islands are often considered well-conserved compared to other insular ecosystems, some areas have been significantly impacted by human activities. Before the establishment of the Galapagos National Park in 1959, which protected 97% of the land surface of the islands (Black, 1973), degradation had already occurred. Introduced goats, present on the islands before Charles Darwin's famous visit in 1835, had devastated native vegetation (Donlan *et al.*, 2011). Three penal colonies operating from the 1830s to the 1950s, further exacerbated habitat degradation (Astudillo & Jamieson, 2023) and the construction of a United States Air Base during World War II further contributed to this trend (Cayot, 1991). These are only some of the factors that have led to habitat degradation of the islands, highlighting the need for ecological restoration to recover the unique plant biodiversity of the Galapagos and improve human well-being.

Ecological restoration is a long-term process that can result in a significant use of resources. As such, a well-designed Restoration Plan with clearly defined objectives ensures that limited resources are allocated efficiently, thereby maximizing the project's impact. The Restoration Plan also serves as a communication tool, aligning stakeholders and fostering collaboration. Appropriate design, planning, implementation, stakeholder involvement, and monitoring for adaptive management have been shown to improved restoration outcomes (Gann *et al.*, 2019).

At the global level, the critical need to halt, prevent and reverse ecosystem degradation led the UN to declare 2021-2030 the Decade on Ecosystem Restoration (United Nations Environment Programme, 2021). This and other initiatives aim to mobilize international efforts and resources to scale up ecosystem restoration activities, address the root causes of degradation, and promote sustainable land management practices.



BACKGROUND

The Galapagos Verde 2050 is a restoration initiative that has been in place during the last ten years and is divided into three phases. During the first phase of the program (2014-2017), among other activities, an Action Plan for the Ecological Restoration of Baltra and South Plaza was developed (Jaramillo *et al.*, 2017). Now, in the second phase of the program (2017-2027), we are publishing this five-year plan which includes an update of the first one and two additional locations: Española and North Isabela. The third phase of the program (2027-2050) includes the addition of Santiago Island, for which an additional plan will need to be developed. In 2022, the GV2050 was restructured as a program comprised of seven research projects.

The Restoration Plan was developed following the principles that Guide the United Nations Decade for Ecosystem Restoration (FAO *et al.*, 2021), the Standards of Practice to Guide Ecosystem Restoration (FAO *et al.*, 2023), and the Society for Ecological Restoration's International Principles and Standards for the Practice of Ecological Restoration (Gann *et al.*, 2019).

Additionally, the document is in alignment with the Galapagos Protected Areas Management Plan (DPNG, 2014), which emphasizes that restoration efforts in Galapagos should not only focus on individual species but also aim to restore ecological integrity and enhance ecosystem resilience.

The Restoration Plan adheres to the following management guidelines outlined in the Galapagos Protected Areas Management Plan:

- Restoration actions should never be a substitute for a preventive management approach.
- Restoration programs should not be stand-alone endeavors but rather integral components of a comprehensive ecosystem management program.
- Ecological restoration[1] projects should be prioritized over rehabilitation[2] projects, unless the former is not feasible.
- Projects that modify ecosystems for recreational purposes should always be avoided.
- Every restoration project must meet a sequential and hierarchical set of requirements established by the GNPD, including scientific, territorial, technical, economic, legal, social, and political feasibility.
- The capacity of Galapagos ecosystems to auto regenerate and their resilience are acknowledged as guiding principles for restoration projects.

By adhering to these guidelines, this estoration Plan ensures a systematic and holistic approach to restoration efforts in the Galapagos Archipelago.

[1] Ecological restoration: "The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Gann et al., 2019). [2] Rehabilitation: "Management actions that aim to reinstate a level of ecosystem functioning on degraded sites, with the goal of renewed and ongoing provision of ecosystem services rather than the biodiversity and integrity of a designated native reference ecosystem" (Gann et al., 2019).

WHAT IS NEW IN THIS VERSION OF THE RESTORATION PLAN?

The main change with respect to the 2017 Action Plan is the inclusion of two study locations: Española and North Isabela, thus expanding the geographic coverage. Additionally, the restoration objectives and actions for Baltra and South Plaza have been updated in accordance with the results of research conducted since the publication of the former Plan (see references in the corresponding sections). A significant enhancement for these islands has been the inclusion of reference ecosystems in accordance with Principle 3 of the Standards for Ecological Restoration (Gann *et al.*, 2019).

ISLANDS COVERED IN THE PLAN

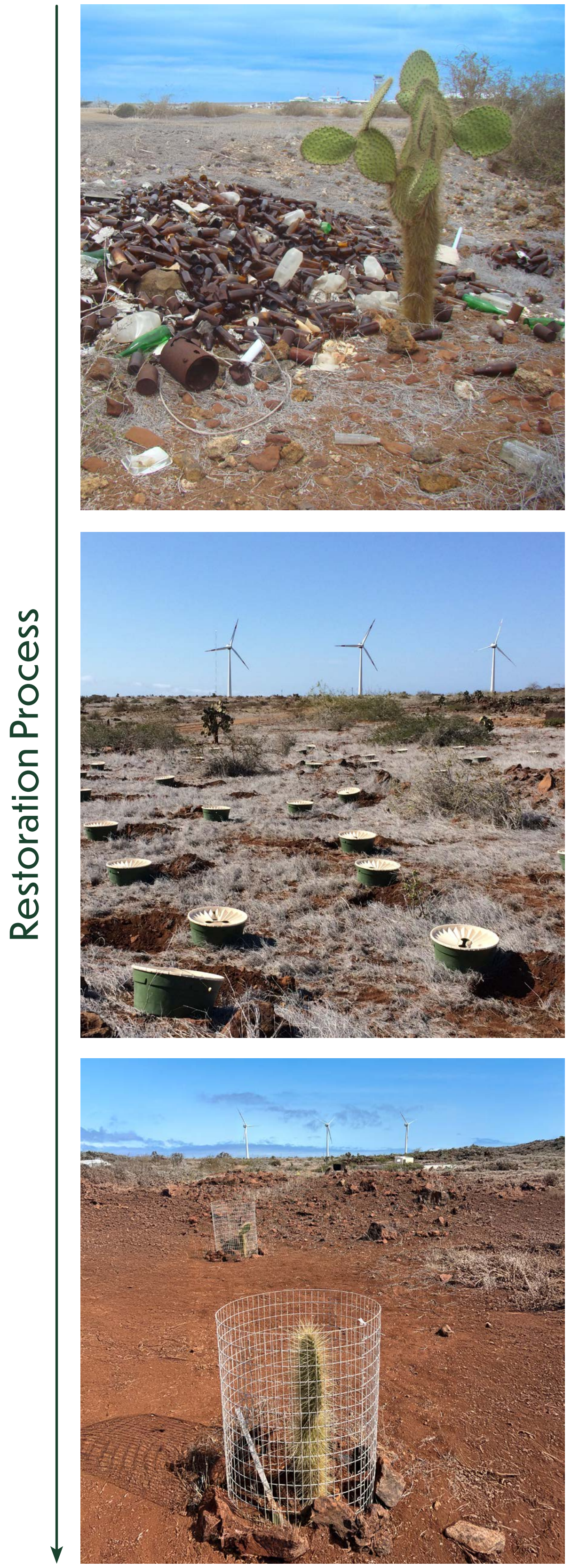
The Restoration Plan outlines key actions to be undertaken from 2025 to 2029 to achieve long-term ecological restoration objectives in Baltra, South Plaza, and Española, while focusing on species recovery in North Isabela. Despite not being an island, North Isabela is ecologically separated from South Isabela by the Perry Isthmus. The first three islands and North Isabela are completely protected within the Galapagos National Park and are considered uninhabited. They share common characteristics, including high biodiversity, areas that have suffered historic degradation that has eased in the last decades, rendering them ideal candidates for ecosystem restoration efforts.

The plan focuses on the restoration of plant communities, recognizing their fundamental role in maintaining and supporting terrestrial ecosystems health through ecological functions. It is important to note that while our emphasis is on vegetation restoration, we recognize the significance of developing complementary plans to restore other components of these ecosystems, such as fauna.

Baltra and **South Plaza** Islands are located to the north and east of Santa Cruz Island, respectively **(Fig. 1)**. **Española** is the southernmost island in the archipelago, located to the southeast of Santa Cruz Island. Finally, **Isabela**, the largest island, is located due west of Santa Cruz Island.

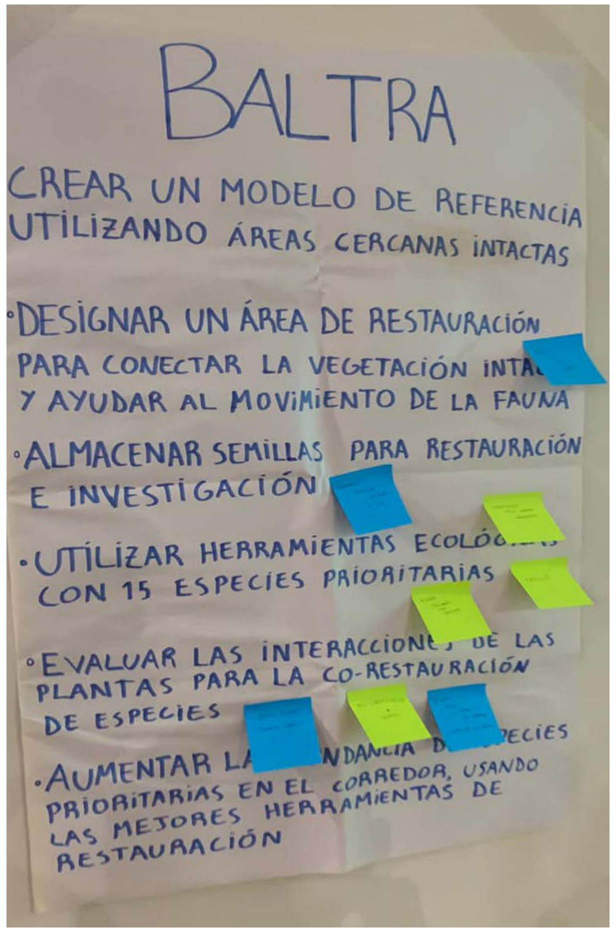
RESTORATION PLAN OBJECTIVE AND EXPECTED IMPACTS

Objective: Contribute to the development of an efficient method of ecological restoration for degraded terrestrial ecosystems in Galapagos and the recovery of endangered plant species.



PARTICIPATION OF LOCAL INSTITUTIONS

Ecological Restoration And
Species Recovery Plan



GNPD PARTICIPATORY WORKSHOP

The development of this Restoration Plan required three years of work, during which thorough planning was carried out, involving multiple edits, revisions, and updates. As a planning document, the active participation of local stakeholders was included, contributing diverse perspectives to ensure that the objectives were practical and the actions feasible under field conditions. Additionally, the final review was conducted during a workshop with the staff of the Department of Conservation and Restoration of Insular Ecosystems of the Galapagos National Park Directorade. This workshop was particularly important because the park rangers possess the practical knowledge necessary to transform ideas into realistic objectives.

During the workshop, the Restoration Plan, including its innovations, objectives, and proposed activities, was presented. Park rangers provided feedback in two ways: first, they annotated their thoughts on the plan's objectives and added recommendations to a document; second, they provided annotations on island-specific activities using post-it notes, which they discussed directly with the GV2050 staff.

Members of the GNPD, Galapagos Conservancy, and the Galapagos Verde 2050 collaborating on a field trip. These are some of the several institutions that provided feedback for this restoration plan.

GENERAL RESTORATION STRATEGIES

The following is a description of the different restoration strategies proposed to execute the Restoration Plan for each island.

ASSISTED REGENERATION

Assisted regeneration is the process of actively removing the causes of degradation or the reincorporation of missing biotic components. This can include control of invasive species, reintroduction[3] of species, creation of habitat, among other interventions. The process is also called "active restoration" (Gann *et al.*, 2019).

[3]Reintroduction: Refers to the intentional release of a species into an area where it was present in the past but is currently locally extinct.

Ecological restoration tools

In this Restoration Plan, we will use the term "ecological restoration tools" to refer to water-saving technologies (WST) and other treatments that have the potential to accelerate the ecosystem recovery process. The Galapagos Islands are primarily arid, with low elevation areas receiving scarce precipitation while the highlands have higher rainfall. Historical rainfall data from two meteorological stations on Santa Cruz Island reveal a median annual rainfall of 277 mm at the Charles Darwin Research Station (CDRS) in the lowlands from 1965-2009, and 813 mm at Bellavista in the highlands from 1987-2009 (Trueman & D'Ozouville, 2010). Periods of prolonged seasonal drought create climatic challenges for restoring these islands. Additionally, a lack of fresh water supplies creates logistical challenges that need to be addressed. To tackle these water challenges, the GV2050 Program evaluated three ecological restoration tools during Phase I: the Groasis Waterboxx ®, the Cocoon, and Hydrogel **(p. 14-15)**. All have shown promising results, increasing the 2-year survival rate of at least seven native and endemic Galapagos species (Negoita *et al.*, 2021)**.** In Phase II, the program is adding two new technologies: Groasis Growboxx ® and biochar **(p. 14-15)**.

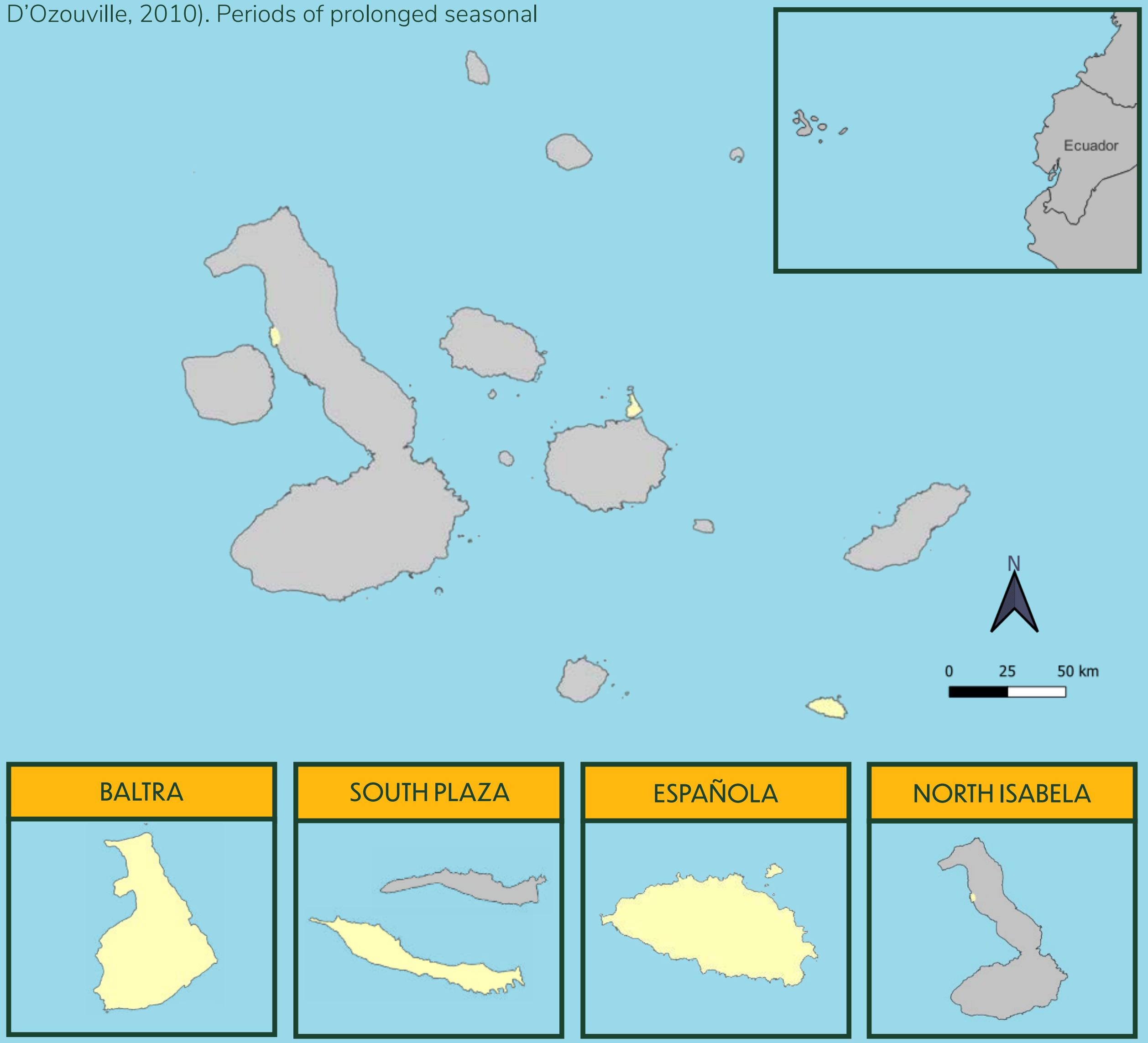


Fig. 1: Map of the four islands covered by this Restoration Plan. The yellow indicates the area targeted for restoration activities.

Ecological Restoration And Species Recovery Plan

GROASIS WATERBOXX ®

Description: A polypropylene container with water, which refills from rain and dew. Seedlings in the center receive water through a nylon wick at the bottom.

Features:
- Increases soil-water availability.
- Protects the base of the plant from herbivory.
- Protects from sunlight overexposure.
- Reusable but must be removed from each plant after several years.

Watering protocol: Seedlings planted with 5L of water in the soil. Then, the Waterboxx plus 15L of water is placed around the seedling. The Waterboxx also collects additional water from rainfall and dew.

COCOON

Description: A biodegradable container that only receives water at the time of planting. Seedlings are placed through the center of the container and receive water through two nylon wicks.

Features:
- Increases soil-water availability.
- 99% biodegradable.

Watering protocol: Cocoon seedlings are planted with 5L of water in the soil. Then, the container is placed inside the planting hole with the plant in the central hole, filled with 15L of water, the lid is closed, and then covered with soil.

GROASIS GROWBOXX ®

Description: A square box with a hole in the middle, made from recycled paper pulp that can be used for planting once. It is placed around a young tree but has four small depressions in the lid where soil and seeds can be placed to germinate them hydroponically in the water stored in the Growboxx.

Features:
- Increases soil-water availability
- 99% biodegradable.

Watering protocol: Growboxx seedlings are planted with 10L of water in the soil. Then, the container is filled with a mix of 10L of water and soil.

CONTROL

Description: Seedlings are planted in the ground without the use of any technologies.

Features:
- Does not require removing technologies.
- Requires smaller holes.
- Planting is done more quickly.

Watering protocol: Plants are planted with approximately 20L of water applied to the base of the seedling and no further water is applied after planting.

HYDROGEL

Description: Hydrogel is a biodegradable polymer powder that can increase the water-holding capacity of the soil by up to 400%, and thus increasing water availability to plants.

Features:
- Increases soil-water availability.
- 100% biodegradable.

Watering protocol: The Hydrogel powder is initially hydrated in a ratio of 12.5 g per liter of water and 1L of this solution is mixed with the soil at the time of planting.

BIOCHAR

Description: Biochar is a product of pyrolysis, where agricultural or forest biomass is burned under reduced oxygen conditions.

Features:
- Increases soil-water availability.
- Long-term storage of soil carbon.
- Improves nutrient retention.
- Improves microbial activity.

Watering protocol: Seedlings are planted with 10 L of water before and after amending the soil with 13 g of Biochar.

Restoration through applied nucleation

Planting trees in nuclei or patches has been proposed as a low-cost active restoration strategy that promotes restoration through seed dispersal and simulates natural successional processes (Zahawi *et al.*, 2013). Gibbs (pers. comm. 2016) suggested creating a series of vegetation patches in Baltra to increase connectivity of less disturbed areas through wildlife movement. Land iguanas, giant tortoises, and several bird species are known to feed on the fruits of native and endemic plants, which facilitates seed dispersal through their feces (Heleno *et al.*, 2011; Racine & Downhower, 1974). Moreover, to maximize the large-scale benefits of restoration initiatives, applied nucleation can be used to link restoration sites and enhance connectivity between them (Gann *et al.*, 2019).

Introduced species control

Control of introduced species should be considered prior any restoration project (Glen *et al.*, 2013), in order to reduce threats and increase projects success. In Galapagos, given its historical occupation and increased connectivity among the islands and with the mainland through man-made mobilization, multiple species have been introduced (Toral-Granda *et al.*, 2017). Since the GNP creation several actions have been performed to eradicate invasive mammals, such as cats, rodents and goats (Balseca, 2002; Phillips *et al.*, 2005). Particularly for plants, the CDF leads a project targeting the control of invasive species and the restoration of *Scalesia pedunculata* in the humid zone of the four inhabited islands (Rentería, 2011; Walentowitz *et al.*, 2021). Therefore, control and eradication of large introduced species as well as smaller ones such as pest and weeds must be considered throughout the restoration process (Tu *et al.*, 2001; Jaramillo *et al.*, 2024).

NATURAL REGENERATION OPPORTUNITIES

Natural regeneration is the process of spontaneous recolonization in a degraded area, and is usually referred as “passive restoration” (Gann *et al.*, 2019). The link between recruitment and succession, makes this process the most cost-effective approach to ecosystem restoration (Shono *et al.*, 2007). The opportunities to speed-up or reinforce natural regeneration require fewer inputs and are usually less expensive than traditional active restoration practices (Shono *et al.*, 2007; Vieira & Scariot, 2006). While active restoration is needed in some areas of Galapagos, complementing it with natural regeneration opportunities could lead to faster and more cost-effective ecosystem recovery.

Furthermore, one of the major constraints for restoring degraded ecosystems in Galapagos is the high labor and funding required. The estimated restoration cost per hectare on Baltra is approximately $75,000 considering the whole plant community, while the cost of restoring a hectare of South Plaza’s, specifically for *Opuntia echios* var. *echios* population is $21,250 (Negoita *et al.*, 2021). These estimates are based on the implementation of the most cost-effective water-saving technologies for each island and species. In South Plaza, the cost of restoring *Opuntia* is based on a target population of 2000 individuals (Sulloway & Noonan, 2015). Lowering these costs by improving natural regeneration has the potential to facilitate the scaling up of restoration activities in Galapagos.

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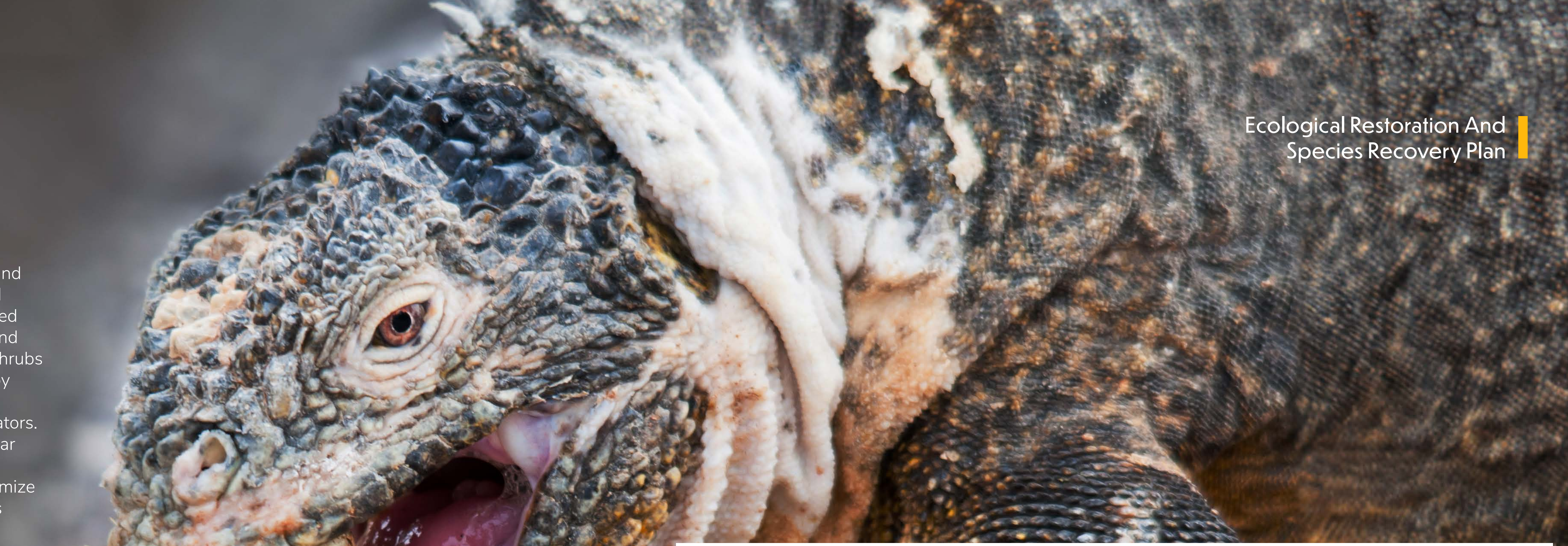


Harnessing Seed Dispersal

This strategy involves managing the area around native vegetation stands, which has high seed deposition, to increase natural recruitment. Seed dispersal is a critical process for maintaining and expanding native vegetation stands. Woody shrubs and trees often release seeds near their canopy and attract seed dispersers with food sources, perching structures, and protection from predators. To enhance recruitment of native seedlings near established shrubs and trees, donut-shaped clearings can be employed. This can help minimize competition between native plants and weeds that emerge from these seeds. However, this approach must be carefully evaluated at small scale to assess its impact on native vegetation before implementation on larger areas. Some of the complexities of control measures on target and non-target plant species are explained in Gardener et *al.*, (2010); Gerzabek et *al.*, (2019); Khatun (2018). Refer to Appendix A for a list of weed control strategies that can be employed around native woody plants or before planting events.

Facilitation by nurse plants

This strategy consists of identifying nurse plants and protecting seedlings of associated species underneath them. Nurse plants can increase plant growth and survival by providing protection against herbivores, nutrients, seed traps, soil moisture, shade and wind protection. This process, known as "facilitation", is particularly important in harsh environments where growing close to other plants ameliorates microenvironmental conditions (Padilla & Pugnaire, 2006).

EL NIÑO: RISKS AND REWARDS FOR GALAPAGOS PLANT RESTORATION

The El Niño Southern Oscillation (ENSO) cycle introduces atypical climatic conditions that can be strategically harnessed to expedite restoration initiatives. ENSO manifests in three primary phases: El Niño, La Niña, and a neutral phase. This cycle occurs on average every two to seven years. The El Niño phase is characterized by higher rainfall that results in increased establishment and growth of native species (Gibbs, 2013). Nevertheless, the effect of El Niño on vegetation is variable; some species experience increased mortality in addition to regeneration. For example, Tye & Aldáz (1999) describe increased mortality of mature *Opuntia* and *Scalesia crockeri* followed by abundant regeneration around deceased adults after the El Niño event of 1997. Grant & Grant (1989) observed declines in young *Opuntia* in the El Niño events of 1982-3 and 1987, on Española, Genovesa, and Daphne islands. The increase in mortality is caused by *Opuntia* taking up so much water that some collapse during windy conditions (Gibbs, 2013). Another factor that could be involved is root rot from saturated soils.

Protecting recruits that grow naturally during El Niño events can increase the number that live to maturity, replacing the dead adults and increasing *Opuntia* populations. Where seedlings and/or cladode-derived plants are plentiful around a dead *Opuntia*, we recommend conducting trials with the translocation[4] of seedlings, fruit, fresh and rooted cladodes. The seedlings/cladodes should be translocated far from the collapsed adults to areas with lower herbivory pressure and with a higher elevation, which facilitates the drainage of rainwater. Translocated individuals can be planted using physical protection strategies and ecological restoration tools. Additionally, as most species will benefit from a higher water supply in humid years, assisted regeneration activities can benefit by repatriating[5] plants during El Niño years. A last strategy to be considered during El Niño events is weed control. Grant & Grant (1989) described low recruitment and high seedling mortality after the rampant growth of vines and other plants caused by the 1982-83 El Niño event. This report suggests that, because of all the plant growth, increasing weed control efforts during El Niño events is important for the survival of young recruits. Timing seedling planting to coincide with El Niño can boost survival rates due to increased rainfall (Gibbs, 2013, 2016).

[4]Translocation: In this text, 'translocation' refers to the movement of individuals from one place to another within the same natural habitat of the species.
[5]Repatriation: Refers to the process of returning individuals of a species to their native or original habitat after having been removed, whether for conservation, research, or due to human impacts.

PHYSICAL PROTECTION STRATEGIES

Protecting plants in their early growth stages is crucial, as they are more vulnerable to damage. Seedlings are at risk of being crushed, and some species, such as *Opuntia cacti*, are particularly susceptible to herbivore damage. *Opuntia* is a vital food source for land iguanas and giant tortoises which play a significant role in the seed dispersal of the species (Tapia *et al.*, 2021; Tapia & Gibbs, 2022). In ecosystems where *Opuntia* populations are abundant, herbivores have enough food to eat from fruits, fallen pads, and seedlings. However, in degraded ecosystems where *Opuntia* is scarce, herbivores consume more seedlings, which hampers regeneration. Therefore, to restore these ecosystems, it is essential to safeguard *Opuntia* seedlings until they are large enough to withstand herbivory. As *Opuntia* plants mature, their spines become more robust, rendering them less susceptible to predation.

Rock circles

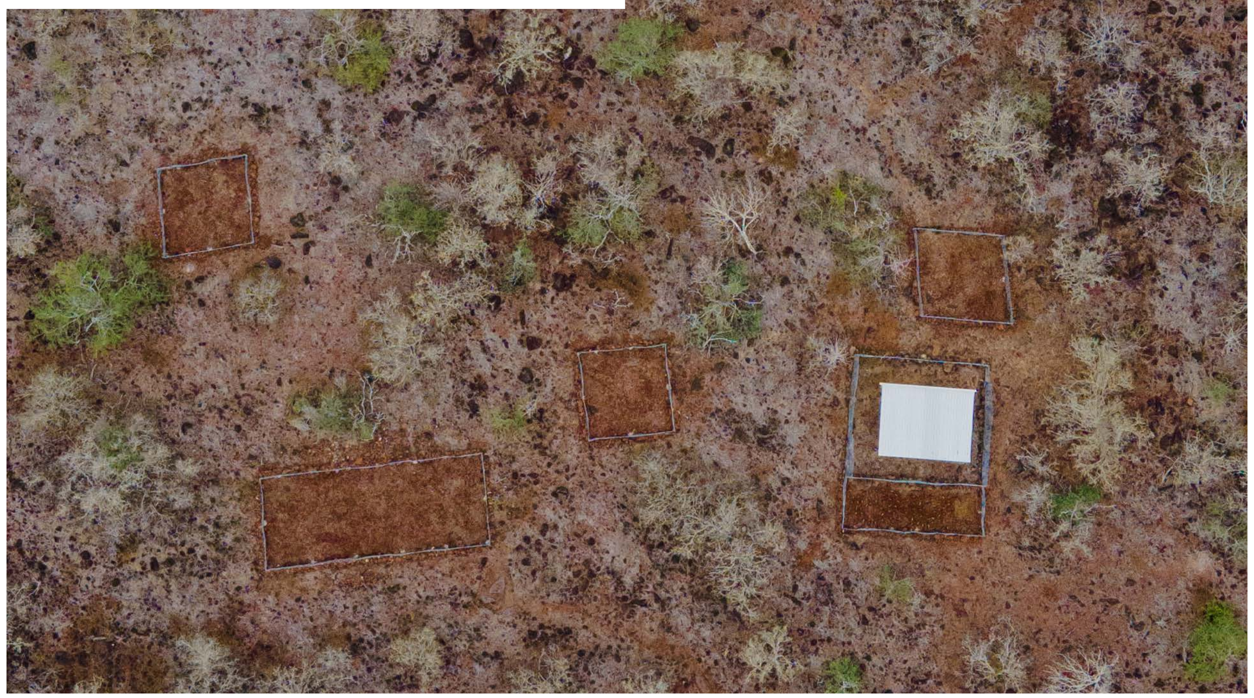
Placing rock circles around seedlings provides shade, some protection from herbivory, and prevents plants from being accidentally crushed. This strategy provides the least protection against herbivory but has several practical benefits. Rocks are readily available and easy to place to form circles. The method also facilitates the identification of target plants amid other vegetation and protects them from being damaged by animals or humans. There are Galapagos plants that appear to prefer to grow in rocky terrain. A couple of example include, *Galvezia leucantha* which grows in lava crevices in North Isabela, and *Bursera graveolens* which has been observed to prefer rocky terrain on North Seymour and possibly other locations (Calle-Loor *et al.*, 2022).

Metal fencing

Metal fencing is widely employed in the Galapagos to protect *Opuntia* seedlings from iguana and tortoise herbivory until plants are tall enough to tolerate predation. Fences placed around individual plants are effective at protecting several individuals spread throughout a large restoration site or when restricting the movement of herbivores through the site is not desired. Cluster fencing is useful when planting groups with a high density of plants, for example, in experimental plots. The cost of cluster fencing is lower than individual fencing since it requires fewer materials and labor per planted individual. On Española Island, cluster fencing has been more effective than individual fencing at preventing tortoise herbivory on *Opuntia cacti*. While giant tortoises crushed some individual fences, a larger fence encompassing approximately 50 cladodes has remained intact for over three years.

Green fences

Another alternative is the planting of spiny native and endemic shrubs as a perimeter fence around plants susceptible to predation from large herbivores, such as *Opuntia*. While metal fences have worked well in preventing herbivory on most islands, they can be an eye-sore for visitors and they need to be removed once a plant reaches a certain size. Further, in some islands such as South Plaza, they deteriorate quickly because of the saline environment. Green fences represent an alternative that reduces herbivory, provides beneficial shade and wind protection. Different species and densities of shrubs are likely to offer different levels of protection. Species that are unpalatable to herbivores have been shown to protect sensitive plant species in other ecosystems (Callaway *et al.*, 2005). These could be species that are present in the habitat of the herbivores but are rarely found in samples of their feces. To determine the efficacy of different shrub species at protecting seedlings, we will first test enclosures composed of a single species perimeter. Those with the best outcome can be used to plant mixed-species enclosures.



SPECIES SELECTION

Choosing the appropriate species for each site is a critical step in ensuring the success of a restoration project. The species selected should be well-suited to the local ecosystem. To guide this selection, several key considerations come into play.

Historical Distribution

Various methods have been used in Galapagos to confirm the historical presence of different plant species, including fossil pollen studies, herbarium records, and historic botanical surveys (Restrepo *et al.*, 2012; Stewart, 1911; van Leeuwen *et al.*, 2008). Interestingly, fossil pollen studies have revealed that some plants thought to be introduced are, in fact, native to the Galapagos (Restrepo *et al.*, 2012; van Leeuwen *et al.*, 2008).

Herbarium records provide historical snapshots of plant specimens, cataloging details such as collection dates, taxonomy, and geographic information. These collections also document shifts in plant species' ranges, invasive species' encroachment, and the status of rare or endangered plants. Consequently, they play a crucial role in ecological restoration by supplying records of the plant species originally present at a site prior to environmental degradation. Notably, the CDS Herbarium represents a significant resource in the Galapagos Islands, housing a collection of over 45,000 specimens, encompassing introduced, native, and endemic plants.

Historical botanic surveys shed light on how ecosystems have evolved over time. Early botanical surveys of the Galapagos, such as those conducted during Charles Darwin's Voyage on the HMS Beagle (1835), the first California Academy of Sciences (CAS) Expedition (1905-1906), and the Allan Hancock Expedition (1933-1934) hold particular significance in this context. They contribute to an understanding of the plant life of the region before significant degradation occurred.

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IUCN Red List Conservation Status

The IUCN Red List plays a vital role in guiding species selection for restoration, as conserving biodiversity and ecosystem integrity are primary objectives of ecological restoration. To achieve these objectives, it is crucial to identify and prioritize endangered species that are at risk of extinction in restoration areas. In the Galapagos, where over half of the endemic plant species are under threat, it is essential to address this challenge. According to the Red Book of the Endemic Plants of Ecuador, 12% are listed as Critically Endangered (CR), 15% are Endangered (EN), and 32% are Vulnerable (VU) (León-Yánez *et al.*, 2011). Recovering endangered species through implementation of appropriate strategies can have a twofold benefit. It can address both the needs of the species itself as well as the needs of the ecosystems that they are a part of. Key aspects of endangered species recovery include monitoring population status, identifying and mitigating primary threats, and evaluating the effectiveness of various recovery strategies. This Restoration Plan focuses on the recovery of five endangered species **(Table 1)** and their core habitats, a strategy aimed at conserving biodiversity, sustaining intricate ecological interactions, and upholding the ecological integrity and resilience of Galapagos ecosystems.

Island	Location	Family	Species
North Isabela	Tortuga Negra Beach	Plantaginaceae	*Galvezia leucantha* subsp. *leucantha*
Española	Punta Manzanillo & 4 islets	Asteraceae	*Lecocarpus lecocarpoides*
Española	Island-wide	Cactaceae	*Opuntia megasperma* var. *orientalis*
South Plaza	Island-wide	Cactaceae	*Opuntia echios* var. *echios*
Baltra	Island-wide	Cactaceae	*Opuntia echios* var. *echios*

Table 1. Table of endangered (EN) plants that are endemic to Galapagos and are addressed in this Restoration Plan. The IUCN status of other endemic plants species on Baltra can be found in Table 2. IUCN status of endemic species sourced from the Red Book of Endemic Plants of Ecuador (León-Yánez *et al.*, 2011).

Ecosystem function

Selecting species for restoration based on ecosystem function is crucial for ensuring the successful recovery and resilience of degraded ecosystems. This approach involves assessing the ecological role of the species present within the ecosystem and prioritizing those that contribute most effectively to restoration goals. This was an important criterion for the selection of Baltra species, which are presented in **Table 2** together with information on their ecosystem role.

Keystone[6] and engineer species are two types of species that should be prioritized for their critical role in maintaining ecosystem integrity and resilience (DPNG, 2014). A noteworthy example for the Galapagos is species from the *Opuntia* genus, which serve as a primary food source for land iguanas and giant tortoises, in addition to providing food, nesting sites, and shelter for native birds. This is why we are working to restore *Opuntia spp.* in Baltra, Española, and South Plaza.

[6]Keystone species: Keystone species are those that have a disproportionately large impact on their community or ecosystem relative to their abundance (Power *et al.*, 1996)

Ecological Restoration And Species Recovery Plan

BALTRA

BALTRA—BACKGROUND

Baltra Island is located to the north of Santa Cruz Island and has an area of approximately 26 km² (Snell *et al.*, 1996). Its low elevation (~60 m) places it entirely within the arid zone. It has a mean temperature of 24 ºC and mean annual rainfall of 97.5 mm (Hamann, 1979). Baltra hosts the main airport in Galapagos, which was modernized in 2013 and listed as a "Galapagos Ecological Airport" (ECOGAL). The aridity, lack of topography, and poor soils make ecosystem restoration on the island both a challenge and a prolonged process (Gibbs, 2013).

Baltra Island has been devastated by human impacts and introduced species. In particular, goats, rodents, and cats have caused great changes to the ecosystem and to the populations of both endemic emblematic species like land iguanas and *Opuntia cacti*, and other less visible but equally important species such as lizards, birds and insects (Balseca, 2002; Jaramillo, 2009). The vegetation of the island has undergone notable transformation, such as the loss in the structure of the native shrub vegetation and the introduction of the now abundant *Cleome viscosa* forb (Velasco *et al.*, 2024). *Cleome viscosa* has not only established on Baltra and North Seymour but has also spread to several other islands within the archipelago (Guerrero *et al.*, 2008; Traveset *et al.*, 2013).

Baltra's land iguana population disappeared during the 1940s due to habitat destruction from goats and the construction of a United States Air Base during World War II (Cayot, 1991). Fortunately, in 1932-33 before the extinction of land iguanas, 70 individuals were transferred to North Seymour, a small island 800 m north where neither goats nor land iguanas were present (Cayot & Menoscal, 1994; Jaramillo *et al.*, 2017; Woram, 1991). In the 1980s, a captive breeding program was initiated in Santa Cruz with iguanas from North Seymour; it culminated in 2006 after the successful repatriation of land iguanas to Baltra (Buitrón, 2000; Cayot & Menoscal, 1994).

The reintroduction of land iguanas constituted a critical first step in the process of ecological restoration of Baltra. This success was accompanied by the eradication of goats and cats, which occurred in 2000 and 2004 respectively (Phillips *et al.*, 2005). The eradication of the former was an important step towards the ecological restoration of the island, as these feral mammals foraged on its plant communities for over a century (Phillips *et al.*, 2012).

In 2013, a pilot project developed by the GV2050 tested the feasibility of using the Waterboxx technology to accelerate the restoration process in Baltra. After obtaining promising results, experiments with Waterboxx, Cocoon, and hydrogel were performed with several native and endemic plant species and compared to controls without a treatment to assess both survival and seedling growth **(Fig 2)** (Hoff, 2014; Land Life Company, 2015). These experiments were established across 8 sites and cover an area of 3.9 ha (Negoita *et al.*, 2021). Among the highlighted results is an estimate for the cost of restoring one hectare in Baltra of $74,848 using the most cost-effective combinations of species and technologies. However, in the scenario that only 10% of the island is restored in patches that could serve as colonization nuclei, the cost for the entire island would be reduced to $15.5 million ($7,484/ha). Thus, in August 2023, a first pilot was created by the GV2050 using this methodology near the Baltra airport. This patch is composed of 36 plots of 10 m², acting as nuclei, with 30 *Opuntia* seedlings in each plot.

RESTORATION SITES IN BALTRA

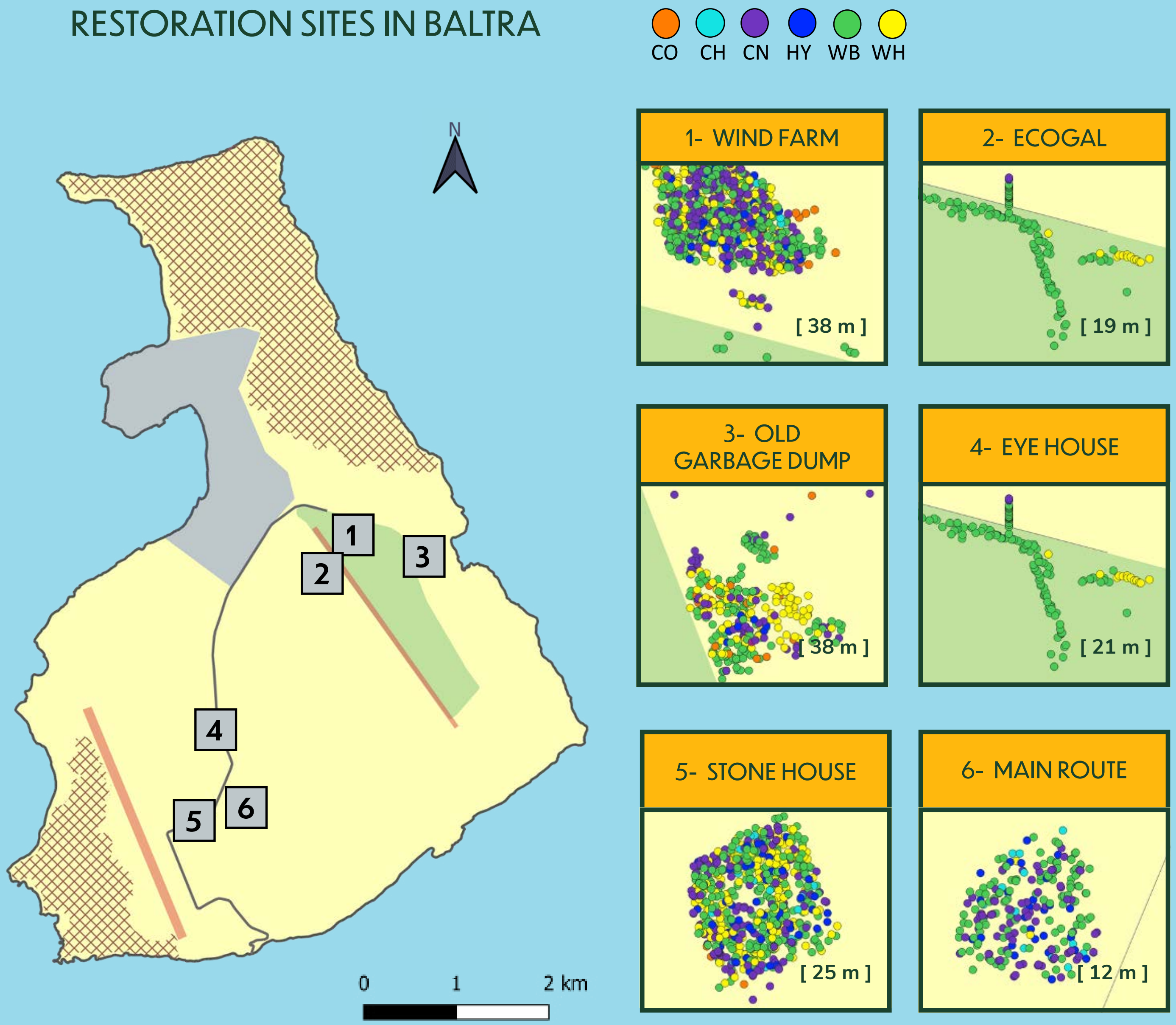


Fig. 2. Study sites on Baltra island. Treatments acronyms: CO, Cocoon; CH, Cocoon plus Hydrogel; CN, Control; HY, Hydrogel; WB, Waterboxx; WH, Waterboxx plus Hydrogel. Main map show anthropogenic areas: the air force base (grey), airport (green), main route (grey line), and runways (orange bars). The less degraded areas of the island are represented in dashed red. Data source and map elaboration: GNPD, CDF, GV2050 Team.

BALTRA—OBJECTIVE

Contribute to the restoration of Baltra by planting 15 key species, connecting the ecosystems of the northeast and southwest, using a reference model, while considering the areas set aside for human use.

BALTRA—RESTORATION ACTIONS

Develop a reference model for restoring Baltra's vegetation using three reference ecosystems

The Restoration Plan published in 2017 set a restoration goal for Baltra of 3000 plants of different native and endemic species to restore ecological processes in 5 hectares, based on expert knowledge (Jaramillo *et al.*, 2017). This goal has served as an important guide for our restoration work. However, for the next steps, following adaptive management principles, more refined objectives are needed (Velasco *et al.*, 2024).

A reference model describes the approximate condition of the target ecosystem if degradation had not occurred (Gann *et al.*, 2019; Winterhalder *et al.*, 2004). A reference model can help us define targets for several key ecosystem attributes which include species composition, structural diversity, ecosystem function, absence of threats, and physical conditions (Gann *et al.*, 2019). In the case of Baltra, three options have been identified as potential reference sites, intact vegetation areas of Baltra, North Seymour Island, and the north coast of Santa Cruz Island. These locations share many similarities because of their proximity and their common geological origin. All were originally submarine lava plateaus that today are separated from each other by narrow channels (Franz, 1980). Ecological surveys on North Seymour and Baltra to assess their vegetation, animal presence, and environmental variables, such as rock cover and slope, were carried out in 2021 and 2022. During the studies, an apparent decline in the *Opuntia* population and the presence of metal debris were observed, suggesting a greater human impact than expected. For this reason, we suggest using the north coast of Santa Cruz, which has suffered less degradation and has similar vegetation to Baltra, as an additional reference site. We plan on applying a methodology similar to prior ecological surveys (Calle-Loor *et al.*, 2022) and use the information gathered from the three reference areas to create a reference model for restoring degraded areas of Baltra.
Due to observations of high herbivory of *Opuntia* by land iguanas in North Seymour, the interactions and population dynamics between these two species should be studied across North Seymour and Baltra. This information is important for preventing both overpopulations and population declines.

Demarcate a restoration area that connects intact vegetation on Baltra, to assist natural regeneration.

According to Gibbs (2013), the first priority for restoring the plant community in Baltra should be the creation of a network of planted patches connecting northeastern and southwestern shrublands. The findings of the 2022 Baltra survey reveal a higher richness of dominant woody species and cacti within these two regions in contrast to the island's central area (Velasco *et al.*, 2024). The proposed patches can connect these two areas and promote wildlife movement and seed dispersion, facilitating the natural regeneration process. The criteria for demarcation of the restoration patches may include:

- Incorporation of existing and planned restoration sites.
- Avoidance of sites with ongoing or planned human activities that may undermine restoration or conservation goals, such as construction projects, energy plants, and infrastructure development.
- Proximity to secondary roads for access for planting, maintenance and monitoring.

- Distance from the main road, to avoid creating habitat close to it that could increase animal strikes. The main road has a lot more traffic than secondary roads.
- Low presence of rocky terrain to facilitate digging holes during planting.
- Proximity to habitat of known seed dispersers (e.g., land iguanas, birds). This will increase the chances of these animals using the restoration area and increasing seed dispersal.
- Distance from the airport, to avoid creating favorable habitat close to airstrips that could increase animal-strike hazards.

Ecological Restoration And Species Recovery Plan

Secure and store enough seeds for restoration and research purposes

The following restoration steps **(p. 30 & p. 32)** will require a substantial quantity of seeds to produce seedlings of 15 priority species. Native seed availability has been found to be a limiting factor in meeting restoration targets, often leading to delays in implementation and a reduction in the originally intended species composition (Erickson & Halford, 2020). All seeds for restoration in Baltra are sourced from wild stands. Therefore, to secure enough high-quality seeds while safeguarding the donor populations' integrity, seed collection should be considered during the planning stage and standard guidelines should be followed (De-Vitis *et al.*, 2020; Erickson & Halford, 2020; Pedrini & Dixon, 2020). In particular, it is critical to follow the guidelines from Pedrini & Dixon (2020):

- To protect the viability of wild donor populations, no more than 20% of the seed produced in one season should be collected, especially when working with endangered species. For annual species, this may be as low as 10%.
- To adequately represent the genetic diversity of the population, seeds should be randomly selected from multiple individuals. For large continuous stands, a more systematized approach such as regular sampling along a transect is more appropriate.
- To ensure good seeds that are mature and ready for harvest, a small sample should be taken and a visual assessment of seed maturity / fill performed prior to commencing seed collection.

In Galapagos there are two climatic seasons, a hot rainy season from January to May and a cold dry season from June to December (Trueman & d'Ozouville, 2010). In general, the flowering time of native and endemic species from the lowlands happens during the hot-rainy season (McMullen, 1993), followed by the seed ripening time from April to June. Seed loss can be avoided by identifying species with a short ripening time. A phenological profile can be created using herbarium specimens to determine the optimum time for seed collection.

Evaluate the use of ecological restoration tools with 15 priority species for the restoration of Baltra

To build on the initial cost-benefit analysis of ecological restoration tools in Baltra by Negoita et *al.* (2021), a new evaluation should be conducted. This should cover species and technologies not previously evaluated, as well as data collected over longer periods for those that were evaluated. Although Negoita et *al.* (2021) estimated the 2-year survival rates of seven Baltra species using several ecological restoration tools, some species were not assessed with all treatments due to inadequate sample sizes. Thus, the evaluation should be expanded to the remaining eight priority species **(p. 32)**. Also, the study should incorporate additional technologies and species not previously assessed, except for Cocoon technology, which was found to be ineffective for Baltra and should be excluded from the new analysis. The arid environment did not facilitate the biodegradation of the box, and it has not demonstrated better growth and survival than other technologies.

As biochar has not been tested on Baltra, preliminary trials should be conducted before proceeding to larger experiments. Among the 15 priority species, dominant and nitrogen-fixing species should be prioritized, as they have a substantial impact on plant community recovery. It is crucial to consider seed availability and seedlings for analysis when planning out each planting session. During the new evaluation, it is recommended to exclude additional watering or maintenance of ecological restoration tools to align with protocols similar to those that the DPNG would follow in future large-scale restoration plantings.

Ecological Restoration And
Species Recovery Plan

Evaluate plant-plant interactions to address which species should be planted together

Plan-plant facilitation -i.e., higher abundance or richness under the crown of nurse species- is an important ecological interaction studied in several arid and semiarid ecosystems (Flores & Jurado, 2003). To further develop restoration strategies that can be easily scaled up, this interaction needs to be measured across Baltra. Two kinds of plots must be compared to estimate this interaction, underneath and outside nurse plants plots (Cavieres & Badano, 2009). For the underneath plots, we will select individuals of the 15 priority species, which can act as nurse species, randomly through the landscape, and record all the woody species growing under their crown and their abundances. Outside plots must be evaluated in a paired fashion, repeating the process of recording woody species but in a plot without the presence of a tall potential nurse plant. Establish the outside plot by making a circle with the same radius as the previous underneath plot and close to it. The methods should be done just after the end of the rainy season when regeneration is at its highest. Considering Baltra's landscape, this procedure should be in areas of higher and lower richness, to compare less impacted areas versus restoration sites.

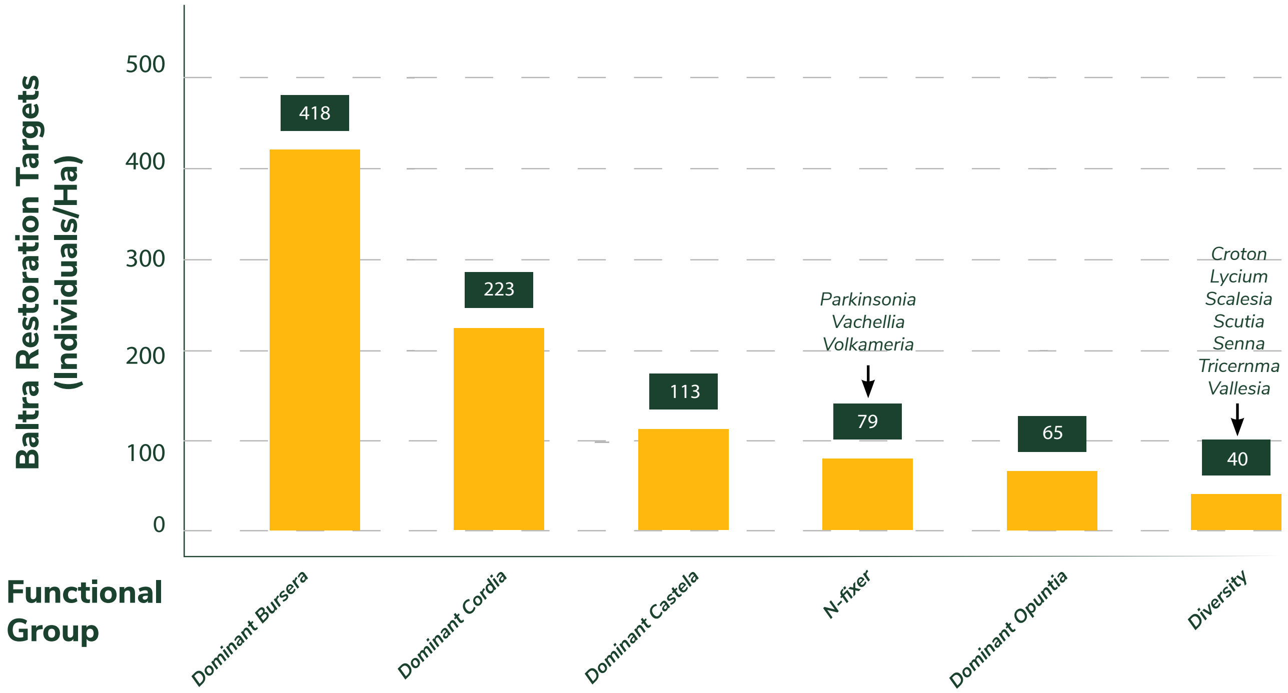
All in all, this procedure can inform which species have the higher potential for being used as nurse species in subsequent restoration steps and, more specifically, what species can be sowed or planted under their crowns.

Increase the abundance of the 15-priority species within the proposed restoration area using the best restoration technologies and natural regeneration strategies

Fifteen key species have been selected for the restoration experiments. Of these, twelve were selected in the first action plan because of their important ecological function (Jaramillo *et al.*, 2020; Jaramillo *et al.*, 2017). Three additional species (*Croton scouleri*, *Lycium boerhaviifolium*, and *Scutia spicata*) were added to this list after analyzing data from a survey of woody species and cacti on North Seymour in 2021. These three species form part of the biodiversity of both islands and are likely important to overall ecosystem health. The full list of priority species is presented in **Table 2**.

We propose planting priority species with the most cost-efficient technologies according to restoration targets informed by the reference model. Currently, these targets are based on the plant density estimates obtained from the North Seymour ecological survey **(Fig. 3)**. However, it is essential to update these recommendations when the results from the ecological surveys of Baltra and the north coast of Santa Cruz become available. We suggest the planting to be done in spaced nuclei to encourage natural regeneration between them. Literature has shown that size and distance between nuclei is variable and dependent on several factors such as site disturbance and species (Holl *et al.*, 2020). However, most literature uses 50 m of distance and nuclei of at least 50 m² (Zahawi *et al.*, 2013; Corbin *et al.*, 2016). Another strategy to increase the abundance of priority species is removing weed around stands of native woody vegetation to promote natural regeneration, expanding the extent of the stands. This is an important strategy for Baltra, which has an abundance of non-native grasses in the disturbed central area (Gibbs, 2013). In a similar way, searching for fallen adults and seedlings of *Opuntia echios* and *Scalesia crockeri* during El Niño years might be advantageous. These two priority species have been reported to have increased mortality and recruitment during these events (Tye & Aldáz, 1999). If recruits of these species are found, consider translocating, planting with restoration technologies, and physical protection strategies.

Fig. 3. Functional group and estimation of woody plant density in North Seymour. N-fixer group correspond to species that fix nitrogen in soil. Diversity corresponds to a group of species with low representativity but important for richness.

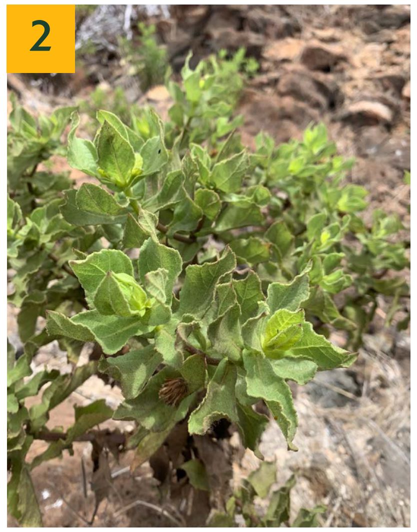


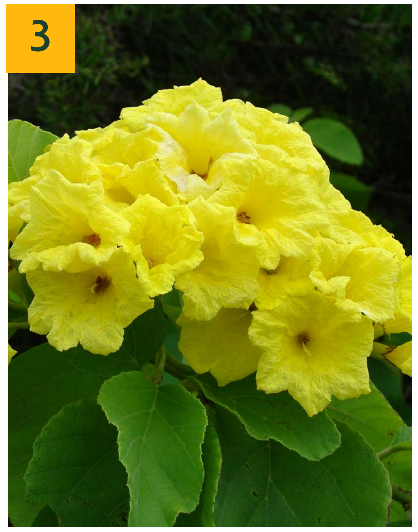
BALTRA – TIMELINE

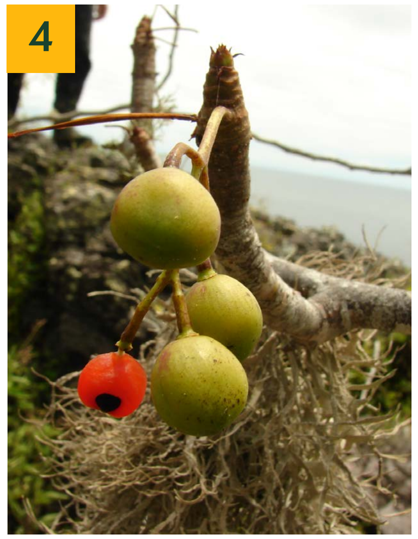
Objetives	Restoration Steps	2025	2026	2027	2028	2029
Restore Baltra	Develop reference model					
	Delimit a restoration area connecting intact vegetation areas					
	Evaluate the use of restoration technologies for restoring Baltra					
	Evaluate plant-plant interactions to address which species should be promoted together					
	Increase abundance of 15 priority species within the restoration patches					

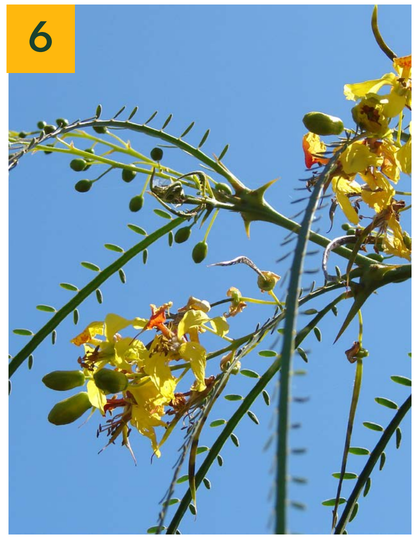
Table 2. Priority species for the ecological restoration of Baltra. IUCN status of endemic species sourced from the Red Book of Endemic Plants of Ecuador (León-Yánez et al., 2011).

Scientific name	Common name	IUCN*	Growth habit	Ecological role
1- *Vallesia glabra*	peralillo	LC	shrub	Food for finches. Has fleshy fruit. Leaves are a host for butterflies. Attracts pollinators, mainly *Xylocopa darwinii.*
2- *Scalesia crockeri*	lechoso	VU	shrub	Host of native and endemic invertebrates. Attracts pollinators such as *Xylocopa darwinii.*
3- *Cordia lutea*	muyuyo	LC	tree	Attracts pollinators and fruits are food for birds.
4- *Bursera graveolens*	palo santo	VU	tree	Food for birds and bird nesting.
5- *Opuntia echios var. echios*	opuntia	EN	tree	Food for land iguanas and birds.
6- *Parkinsonia aculeata*	green twig	LC	tree	Nitrogen fixation, with showy flowers that attract endemic butterflies.









Scientific name	Common name	IUCN*	Growth habit	Ecological role
7- *Senna pistaciifolia var. picta*	senna	-	shrub	A source of food for birds and iguanas. Yellow flowers attract insects and birds.
8- *Tricerma octogonum*	arrayancillo	-	tree	Its bright red fleshy fruits with three seeds are a source of food for birds.
9- *Croton scouleri*	chala	LC	shrub	Dioecious species. Food for land iguanas and birds; there are four species of finches that feed on the seeds.
10- *Vachellia macracantha*	acacia	-	tree	Nitrogen fixation, with showy flowers that attracts endemic butterflies.
11- *Scutia spicata*	hawthorn	-	shrub	A source of food for lizards, land iguanas, and birds.
12- *Castela galapageia*	bitter	LC	shrub	Pioneer species in the arid zone, facilitates the colonization of other target species such as *Scalesia* and *Opuntia.*
13- *Lycium minimum*	lycium	LC	shrub	Attract pollinators and provides soil stability and coverage.
14- *Lycium boerhaviifolium*	silver leaf	EN	shrub	Nesting structure for birds.
15- *Volkameria mollis*	horse's knee	LC	shrub	Nitrogen fixer, with showy flowers that attract endemic butterflies.

***IUCN Status Endemic Plants:** VU=Vulnerable, EN=Endangered, LC=Least Concern."-" = denotes species without information.

SOUTH PLAZA

SOUTH PLAZA—BACKGROUND

South Plaza, an island of about 13 hectares, is located off the east coast of Santa Cruz Island. Due to its landscape, biodiversity and proximity to Puerto Ayora, it is one of the most visited sites of the Galapagos National Park, with an average of 46,000 visitors per year (DPNG, 2018). However, the ecological integrity of the ecosystem is at risk. There is a clear decline in the population of cacti (*Opuntia echios var. echios*), a species that has significant aesthetic value and is the main food source for the land iguana (*Conolophus subcristatus*) (Jordan *et al.*, 2005; Lacour, 1984; Snell *et al.*, 1994; 2008).

In 1957 at the eastern end of the island there were 60 large cacti, now only six survive, equivalent to a loss of 90% (Sulloway *et al.*, 2014; Sulloway & Noonan, 2015). Similar losses are evident at the western end of the island, while the mortality of *Opuntia* is somewhat lower, at around 55%. For the entire island, it is estimated that from 1957 to 2014 there has been a mortality of about 60% (Sulloway & Noonan, 2015). Currently, there is a small population of sub-adult cacti that started growing after 1957 and grow in areas with cliffs or through thorny vegetation such as *Castela galapageia*. While a few sub-adults have survived the herbivory of land iguanas, they are small, which seems to be a consequence of the continued predation of new cladodes by iguanas (Sulloway *et al.*, 2014; Sulloway & Noonan, 2015).

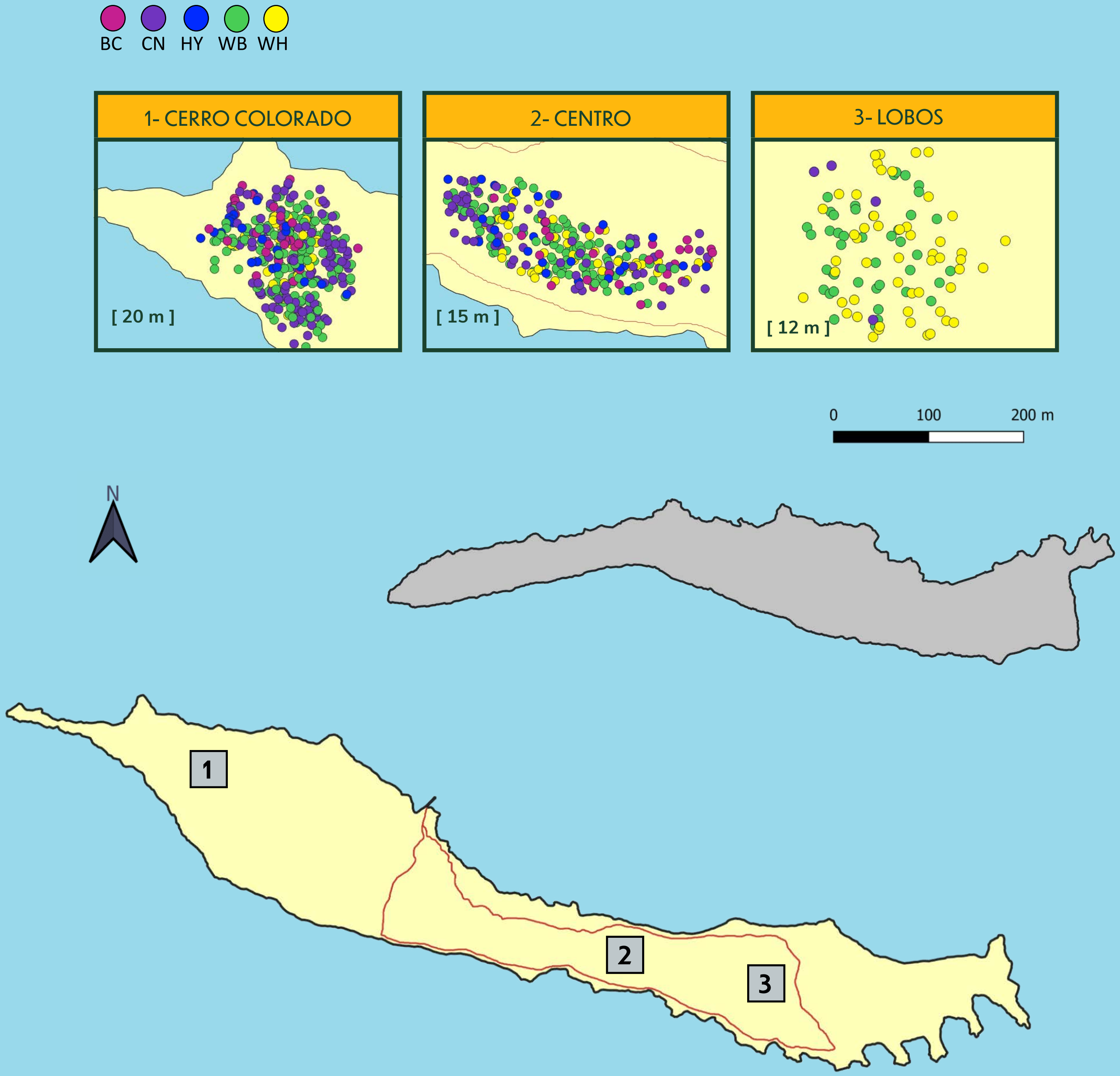
The ecosystem of South Plaza, unlike Baltra, has not undergone a major human disturbance. However, since 1983 a population of introduced house mice (*Mus musculus*) established and impacted the flora of the island. Specifically, the mice have been observed eating the roots of *Opuntia echios* var. *echios*, which might have resulted in increased structural instability (Campbell *et al.*, 2012; Jaramillo *et al.*, 2017; Snell *et al.*, 1994). According to Snell *et al.* (1994), between 1983 and 1993, the mice were responsible for the death of at least two thirds of the population of *O. echios* var. *echios*. In 2012, the eradication of *Mus musculus* was performed through aerial broadcast of brodifacoum cereal baits (Castaño *et al.*, 2022).

However, Sulloway and Noonan (2015) argue that these mice only had a minor impact on the population of cacti. They suggest two other factors as the main drivers of the loss of *Opuntias* within the last five decades. First, the severe El Niño events resulted in the decline of adults within the population due to the extreme rainfall and strong winds. Second, the disappearance of the Galapagos hawk (*Buteo galapagoensis)* on Santa Cruz, and the ban on the poaching of iguanas resulted in a much higher than normal population density of land iguanas, which were being hunted by the hawks and local fishermen. Since the cladodes, fruits, flowers and juveniles of *Opuntia* are the main food source for the land iguanas, the recruitment of new *Opuntia* on South Plaza has been close to zero over the last five decades (Sulloway & Noonan, 2015).
In 2014, we started restoration efforts on the island, planting *Opuntia* seedlings in three study sites **(Fig. 4)**. Two are located next to the tourist trail, allowing visitors to view the process of ecological restoration. Between 2014 to 2021, the *Opuntia* population was more than doubled **(Fig. 5)**. In 2022, a study characterized plant communities on North Plaza and South Plaza using high-resolution aerial imagery (Tapia & Gibbs, 2022). It was found that the presence of land iguanas on South Plaza significantly reduced cacti and woody plant cover, when compared to North Plaza, where land iguanas are absent. These findings highlight the significant role of land iguanas as ecosystem engineers, emphasizing the importance of considering them in restoration efforts for South Plaza.

Another unexplored factor that could play a role in *Opuntia* decline is soil. While we currently lack information about the soil properties of South Plaza some indications for this exist. Literature has shown that the urine and feces of animal can often increase nutrient inputs, alter soil pH, and increase soil salinity in other ecosystems (Wait *et al.*, 2005). A potential problem could be the case that in the eastern part of South Plaza, there is high presence of seabirds, sea lions, and iguanas, which may have an effect on soil chemistry and *Opuntia* recruitment. The GV2050 is currently conducting research to confirm this hypothesis, it may be advisable to prioritize restoration efforts in areas of South Plaza where the soil is more conducive to *Opuntia* growth. Furthermore, the knowledge gained from studying soil properties on South Plaza can improve our understanding of how wildlife influences soil dynamics and impacts plant communities in the Galapagos.

RESTORATION SITES IN SOUTH PLAZA

Fig. 4. Study sites on South Plaza Island. Treatments acronyms: BC, Biochar; CN, Control; HY, Hydrogel; WB, Waterboxx; WH, Waterboxx plus Hydrogel. The red lines across the island are the tourist trail. Data source and map elaboration: GNPD, CDF, GV2050 Team.



Ecological Restoration And
Species Recovery Plan

Fig. 5. Estimation of *Opuntia echios* var. *echios* population size on South Plaza from 1980 to 2021 according to several sources. Population estimates for 1980 to 1993 come from Snell *et al.* (1994), for 2013 from Sulloway & Noonan (2015), and from 2014 onwards from GV2050 monitoring data. GV2050 started planting activities in 2015 (shown in yellow).

SOUTH PLAZA—OBJECTIVE

Contribute to the recovery of the population of the keystone species *Opuntia echios* var. *echios* to its historical population size and distribution in South Plaza.

SOUTH PLAZA—RESTORATION ACTIONS

Establishing *Opuntia echios* var. *echios* seedlings in South Plaza

The findings of a study that compared photographs taken more than 50 years ago suggest that the population of *Opuntia* on South Plaza once consisted of ~2000 individuals (Frank Sulloway, pers. comm. 2015). Prior to GV2050 intervention, the population consisted of only 426 individuals (Sulloway & Noonan, 2015). This number has now increased to 1234 *Opuntias* **(Fig. 5)**. To achieve the desired target of 2000 *Opuntias*, assuming a 10% mortality rate for established *Opuntias* and a 63% survival rate for new plantings (Negoita *et al.*, 2021), we would need to plant an additional 1340 *Opuntias*. It's worth noting that this estimation does not consider natural recruitment, which may reduce the number of *Opuntias* needed. Therefore, it is advisable to estimate recruitment to refine the target.

To restore the *Opuntia* population to its historical levels, Sulloway (Frank Sulloway, pers. comm. 2015) suggests emulating the natural replacement rate observed on Santa Fe Island, aiming to replicate the natural age structure. However, striving for an exact replication of the age-structure through planted seedlings is impractical because it would require decades or even centuries of continuous planting. For this reason, we propose a pragmatic approach: planting five cohorts of 250-300 *Opuntias*, spaced five years apart. This strategy aligns with our objective to reach 2000 individuals by the year 2050, through five repatriated cohorts plus natural regeneration, while ensuring some age diversity.

To approximate the ecosystem as closely as possible to its successional state prior human disturbance, seedlings should be planted in areas known to have had cacti in the past. Historical photographs are a useful reference for determining these areas. It is recommended to continue planting only in the central part of the island and to keep in observation the eastern and western parts. There is a high mortality of *Opuntia* seedlings in the eastern area that should be investigated before resuming active restoration. In contrast, planting in the western area has been very successful and there is no need to continue planting in this area.

The goal of recovering the *Opuntia* population is to restore the ecosystem function of the South Plaza ecosystem. For this, we need to consider the interaction of *Opuntia* with other components of the ecosystem, such as the response of the iguana population, while we work to reach the goal of 2000 *Opuntia*. A restored population of *Opuntia* that can sustain a healthy iguana population would reflect the recovery of the island's ecological integrity.

Evaluate the effectiveness of using ecological restoration tools for restoring the population of *Opuntia echios* var. *echios* in South Plaza

The GV2050 has analyzed the cost-efficiency of using two ecological restoration tools, Waterboxx, and Waterboxx-hydrogel, as well as planting with no technology (Tapia *et al.*, 2021). Among these, Waterboxx is the most cost-effective technique for out-planted *Opuntia* seedlings on South Plaza. Negoita *et al.* (2021) estimated the 2-year survival of *Opuntia cacti* planted with Waterboxx to be about cuadruple (64%) that with Waterboxx-hydrogel (13%) and no technology (15%). The same study estimated the cost per surviving *Opuntia* to be $218 for Waterboxx, $434 for Waterboxx-hydrogel, and $328 with no technology. There is no need to keep testing this, except to compare new techniques and technologies. Hydrogel and biochar are among the technologies that have not been tested in South Plaza but have shown promising results in other locations.

Develop a reference model for the ecological restoration of South Plaza using North Plaza and Santa Fe as reference ecosystems

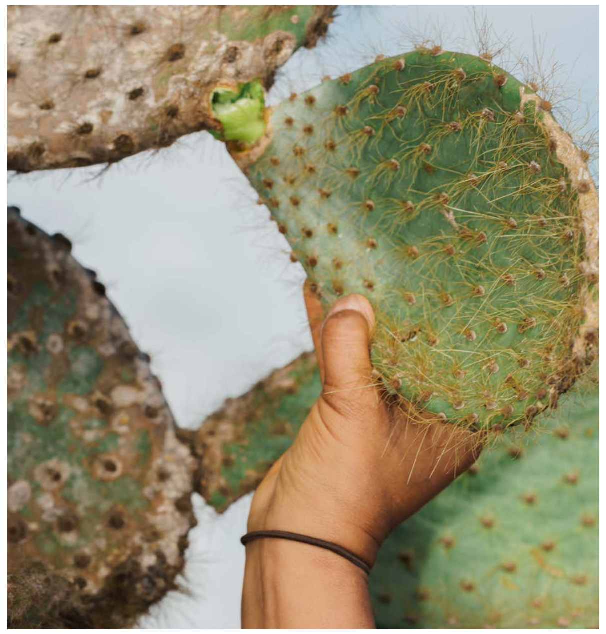
North Plaza, located close to South Plaza and sharing similar geology, has never had land iguanas, two factors we believe make it an ideal reference ecosystem for estimating *Opuntia* natural regeneration and density in the absence of land iguanas. Similar studies have been used to evaluate the role of herbivory on plant regeneration (Negoita *et al.*, 2016). Tapia & Gibbs (2022) provide relevant information about the vegetation of both islands. While initial data from aerial imagery has been gathered, conducting on-the-ground surveys is essential for establishing more robust restoration targets. These surveys should encompass recording *Opuntia* and woody plants, recordings of environmental variables, documentation of animal presence, and soil sampling. By combining these approaches, we can enhance our understanding of ecosystem dynamics and lay a solid foundation for ecological restoration efforts.

To ensure a better comparison, it is recommended to include Santa Fe as an additional reference ecosystem, as it is already used in the restoration program to replicate the *Opuntia* replacement rate (Sulloway pers. comm.; Jaramillo *et al.*, 2017). Santa Fe has undergone degradation due to goat presence and the removal of a crucial ecosystem element, giant tortoises. However, the goat population was eradicated in 1971, leaving the endemic land iguanas as the primary herbivores on the island until giant tortoises were reintroduced in 2020 (Tapia *et al.*, 2021). The presence of *Opuntia* cacti and land iguana populations on Santa Fe renders it a valuable reference point for South Plaza. Such a comparison can offer valuable insights into the dynamics between these two species and their potential abundances per hectare. This, in turn, can enhance our understanding of restoration endeavors on South Plaza.

Translocate seedlings/cladodes during El Niño events

The current plan for South Plaza is to plant 250-300 *Opuntia* every 5 years until the population size of 2000 *Opuntia echios* var. *echios* is achieved, with a diversity of age classes. This target is similar to the average frequency of El Niño events every seven years. During these events, the increase in natural regeneration can be leveraged to relocate seedlings/cladodes and plant them using physical protection strategies and ecological restoration tools. In the event that enough seedlings/cladodes can be relocated during these events, it will no longer be necessary to cultivate plants ex situ to achieve our target population.

According to Negoita et al. (2021), the estimated cost for each surviving *Opuntia* planted using the most cost-efficient technology is $218. Of this cost, it is estimated that $61 (28%) is used for seedling production expenditures. Therefore, the potential translocation of seedlings/cladodes from the same island could offer a more economical approach to repopulating *Opuntia* on South Plaza, by reducing overall costs associated with ex situ seedling production.



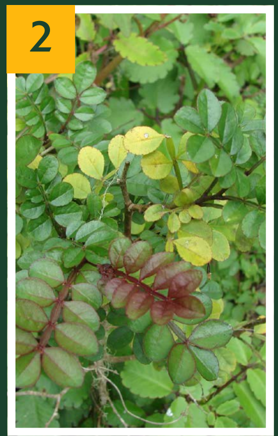
Establish enclosures of spiny native shrubs to evaluate the efficacy of using “green fences’ to protect *Opuntia* seedlings

There are many arguments to test green fences in South Plaza (Castro, 2004). Currently, metal fences have to be painted with rust-resistant paint to avoid rapid deterioration by saline environment/wind, which adds to restoration costs. Some of the restoration sites are located next to the tourist trail and replacing metal fences with green fences could improve the aesthetic of the area. A first step would be to collect seeds for ex-situ plant propagation. Five species of native thorny shrubs from South Plaza have been suggested for use as green fences **(Table 4)**. Trials will be needed to determine the most effective species for protecting *Opuntia*. Species selection may be determined by seed availability. Besides direct collection from plants, iguana feces can provide another seed source. Feces are currently being collected to gather information on the diet of South Plaza land iguanas and to procure seeds for restoration efforts. It is unclear if the species found in the feces would make an effective barrier, as iguanas might consume the entire plant. However, they might only eat the fruit, avoiding stems and thorns, or feed on fallen fruit. Again, emphasizing the need for trials.

A small population of sub-adult *Opuntia* have been observed on cliffs or through thorny vegetation such as *Castela galapageia*, but have remained small, probably due to iguana herbivory (Sulloway & Noonan, 2015). There is an area of scrub vegetation in the central western part of South Plaza, which may provide some natural protection for young *Opuntia*. The 2014 *Opuntia* census shows some young and sub-adult *Opuntia* within this scrub habitat (Jaramillo *et al.*, 2017). The intensity of herbivory might be too severe for plants to achieve sufficient growth and develop resilience without external intervention. A study in this area could involve a detailed analysis of the interaction between herbivores and young and sub-adult *Opuntia*. If herbivory is high, we can then start a trial using physical protection strategies. If few *Opuntia* seedlings are found, this could be a trial area for planting cladodes, fruit or translocated seedlings to test the protection of spiny shrubs.

Table 3. Suggested plants species for green fence enclosures known to be present in South Plaza.

Plant Species	Family	Growth form; type of spines
1- *Scutia spicata*	Rhamnaceae	shrub; large spines
2- *Zanthoxylum fagara*	Rutaceae	tree; thorns like cat's claws
3- *Volkameria mollis*	Lamiaceae	shrub; small thorns
4- *Castela galapageia*	Simaroubaceae	shrub; small thorns
5- *Lycium boerhaviifolium*	Solanaceae	shrub; long trailing branches

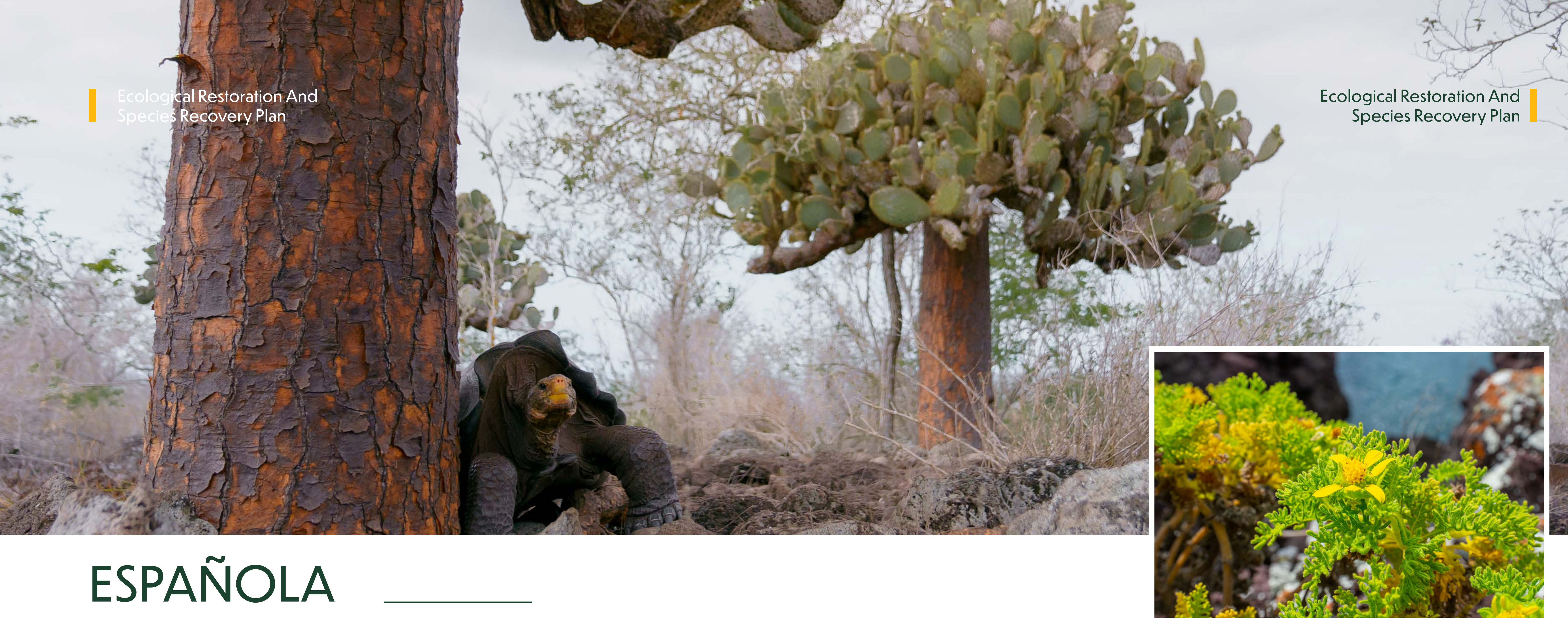


SOUTH PLAZA—TIMELINE

Objetives	Restoration Steps	2025	2026	2027	2028	2029
Restore the *Opuntia* population in South Plaza to historical numbers	Plant 250-300 *Opuntia* seedlings					
	Evaluate the use of ecological restoration tools for restoring *Opuntia*					
	Conduct the Plaza Islands Ecological Survey					
	Translocate seedlings-cladodes during El Niño events					
	Evaluate the efficiency of green fences					

Ecological Restoration And
Species Recovery Plan

Ecological Restoration And Species Recovery Plan



ESPAÑOLA

ESPAÑOLA—BACKGROUND

Española is a small island of 60 km² and relatively flat, with a maximum altitude of 220 meters above sea level, which means that most of the island is arid (Coronel, 2002; Snell *et al.*, 1995). In the 17th and 18th centuries, the island was home to a large population of Española giant tortoises (*Chelonoidis hoodensis*) , estimated at approximately 7,800 adults (Tapia et *al.*, 2021). Unfortunately, due to heavy hunting by whalers and other humans, the tortoise population plummeted, and by 1964, only 14 individuals remained. All Española tortoises were captured for a captive breeding program commenced in 1965 (Márquez *et al.*, 2019). The breeding program was highly successful, culminating in the successful repatriation of over 2,000 tortoises to the island by 2021 (Cayot, 2021; Márquez *et al.*, 2019; Tapia *et al.*, 2021). The absence of giant tortoises likely impacted the vegetation on Española, as these herbivores play a vital role in seed dispersal and structuring plant communities (Gibbs *et al.*, 2014).

Española is the only nesting site for the critically endangered waved albatross (*Phoebastria irrorata*), the only species of tropical albatross (Anderson *et al.*, 2003; Birdlife International, 2018). With an 8 feet wingspan, these large birds need flat and open areas to be able to take off and land. Giant tortoises help maintain these areas, usually referred to as “runways”, by feeding on woody vegetation. It will take several decades for the tortoise population to fully recover and start re-engineering the vegetation. Until then, restoration efforts are needed to ensure albatross survival, such as vegetation management and encouraging tortoises to return to areas near runways (Tapia & Gibbs, 2023).

The vegetation in Española was further affected by the introduction of goats in the late 19th Century (Marquez *et al.*, 2019). The Galapagos National Park Directorate and the Charles Darwin Foundation eradicated the goats from the island in 1978 (Coronel, 2002). However, the populations of two endemic plant species did not recover: *Opuntia megasperma* var. *orientalis* and *Lecocarpus lecocarpoides* (Atkinson *et al.*, 2008). Both species are now listed as “Endangered” (EN) in the red list of endemic plants of Ecuador (Tye, 2011).

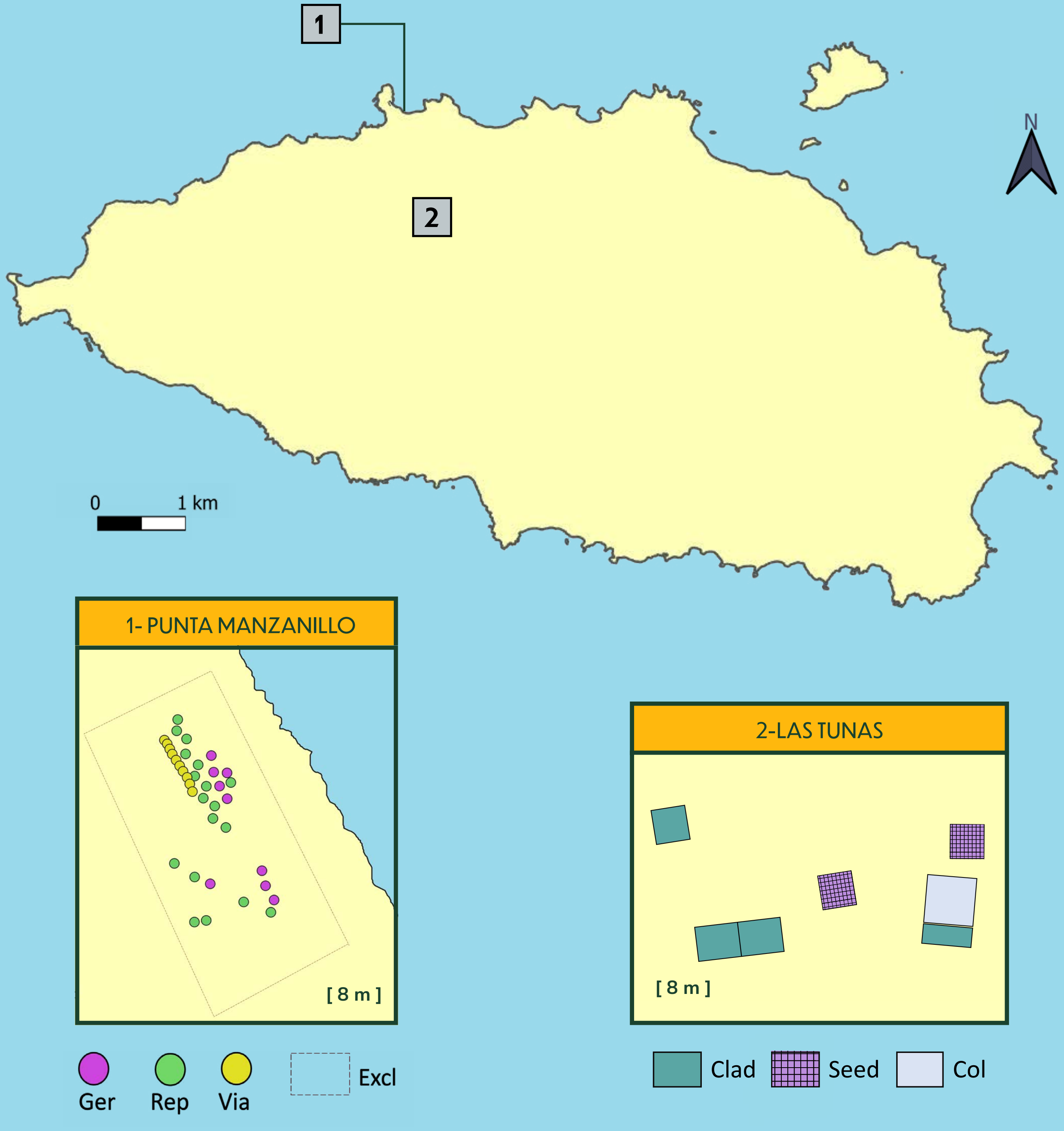
Opuntia megasperma is a keystone plant species because it constitutes a major food source for giant tortoises, land iguanas, mockingbirds, and finches. *Opuntia* in turn, depend on tortoises and iguanas for seed dispersal, and studies have shown that passage through the alimentary system of these herbivores increases germination (Estupiñán & Mauchamp, 1995; Racine & Downhower, 1974). This species has a slow growth rate of 0.5-7.5 cm per year (Coronel, 2002). Factors that may impede the natural recovery of *Opuntia* in Española include the arid environment, the slow growth rate of *Opuntia*, seedling herbivory by tortoises and birds, and high adult mortality during El Niño events (Cevallos & Jaramillo, 2024).

In 2017, the GV2050 Program began implementing a new and large-scale adaptive management strategy for restoring *Opuntia*. Active restoration began in Las Tunas, a site located 1.5 km inland and at ~80 meters above sea level **(Fig. 6)**. This site is one of the three zones with highest abundance of *Opuntia* in Española , with 171 of the 521 individuals found across the island in 2000 and 2001 (Coronel, 2002). The high presence of adults in this site, suggests that historically it had a large population of *Opuntia*.

Lecocarpus lecocarpoides is another species endemic to Española Island and four of the surrounding islets in Gardner Bay (Gardner, Osborn, Oeste, and Xarifa). It belongs to a genus endemic to Galapagos, which makes it important for studying evolution and speciation. Our field observations suggest that it might be an important host plant for moths, as we have recorded silk cocoons, pupae, and larvae feeding on the fruits.. The population at Punta Manzanillo, the only known population on the main island, was thought to be extinct for almost a decade. Despite several searches, there were no records of this species found from 2012 to 2020 (Atkinson, 2007; Tapia *et al.*, 2019). Fortunately, an expedition in 2020 found ~48 small plants in Punta Manzanillo (Calle-Loor & Jaramillo, 2024). Immediately after discovering these individuals, the GV2050 began recovery efforts. The population fluctuates, largely due to the short life cycle of this plant **(Fig. 7 and 8)**.

RESTORATION SITES IN ESPAÑOLA

Fig. 6. GV2050 study sites on Española Island. Abbreviations: Germ, germination experiment; Rep, repatriated plants; Via, viability experiment; Excl, exclusion, Clad, experiment with cladodes and seedlings; Seed, experiments with seeds; Col, rainwater collector. Data source and map elaboration: GNPD, CDF, GV2050 Team)



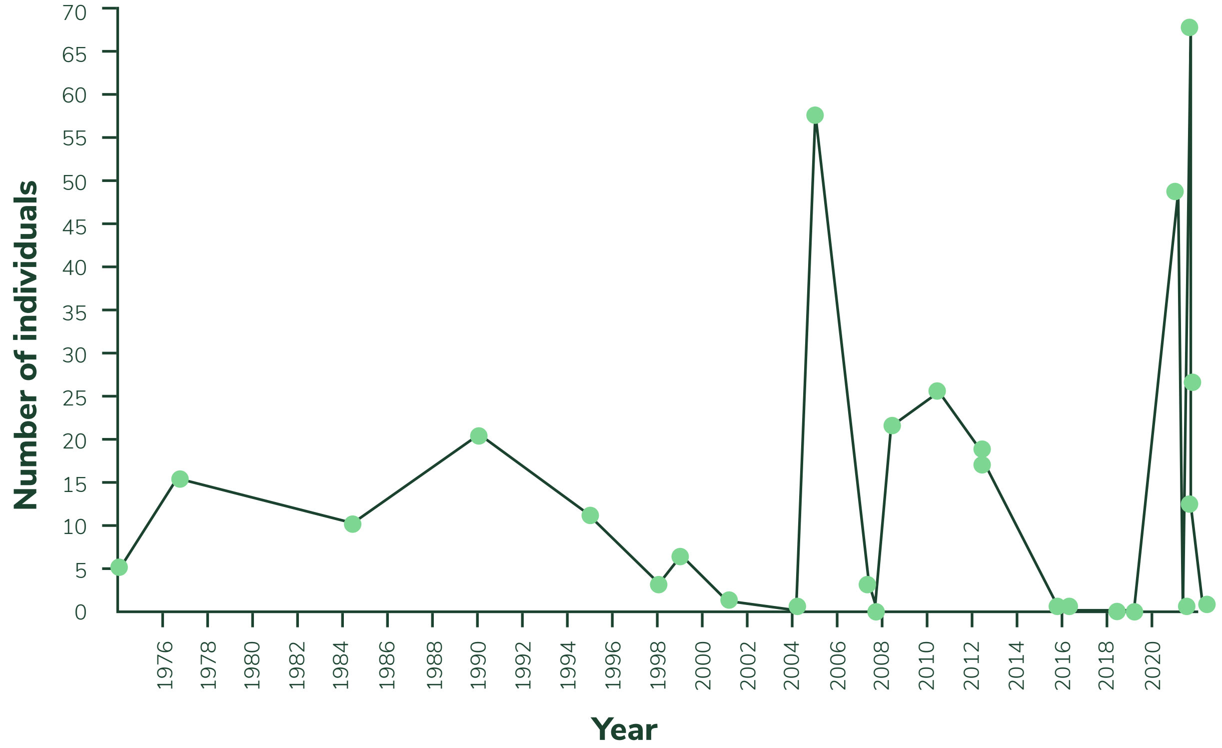


Fig. 7. Population variation in *Lecocarpus lecocarpoides* at Punta Manzanillo from 1974 to 2021 according to several sources. Data on number of individuals present in Punta Manzanillo was obtained from Sønderberg Brok & Adsersen (2007), Herbarium CDS data and GV2050 field observations. Graph elaboration: GV2050.

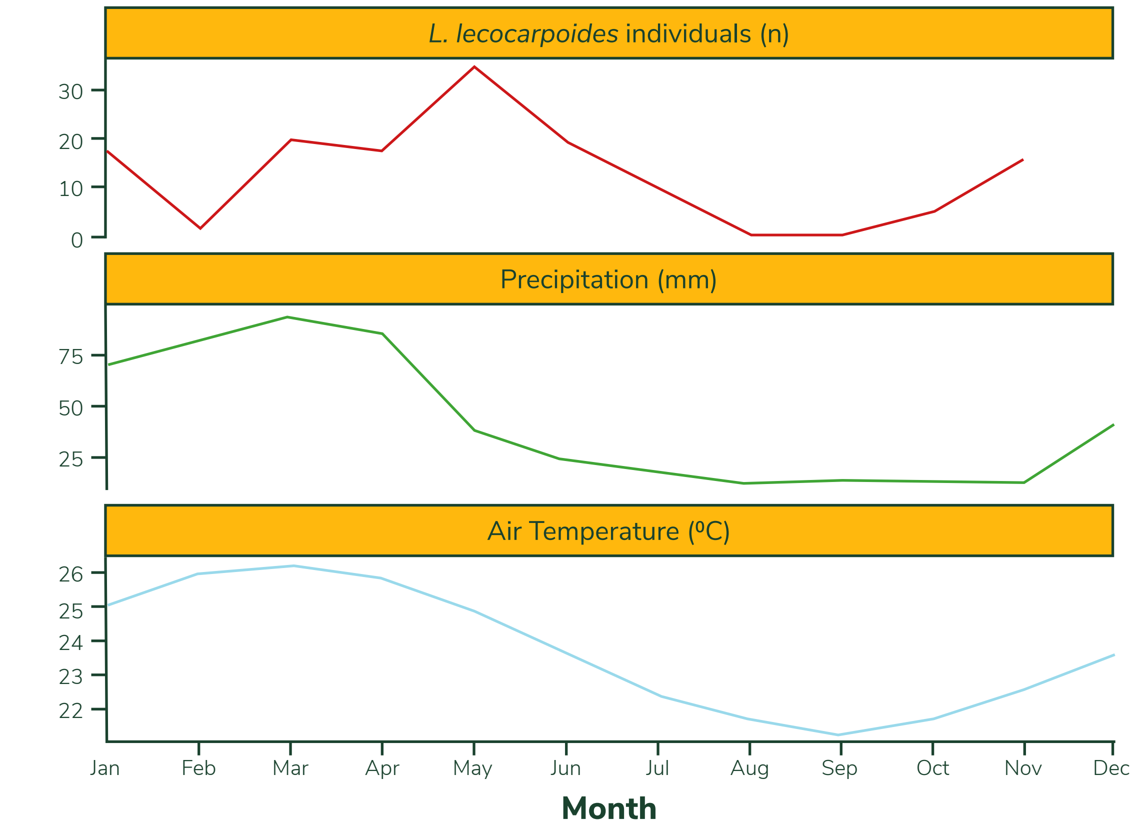


Fig. 8. Average number of *L. lecocarpoides* individuals registered, precipitation, and air temperature per month at Punta Manzanillo (1974-2021). Mean temperature and precipitation were extracted from Worldclim historical climate data (1970-2000) with a 2.5m resolution. Data on number of individuals present in Punta Manzanillo was obtained from Sønderberg Brok & Adsersen (2007), Herbarium CDS data and GV2050 field observations. Graph elaboration: GV2050.

The *Erythrina velutina* tree stands out for its presence on remote islands in the Galapagos archipelago, as evidenced by the research conducted by Grant *et al.*, in 1991. Although it is not endemic, this species plays a critical role in the ecosystem as a nitrogen-fixing legume, significantly contributing to the health and fertility of the soil (Silva *et al.*, 2020). Cayot (2021) highlights its limited presence on Española Island, with only three trees recorded. Considering evidence from other remote islands and seed flotation experiments by Grant et *al.* (1991), *Erythrina velutina's* ability to disperse over long distances and establish itself in new environments was demonstrated. The germination of its seeds following significant events like El Niño underscores its survival potential and adaptability.

ESPAÑOLA—OBJECTIVES

1. Contribute to the ecological restoration of Española Island through the recovery of the keystone species *Opuntia megasperma* var. *orientalis*.
2. Recover the only population of the endangered species *Lecocarpus lecocarpoides* in Española.
3. Assess the status of individuals of *Erythrina velutina* in Española to develop effective conservation strategies

ESPAÑOLA–RESTORATION ACTIONS

Determine appropriate protection strategies for *Opuntia* that do not affect native wildlife

GV2050 found that protecting each plant with an individual fence and planting among shrubs are not effective strategies for protecting seedlings and *Opuntia* cladodes. Tortoises can crush individual metal fences and make their way through the shrubs, and birds manage to extract seedlings during their flight. Using larger and more robust metal fences to protect groups of seedlings planted in restoration plots have been more successful at preventing tortoise herbivory. These fences need to be sealed with a 'roof' made from fencing material or shade mesh to prevent herbivory by birds. Currently, the fenced plots have been planted with a high density of Opuntia within each plot. These individuals will be relocated to other areas once they reach a size that can withstand herbivory. This approach reduces the need to construct multiple expensive structures.

Evaluate the efficiency of using different restoration strategies to increase the germination success of *Opuntia* seeds

GV2050 has identified several treatments with the potential to increase germination. These include using seeds from different sources (tortoise feces, fresh fruits, and decomposed fruits). *Opuntia* seeds collected from giant tortoise feces were found to have higher germination rates than those collected directly from fruits (Estupiñán & Mauchamp, 1995). Field observations suggest that decomposing *Opuntia* fruits in containers for several months before sowing the seeds might also increase germination. Another strategy is to combine these different seed sources with ecological restoration tools that can be applied to the soil when sowing (hydrogel and biochar).

Evaluate the efficiency of using different restoration technologies to increase the survival of *Opuntia* seedlings and cladodes

The *Opuntia* cacti planted with Groasis Waterboxx and protected by fences show a much higher average survival rate than the cacti planted as controls, 95% compared to only 6%. (Cevallos & Jaramillo, 2024). However, the effect observed in the interaction between some species and the boxes suggests that it is necessary to adjust the methodology before continuing their use.. An alternative technology that is already being tested on the island's plots, together with hydrogel and controls, is biochar. Monitoring of these plots will need to continue for the next few years to understand the effect of the treatments on *Opuntia* survival.

Use a combination of seedlings and cladode plantings to maintain genetic diversity

Opuntias can be planted both from cladodes collected in the field and from seedlings grown ex-situ or in-situ. While the collection of cladodes is quick and inexpensive, the use of seedlings are necessary to maintain the *Opuntia* population's genetic diversity. A two-year survival of 54% (39 of 72) was observed for cladodes planted with no technology or watering inside a fenced plot (Cevallos *et al.*, 2023; Cevallos & Jaramillo, 2024).

Promote natural regeneration of *O. megasperma*, especially during higher rainfall El Niño events, to complement assisted regeneration efforts

Survey for *Opuntia* seedlings or rooted cladodes during the rainy season and El Niño events, when higher presence of these is more likely. These seedlings and cladodes can be protected in place or translocated to new locations new localities with low density of *Opuntia* using previously mentioned physical protection strategies. Consider assessing different weed control strategies to prevent the mortality of *Opuntia* seedlings, especially during periods of heavy rain that stimulate the vegetation growth. Grant & Grant's report (1989) suggests that weed control may be an important factor in the survival of young recruits. We found it necessary to remove weeds within the restoration plots in Las Tunas in order to monitor them. As explained in page 70, there are several techniques for weed removal that can increase recruitment.

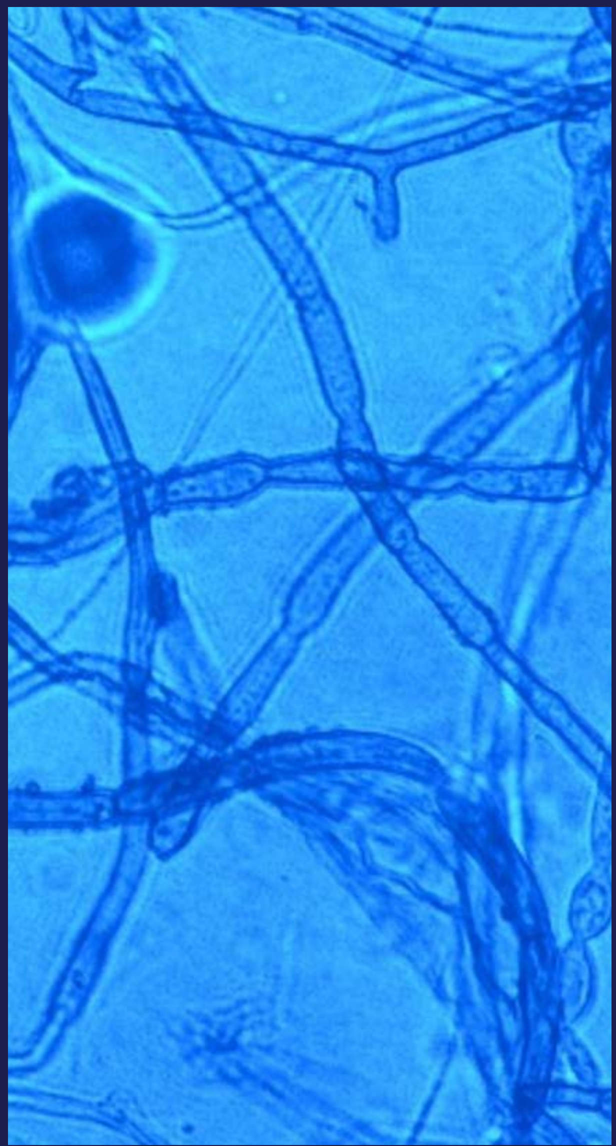
Ecological Restoration And
Species Recovery Plan

Evaluate the effect of different treatments on the germination of *L. lecocarpoides*

Assess different germination treatments, such as seed soaking and scarification, directly in the natural habitat of *L. lecocarpoides*, in Punta Manzanillo. Any method that allows seeds to germinate directly at this site will reduce the need to repatriate seedlings from Santa Cruz to Española and will lower their mortality due to transport and planting stress. We do not recommend the use of hydrogel at this site because our experiments show that its water absorption capacity decreases with increasing water salinity. Since *L. lecocarpoides* grows in sand just a few meters from the ocean, the environment is highly saline, reducing the effectiveness of the hydrogel.

Monitor the population status and distribution of *L. lecocarpoides*

A monitoring plan is essential to assess whether the implemented actions achieve the expected results (IUCN, 2017; Mauchamp, 2007). Since *L. lecocarpoides* has been reported to behave as an annual plant in Punta Manzanillo, its population is expected to fluctuate annually. We recommend monitoring the population at least once a year after the warm-wet season, when population size is likely to be at its highest. Additional monitoring throughout the year is also valuable to understand this species' life cycle and population dynamics. This information can be used to estimate minimum viable population size, through a Population Viability Analysis (PVA) study.



Increase the population of *L. lecocarpoides* in Española using active restoration and promoting natural regeneration

At present, we conduct periodic monitoring of the population of *L. lecocarpoides* at Punta Manzanillo. In the event of detecting new individuals, the possibility of implementing ecological restoration tools and irrigation will be considered to promote growth and survival. Additionally, any introduced plants that may pose a source of competition will be removed.

To promote natural regeneration and reduce human use of the area, a fence was installed around the population of *L. lecocarpoides* in Sept 2021. Furthermore, we plan to supplement the natural population with seedlings grown ex-situ following an experimental design. This species is particularly difficult to germinate due to the hard outer covering of the seeds. Nevertheless, germination can be greatly increased by using seed scarification techniques described in Pulido (2020). The resulting seedlings can be planted in the same area or in a second location with similar habitat conditions.

Evaluate the role of soil fungi on the germination of *L. lecocarpoides*

The GV2050 has observed that some of the *L. lecocarpoides* seeds that germinated in the laboratory were infected by fungi. This suggests that fungi could facilitate germination by breaking down the outer seed coat. This hypothesis can be tested by conducting germination experiments inoculating *L. lecocarpoides* seeds with fungi from Punta Manzanillo following previous studies (Delgado-Sánchez *et al.*, 2013). In 2021, seven taxa of soil fungi were isolated from soil samples collected from the rhizosphere of naturally occurring *L. lecocarpoides* plants. Of these, five were identified to genera, and two remain unidentified (Enríquez-Moncayo *et al.*, 2021). The molecular characterization of the seven taxa would allow for species-level identification and their possible ecological function.

Ecological Restoration And Species Recovery Plan

Identify threats to the population of *L. lecocarpoides* in Punta Manzanillo through the study of its habitat and biological interactions

It is well known that plants in the Galápagos face various threats, such as the introduction of invasive species, habitat degradation due to human activities, climate change, herbivory by introduced species, and the presence of pests and diseases. However, in many cases, it is neither feasible nor cost-effective to address all these threats simultaneously (IUCN, 2017).

Therefore, it is essential to study the habitat and biological interactions of Lecocarpus lecocarpoides complete its life cycle. Useful tools for obtaining valuable information are biodiversity inventories, temperature loggers, precipitation loggers, and camera traps. With this information, a 'problem tree' can be constructed to analyze and organize threat information (IUCN, 2017).

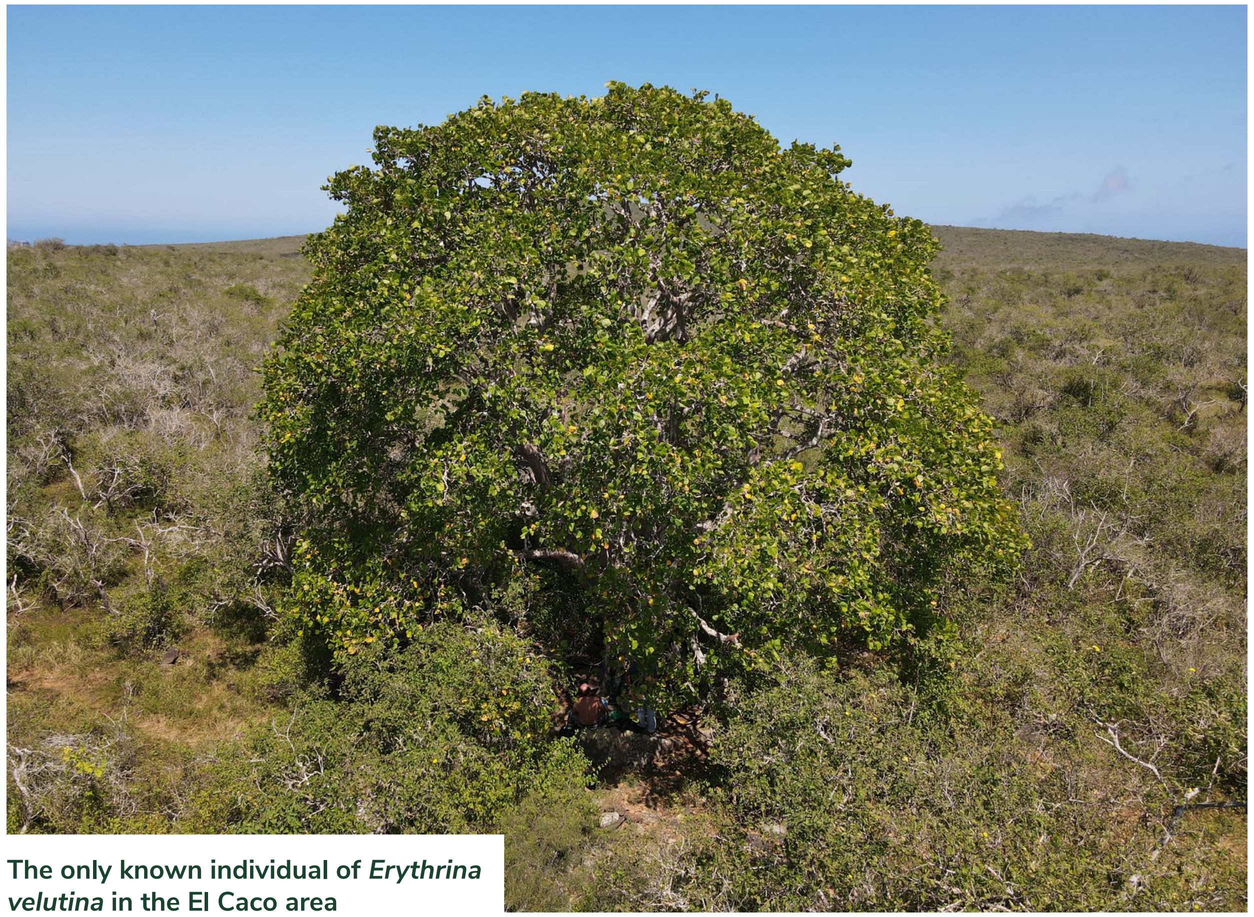
Assess the population status of individuals of *Erythrina velutina* in Española to develop effective conservation strategies

The following steps are proposed to expand our knowledge about the few individuals of *Erythrina velutina* on Española and develop conservation strategies:

- **Evaluate the number, phenology and health status of *Erythrina* trees in El Caco**
  To assess the potential of a higher population of *Erythrina* trees in Española, a comprehensive field excursion must be done to register the number and height of trees, while at the same time regenerating seedlings must be searched through the area to account for potential new individuals. For all plants, the phenological status (vegetative, flowering, fruiting) will be recorded. Each plant identified must be screened for pest and diseases that could be deteriorating their health status.

- **Search for historical data and new collections**
  To establish how long the species has been present in Española, a literature review is needed. For this, articles, reports and other documents will be screened for potential information. Additionally, during field excursions new plant material must be collected to increase the records at the CDS herbarium.

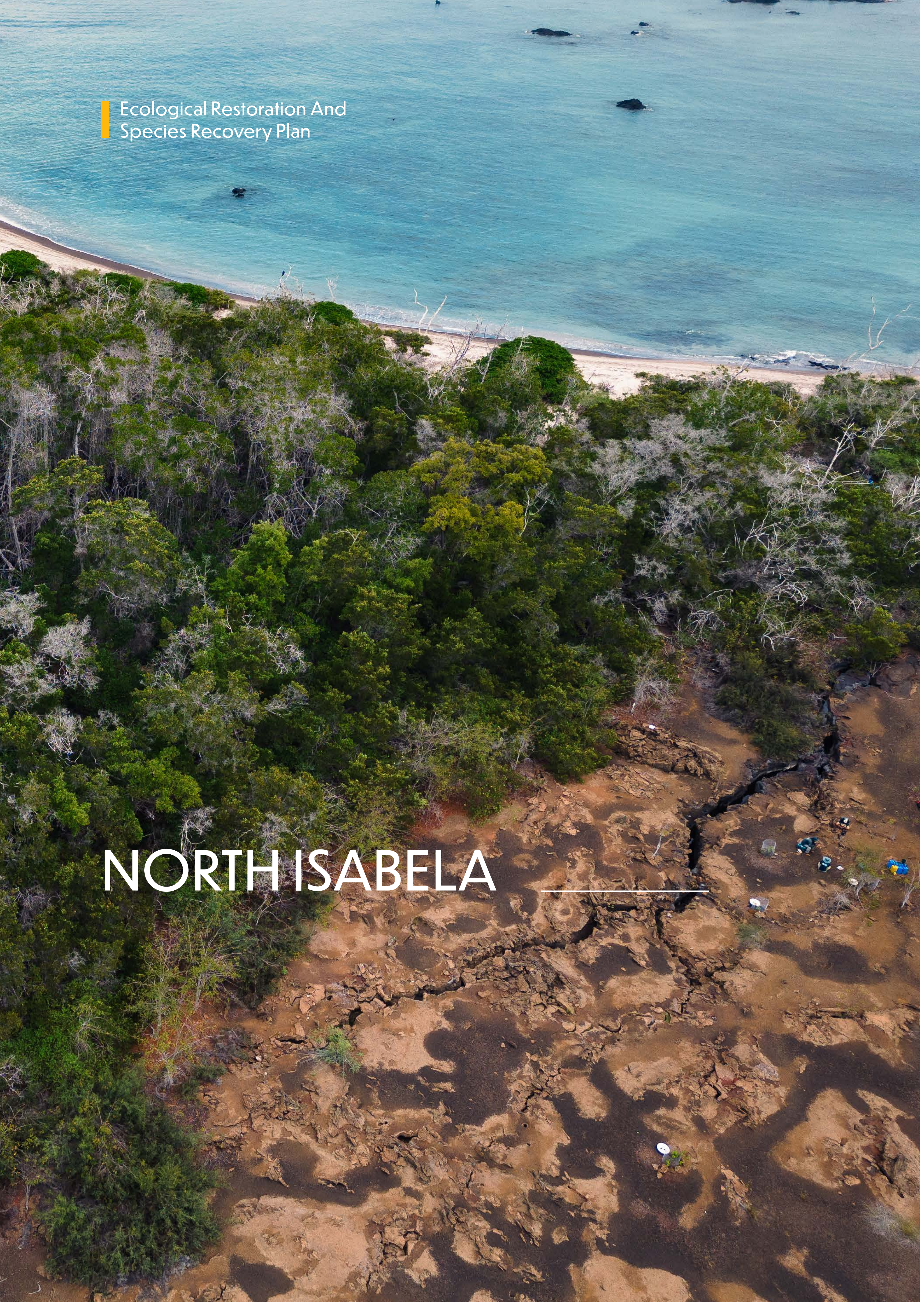
- **In-situ propagation**
  In order to increase population size, propagation techniques must be evaluated. As a first trial, shoots must be cut and place on soil to assess if this has potential to propagate vegetative.



The only known individual of *Erythrina velutina* in the El Caco area

ESPAÑOLA—TIMELINE

Objetives	Restoration Steps	2025	2026	2027	2028	2029
1- Recover *Opuntia megasperma*	Determine appropriate physical protection strategies for *Opuntia*.					
	Evaluate the efficiency of using restoration strategies to increase *Opuntia* germination.					
	Evaluate the efficiency of using restoration technologies to increase the survival of *Opuntia* seedlings and cladodes.					
	Use a combination of seedlings and cladode plantings to maintain genetic diversity.					
	Promote natural regeneration of *O. megasperma*.					
2- Recover *Lecocarpus lecocarpoides*	Evaluate the effect of pre-germination treatments on the germination of *L. lecocarpoides*.					
	Monitor the population status and distribution of *L. lecocarpoides*.					
	Increase the population of *L. lecocarpoides* in Española by promoting natural regeneration and supplementing the natural population.					
	Evaluate the role of soil fungi on germination of *L. lecocarpoides*.					
	Identify threats to the population of *L. lecocarpoides*.					
3- Assess *Erythrina velutina*	Evaluate the number, phenology and health status of *Erythrina* trees in El Caco					
	Search for historical data and new collections					
	In-situ propagation					



NORTH ISABELA

Ecological Restoration And
Species Recovery Plan

NORTH ISABELA—BACKGROUND

Isabela is the archipelago's largest island, its landmass exceeding the combined area of all other islands (Snell *et al.*, 1996). It is among the youngest, forged by six merging shield volcanoes through their lava flows (Geist *et al.*, 2005). From 1950 to 2000, ten eruptions occurred from five of these volcanoes (Naumann & Geist, 2000). At 1707 meters, Wolf Volcano is the highest point in the Galapagos Archipelago (Geist *et al.*, 2005). The Perry Isthmus, a lava isthmus stretching 10 km, bisects Isabela into its northern and southern regions. Human activity is predominantly situated in the southern sector of the island. This Restoration Plan is directed at the unpopulated northern region of Isabela.

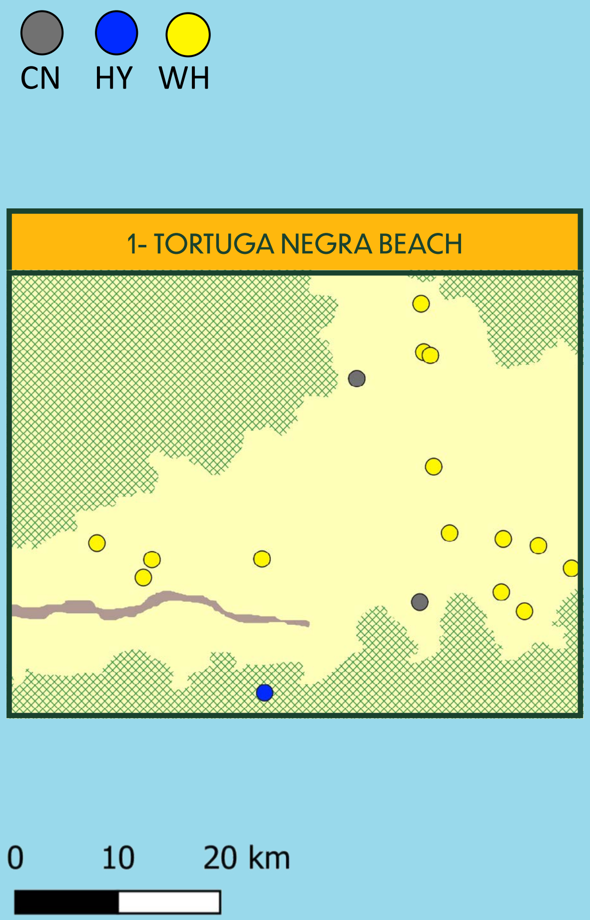
Isabela harbors a greater population of giant tortoises than all other islands combined, hosting unique species on each of its volcanoes (Beheregaray *et al.*, 2004). Invasive feral goats, along with some donkeys, posed a substantial threat to the indigenous vegetation. This threat was addressed in a significant conservation effort culminating in 2005 with the successful removal of over 60,000 goats from Isabela during a six-year initiative known as the Isabela Project (Campbell *et al.*, 2013; Carrión *et al.*, 2011). Although the goats were eradicated by 2005, recovery of some endemic plant species has not yet been observed.

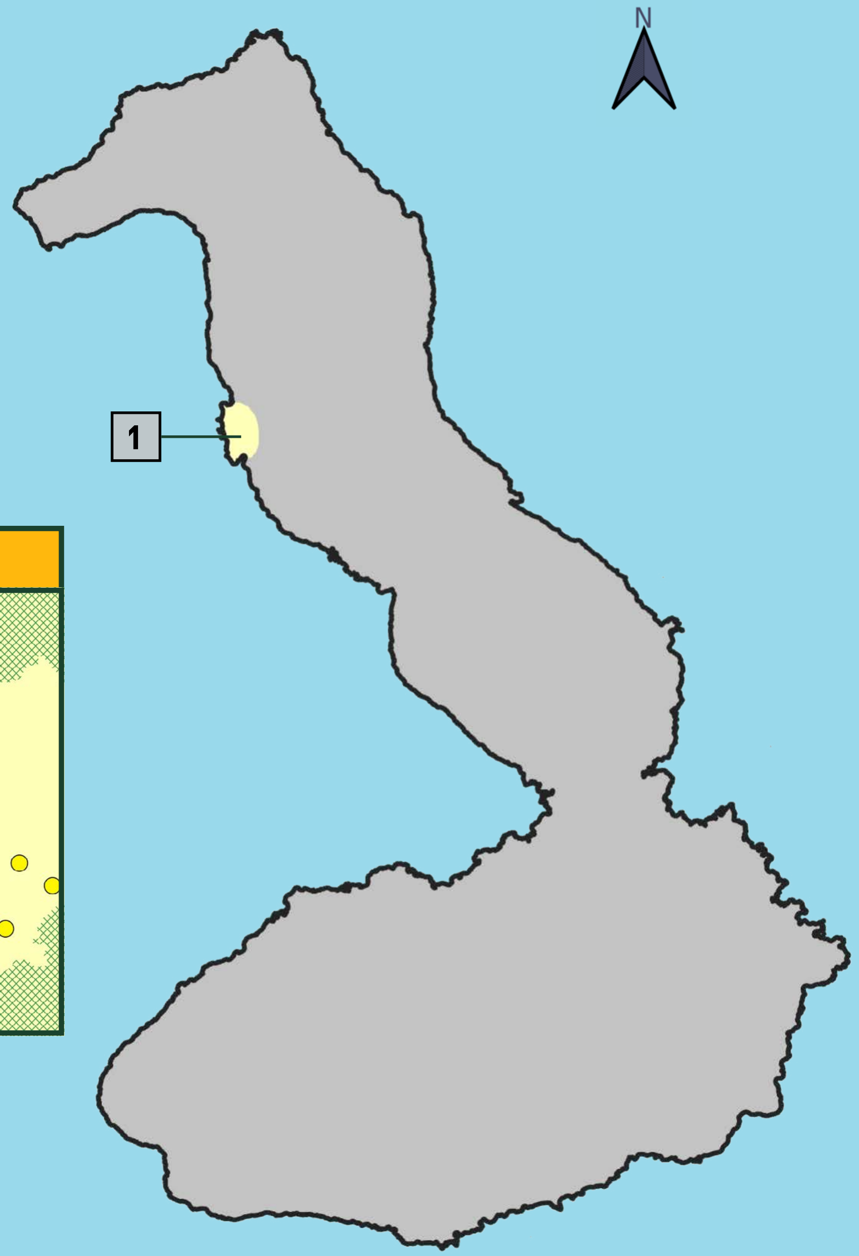
Galvezia leucantha is one of the species presumed to have been affected by the intense herbivory of goats in the past. This species is classified as endangered in the red list of endemic species of Ecuador (León-Yánez *et al.* 2011). *Galvezia leucantha* has three recognized subspecies: subsp. *leucantha* was historically distributed on Isabela and Fernandina, subsp. *pubescens* on Rábida, and subsp. *porphyrantha* on Santiago (Tye & Jäger, 2000; Guzmán *et al.*, 2017). In 2007, an expedition revealed that only six individuals were left in Playa Tortuga Negra, one of the few known locations where *Galvezia leucantha* had been registered in North Isabela (Jaramillo & Tye, 2018). Shortly thereafter, GV2050 started recovery efforts in Playa Tortuga Negra. Galapagos Conservancy and the Galapagos National Park Directorate conducted searches for *G. leucantha* subsp. *leucantha* in 2019 and 2020 in Fernandina, Wolf Volcano, and Darwin Volcano with no success (Tapia, 2019; 2020; Tapia *et al.*, 2019) and the subspecies is now considered to be present only in Playa Tortuga Negra **(Fig. 9)**.

The last known population of *G. leucantha* subsp. *leucantha* is located on a lava field near Playa Tortuga Negra. This site is 50-100 m from the coastline and is surrounded by a patch of mangrove forest, which is home to the critically endangered Mangrove Finch (*Camarhynchus heliobates*). The GV2050 has been working on this site since 2017 **(Fig. 10)**. After several ex-situ germination and repatriation efforts, the population increased from 5 individuals in 2017 to 20 adult individuals in 2021. In addition to these, eight seedlings were found during population monitoring in August 2021, indicating the beginning of natural regeneration. However, the long-term viability of this unique population faces serious threats due to its small size and the risks posed by diseases and herbivorous insect pests. Therefore, it is important to intensify conservation efforts at "Playa Tortuga Negra". In the absence of locating and protecting additional populations, it is imperative to consider the creation of a second population, either in historically inhabited locations or in new sites that offer favorable environmental conditions for their development.

RESTORATION SITES IN NORTH ISABELA

Fig. 9. Study sites on Isabela Island. Treatments acronyms: CN, Control; HY, Hydrogel; WH, Waterboxx plus Hydrogel. The grey area in the inset denotes a crevice. The green hatched area corresponds to the surrounding vegetation, mainly mangroves. Data source and map elaboration: GNPD, CDF, GV2050 Team





Ecological Restoration And
Species Recovery Plan

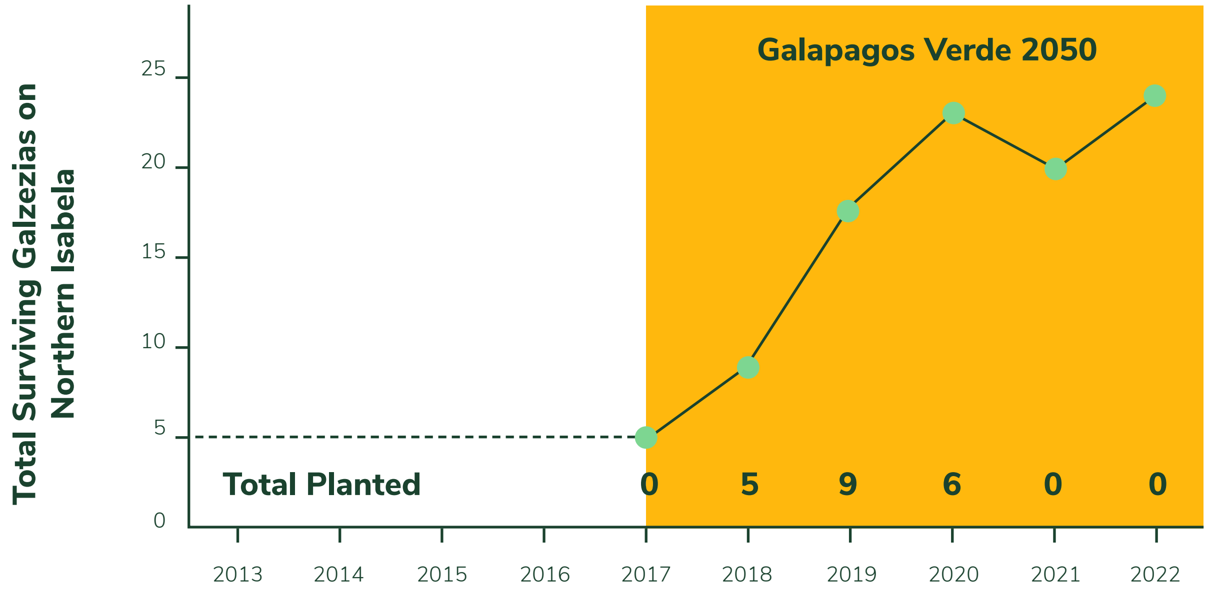


Fig. 10. Population of *Galvezia leucantha* subsp. leucantha at Playa Tortuga 2017-2022. Included are naturally occurring adults and seedlings, plus plants grown ex-situ by GV2050 from seed collected at the site. Data source and graph elaboration: GV2050.

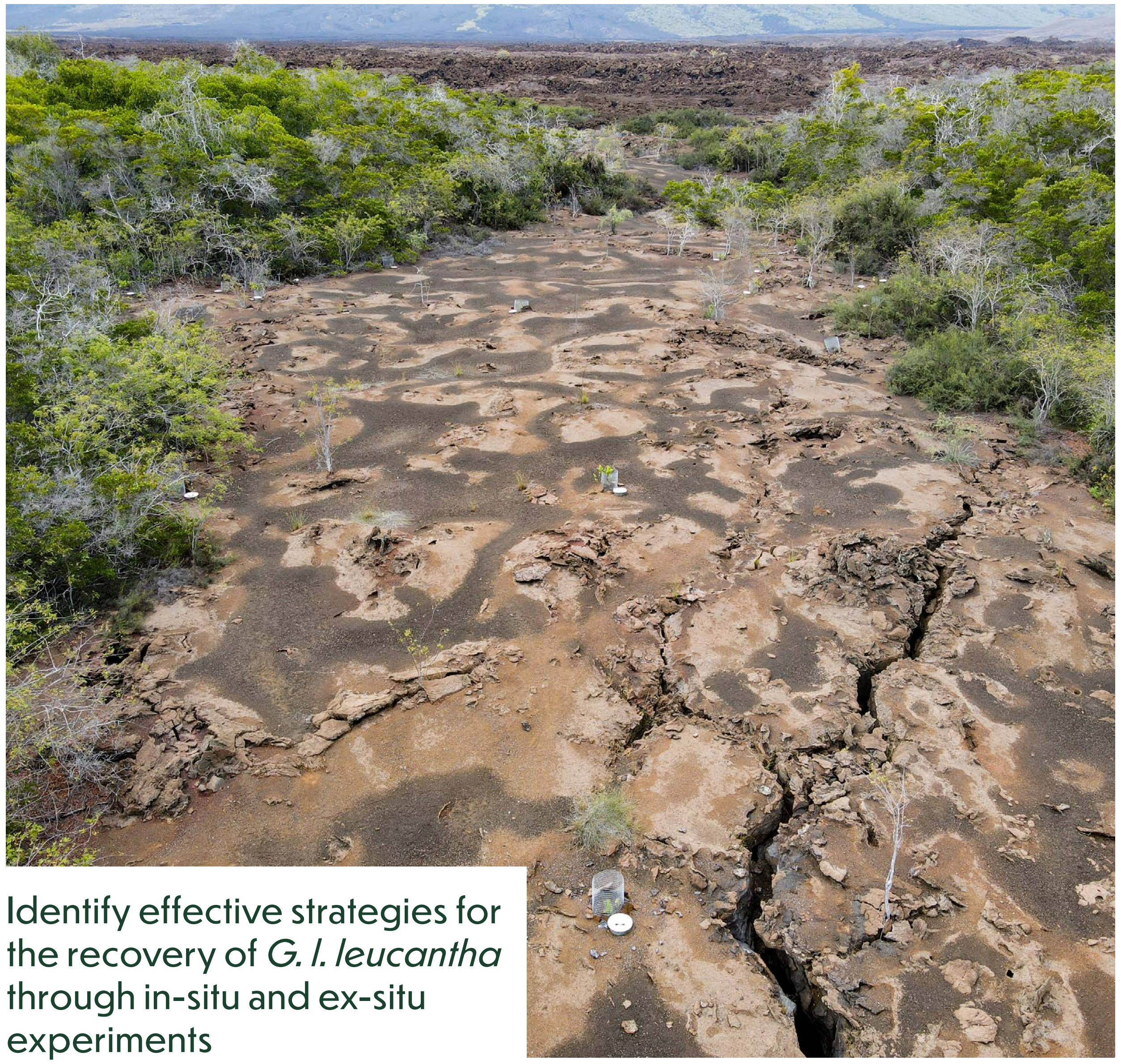
NORTH ISABELA—OBJECTIVE

Contribute to the recovery of the endangered *Galvezia leucantha* subsp. *leucantha*, registered only in North Isabela.

NORTH ISABELA—RESTORATION ACTIONS

Establish a second population of *G. leucantha* subsp. *leucantha*

Canal Bolívar stands out as an ideal location for establishing a second population of *G. leucantha*. It is located ~7 km south-east of Playa Tortuga Negra, and with similar environmental characteristics, as noted by Jaramillo *et al.* (2017). This location is not only similar to Playa Tortuga Negra in ecological terms but also holds a significant place in botanical history with the collection of the oldest record in the CDS herbarium, near Tagus Cove (CDF, 2023). The presence of an established and often-visited GNPD control booth further underscores Canal Bolívar's suitability by ensuring consistent monitoring and care for the plants. Seedlings grown in the CDRS will form the basis of this second population. This effort will increase the resilience of the subspecies to natural disasters or extreme climatic events and enhance our understanding of the biological characteristics of the species. Such insights are important to guiding future recovery actions and to promote the long-term conservation of the species.



Identify effective strategies for the recovery of *G. l. leucantha* through in-situ and ex-situ experiments

Continue germination and repatriation efforts with *G. leucantha* subsp. *leucantha* to identify best methodologies to increase population size. Current strategies include protection with metal fences, storing seeds in a seed bank, seed germination trials, ex-situ propagation, and the use of Waterboxx technologies. Due to the endangered status of the plants, the Waterboxx technologies should be filled periodically to increase plant survival, especially during the dry season. Once the population exceeds the target population size, which will be defined based on demographic data **(p. 64)**, it will be possible to test other ecological restoration tools. Because of the very small population size it is important to balance effective recovery strategies with protecting the current population.

Monitor the population status and distribution of *G. l. leucantha*

Monitor all *G. leucantha* subsp. *leucantha* individuals near Playa Tortuga Negra and Canal Bolivar (once established) at least twice a year to assess population status and outcomes of recovery efforts. We follow a standard monitoring methodology described in Jaramillo *et al.* (2021). When new seedlings are found, we protect them and record their geographic coordinates, so that they can easily be found in future monitoring expeditions. We are also planning to review CDS Herbarium data and reports from previous searches in North Isabela and Fernandina to determine if new searches are advisable in other areas.

Identify threats to the population of *G. l. leucantha* through the study of its habitat and biological interactions

Identify and address the most important threats faced by *G. leucantha* subsp. *leucantha* to accelerate recovery. The strategies used for this purpose include conducting biodiversity inventories, registering temperature and precipitation in Playa Tortuga Negra, and installing camera traps to understand interactions with surrounding wildlife. In 2023, an infestation of introduced scale insects (*Coccus* spp.) was detected and treated. Therefore, it is important to monitor changes in the amount of scale insects, fungi, and other pests affecting *G. leucantha* subsp. *leucantha* individuals (Jaramillo *et al.*, 2024).

Encourage natural regeneration of *G. leucantha* subsp. *leucantha*

Increase in-situ seed germination and seedling survival of *G. leucantha* subsp. *leucantha* by applying assisted natural regeneration strategies. The creation of improvised seedbeds is proposed in restoration areas that present favorable conditions similar to those where natural regeneration has been observed. It is suggested to water the seedbeds whenever possible. A potential strategy to increase germination is using hydrogel and Waterboxx technologies to increase soil moisture around seeds. Furthermore, it is suggested to improve the conditions of seedlings growing naturally. To increase soil moisture, available nutrients, and protect the plants from herbivory, we recommend employing the restoration strategies mentioned earlier in this document, such as the use of ecological restoration tools and metal fences.

Establish a minimum population size target to increase the likeness of long-term persistence of the *G. leucantha* subsp. *leucantha* population.

Determine a minimum restoration target for the population of *G. leucantha* subsp. *leucantha* in Playa Tortuga Negra. Consider the following recommendations:

- Develop a population model though field surveys and experiments to measure key demographic parameters such as germination rates, growth rates, reproduction (flowering and fruiting rates), and mortality rates. Long-term monitoring and data collection across different seasons and environmental conditions are essential to capture variations on these parameters.
- Evaluate the risk of extinction and the long-term viability of a population through a Population Viability Analysis (PVA). Establish a population target well above the minimum viable population obtained through the population model, to provide a buffer against disasters or extreme weather events.
- Consider the population size of other subspecies of *G. leucantha* subsp. *leucantha*. Since there are no historical records of the population size of the *G. leucantha* population in Playa Tortuga Negra before it was disturbed, other subspecies with stable populations could be used as a reference. All three subspecies share similar habitats on cliffs, lava flows, and craters (Guzmán *et al.*, 2017). Ideally, the reference populations should exhibit conditions closely resembling those found in Playa Tortuga Negra.

NORTH ISABELA—TIMELINE

Objetives	Restoration Steps	2023	2024	2025	2026	2027
Aid in the recovery of *Galvezia leucantha subsp. leucantha*	Identify threats to the population of *G. leucantha* through the study of physical and biological interactions					
	Identify effective strategies for the recovery of *G. leucantha* through in-situ and ex-situ experiments					
	Monitor population status and distribution of *G. leucantha*					
	Encourage natural regeneration of *G. leucantha*					

Ecological Restoration And Species Recovery Plan

GENERAL PROTOCOLS FOR ALL ISLANDS

Ecological Restoration And
Species Recovery Plan

COLLECTION, HANDLING, AND STORAGE OF SEED FROM REMOTE ISLANDS

In all islands covered by this Restoration Plan, sorting, drying and transporting of seeds will be conducted according to protocols established by the Galapagos National Park Directorate (DPNG, 2008a; 2008b). Seed collection will depend on the phenology of the collected species, some of which produce fruits all year round and others that only have fruits every two to six months. Therefore, seedling production will be planned according to seed availability and restoration objectives.

***Opuntia*:** Mature fruit from adult cacti will be collected from a large area to maintain genetic diversity. For South Plaza and Española, collection will occur throughout the island. Then all fruits will be transported to CDRS and processed following the protocols established by the Galapagos National Park Directorate (DPNG, 2008a; 2008b). In addition, to ensure the production of viable seeds, land iguana and giant tortoise feces will be collected. Droppings will be oven-dried and sieved to obtain *Opuntia* seeds.

Protocols include the following:

- Place all fruits and seeds collected in the same island of origin in paper bags. Label bags with island, locality, date, species, and collectors.
- Place paper bags from the same island or origin in plastic bags and seal. Label bags.
- Spray exterior of plastic bags with biodegradable pyrethrin-based insecticide.
- Transfer the double-bagged seeds from island of origin to the Charles Darwin Research Station (CDRS) in Santa Cruz Island.
- Oven-dry seeds at 35-40 °C in the paper bags for 2 days at the CDS Herbarium to destroy any pests and increase seed longevity by lowering their moisture content. This process works for most species (FAO, 2014) but should be tested when applying for the first time with a particular species to avoid damage. Significantly larger or smaller seeds will likely need to be dried at different temperatures or for different lengths of time.
- Store seeds in sterile jars at CDRS, labeled with island, locality, date, species, collectors.
- Transport clean, dry, sterilized and graded seeds into the GNPD greenhouse in Santa Cruz.
- Locate seeds within the designated area solely for germination of species of their island of origin.

SEED GERMINATION

The germination protocol currently used by the CDF and GNPD in the greenhouse includes the following steps:

- **Preparation of Substrate:** Place seeds in an inert substrate composed of vermiculite and peat in germination trays or seed beds.
- **Protection from Birds:** Ensure that birds do not have access to the germination area to prevent damage to seeds and seedlings.
- **Watering:** Water the seeds daily or as needed, depending on the species' requirements.
- **Monitoring:** Regularly monitor the development of seedlings.
- **Transplanting:** Once the seedlings have developed their first true leaves, transplant them from the substrate to forest trays.

GROWTH AND ADAPTATION OF SEEDLINGS IN EX-SITU GREENHOUSES

Once germinated, move seedlings to the growth area within the greenhouse. The time between these two phases will vary according to the species. Plants also need an adaptation phase before being taken to island of origin to be planted. **The following steps are needed:**

- Once plants are transplanted to forest trays, they will remain in these containers during all phases of growth and adaptation in the same greenhouse to be taken to their final location. In the GNPD greenhouse two completely inert substrates are used, both with physicochemical elements necessary to sustain the plant in all its phases up to plantation (Chango pers. comm. 2014). In the initial phase, seeds are placed in a germination substrate containing a mix of peat moss, perlite, and vermiculite. After germination, the seedlings are placed in seedling production substrate made out of peat moss and perlite. During the growth phase, inspect the forest trays for weeds and pests frequently and treat any infestation.
- In the adaptation phase, watering frequency is reduced, and plants are located in an area where they no longer have 100% protection from sunlight. This helps them to adapt to the sunny and arid conditions of the natural habitat. The GV2050 greenhouse is preferred for adaptation due to its location in the arid zone more similar to most planting sites. The greenhouse has a 50% shade cloth mesh, that allows for some sun exposure.

Ecological Restoration And
Species Recovery Plan

TRANSPORTING SEEDLINGS FROM SANTA CRUZ TO THEIR ISLAND OF ORIGIN

The transportation of seedlings from Santa Cruz back to their island of origin requires following biosecurity standards described by the protocol for transportation of living organisms within and among the Galapagos Islands (DPNG, 2008a, 2008b). This step is critical to avoid the risk of carrying any type of organism from one island to another.

Additionally, positive and successful experience gained with similar studies on other islands as occurred on Española Island are followed (Atkinson *et al.*, 2008; Coronel, 2002). The following protocols are described below:

- Seedlings remain in the adaptation phase and will be analyzed and observed before being transported to their island of origin, followed by these steps:

  Removal: seedlings are carefully removed from their containers (plastic bags/cones) with inert substrate.

  Careful monitoring: Each plant will be checked to ensure there are no signs of disease or any type of plague.

  Pest control: In case a pest is detected during monitoring, species identification and advice on control measures will be requested from CDF entomologists.

- In the case of *Opuntia*, being a succulent plant and based on the experience in the re-establishment of *O. megasperma* var. *orientalis* on Española Island, the same protocol is performed (Coronel, 2002; DPNG, 2008a) followed by these steps:

  Rinse: cacti are washed with water.

  Transplanting: cacti by nature are slow growing plants. Therefore, seedlings are small, so they are transported in the same trays with new vermiculite.

- Galapagos Biosecurity Agency inspection

  Detailed inspection by professionals and specific instruments, required to secure a safe transport of organisms.

  After a successful inspection a permit of mobilization is obtained.

- To transport, seedlings are placed in metal boxes that are cleaned with alcohol and then sealed (DPNG, 2008b). Additionally, a plant-safe insecticide will be sprayed inside the boxes.

WEED CONTROL TECHNIQUES

The following are some of the techniques suggested by The Nature Conservancy (Tu *et al.*, 2001) for weed control in natural areas, many of which are used in the Galapagos. These can be used for clearing weeds around native woody plants or before planting events:

- Hand weeding is effective for small weed infestations or weeds growing among native plants. A downside is that it disturbs the soil, which can trigger the germination of more weeds.
- Herbicides are generally more cost-effective and less time-consuming than hand weeding. Nevertheless, they should be used with great care in natural areas to avoid harming native vegetation and killing beneficial soil organisms.
- Cutting weeds with a mower, weed-eater, or scythe is also faster and more cost-effective than hand weeding. However, there caution must be taken as there is always a risk of accidentally cutting native or endemic seedlings.
- Solarization is the process of covering an area with clear plastic to increase soil temperature and kill weeds. Some advantages are that it does not use chemicals and kills weeds instead of cutting them; solarization avoids soil disturbance which can trigger weed seed germination.
- Growth-and-kill cycles: This technique reduces the seed bank of weeds. Apply weed-clearing techniques (herbicides or solarization) after rain-germinated grasses have emerged. Monitor for native seedlings and leave gaps in tarping to protect them. Repeat the process several times until weed seedbanks are reduced.
- Mulching involves covering the area around the target plant with leaf litter or other on-site vegetation to prevent seeds and seedlings from weeds receiving sunlight. It can also help preserve soil moisture. However, one drawback is that it may also impede the growth of desirable native and endemic species.

Before applying any techniques to clear out weeds, it is important to monitor the sites for native and endemic seedlings and apply physical protection strategies and ecological restoration tools to increase seedling growth and survival.

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