Metodologia y diseño experimental para estudiar el efecto y costo-beneficio de arradores de agua para el restauración ecologicao de Isla Baltra, Galapagos

Introduction:

Baltra island requires substantial human intervention to overcome the severe degredation that occurred as a result of the WW2 US military base. We now have a reference dataset of tree and cactus abundance from Seymour Island, which can allow us to generate the most accurate restoration target to-date. Though Seymour Norte is not completely free of human impacts either, it was far less impacted than Baltra and provides a quantitative measure for what to strive for on Baltra Island. Furthermore, Seymour currently has a thriving population of Galapagos Land Iguanas, which makes it a more similar ecosystem for reference to Baltra, where land iguanas are native.

Though we already have much data from our many plantings on Baltra, now that we have reference ecosystem data we can begin to focus on examining all of those species at once. These data were an extrememly valuable contribution for the initial preliminary phase of the project because now we better understand how to adjust our methods and data collection to provide the most effective results for restoring the entirety of the island. First, we now know there are several key species that we need to study for learning how to best germinate, grow, and plant these species most cost-effectively. Second, we must adapt our protocols to those that would be used by the DPNG so that our results are directly applicable when applied at a large scale by the national park or other organizations. Third, we must control for more factors to get more statistically powerful results, and third, we must collect data on the costs of every planting expedition—ideally separating planting and monitoring in order to clearly evaluate accurate costs.

Methods:

The density of nine tree or cactus species on Seymour Norte island suggest the relative abundance of those species that should be planted on Baltra (Figure 1). However, because the species on Seymour are not necessarily the same as those found on Baltra, we needed to adapt those data to the species we have on Baltra. To do that, the species on Seymour were grouped into plant functional types to create the relative density of those functional groups. Thankfully, the most abundant species on Seymour Norte were also present on Baltra, so those species' abundances were reflected from Seymour to Baltra without functional groupings (Figure 2).

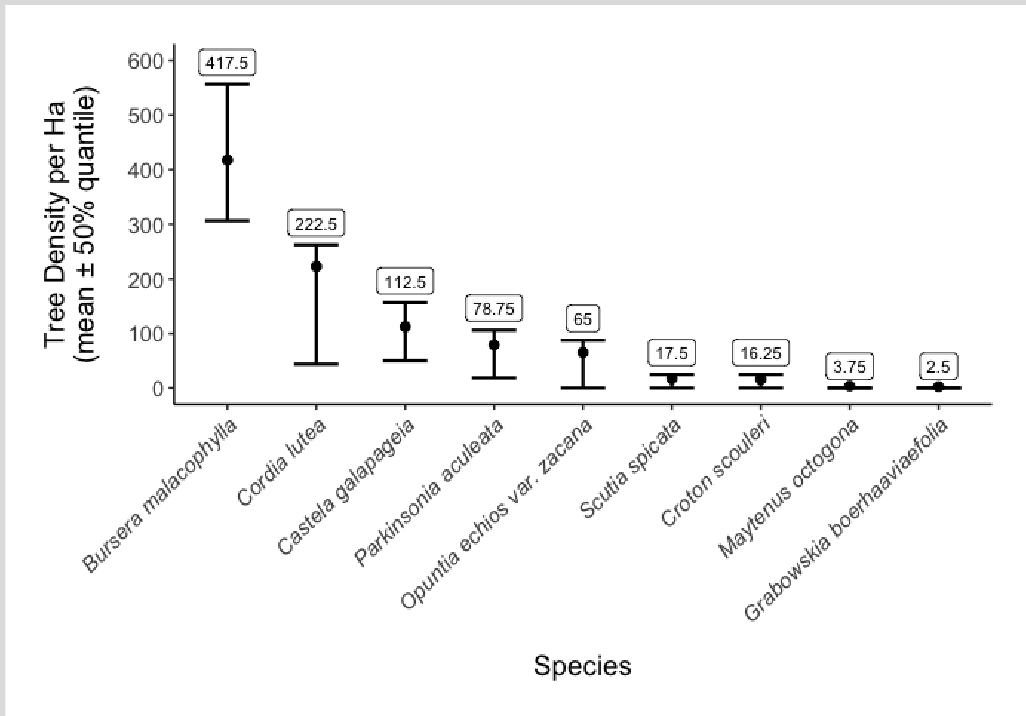

Figure 1. Density of all tree and cactus species encountered in 20 400m2 plots on Seymour Norte Island, April 2021.

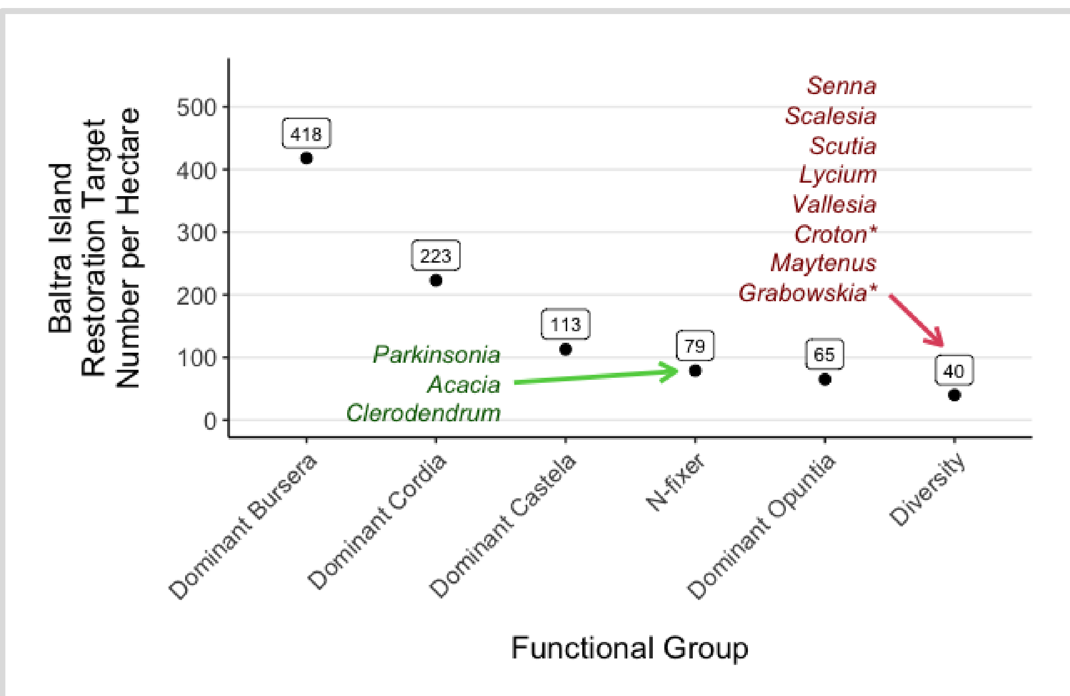

*Figure 2. Restoration target for Baltra Island based on functional groupings where species did not match between the two islands. *Grabowskia and Croton were not officially recorded as present on Baltra Island at the time writing this report.*

To implement these restoration targets, the first step is to complete a full study on the cost-effectiveness of restoring each species using water-saving technologies. This study is similar to what has been done previously on Baltra island (and in other ecological restoration sites with GV2050), but with several key differences:

1) **All treatments receive equal amounts of water at the time of planting.** This is important for ensuring that we can accurately gauge the effect of water-saving technology and separate it from the effect of just adding more water. All water must be measured using pre-marked buckets to ensure equal water is used.
2) **Plantings will not receive any more water or physical attention after planting other than taking monitoring measurements.** This is important for ensuring that our results match with the protocols that are likely to be used by the GNPD. For example, it is very unlikely that the national park will have the resources to visit and clean every water-saving technology or add water after planting. For that reason, we should collect data using the same protocol. This includes no cleaning or 'fixing' Groasis waterboxxes if pieces come loose, etc. The only exception is if a hole in the technology provides any possible threat to birds or other wildlife, in which case it can be fixed (for example, if the watering hole is open). Water-saving technologies are said to be valuable and cost-effective because they can be placed and 'forgotten' until it is time to remove them (as is the case with the Groasis Waterboxx). Additionally, regular care and maintenance is not always feasible in the case of large-scale remote restoration work, so our results must be directly applicable to those end goals.
3) **Several datapoints (in addition to normal monitoring) must be recorded during monitoring:**
    - **a.** The state of the technology should be recorded: is the lid still on, is it missing, are any parts loose or missing? This is important for recording and understanding the long-term effectiveness and functionality (and potential plastic garbage contamination) of the technologies. For example, how many plastic parts from the technologies are expected to get lost and 'pollute' during large-scale restoration. This is an important 'cost' that must be taken into account.
    - **b.** Each planting expedition needs to record all costs by category, number of days/hours, and number of field staff with roles. This is critical for getting a realistic and accurate cost estimate for scaling restoration efforts beyond our work. By recording these data in detail for each expedition, we can better separate and remove the time and resources required for our monitoring (which is not included when restoration is actually implemented).
    - **c.** The date when Groasis Waterboxx is removed from each individual plant must be recorded. This is essential for providing a suggested time-table for each species on Baltra Island.
    - **d.** The age of each seedling at the time of planting must be recorded in case there are any effects of seedling age on later survival. Seedlings can be labeled before taken to the field and then their age is added to the datasheet when doing the initial monitoring.
4) **All plantings must be randomly stratified with a balanced treatment design within each site.** In other words, all plantings are located randomly with respect to treatment and species, and there is maintained a balanced number of treatments within each site (e.g., one site does not have more controls than another site). Randomizing locations can be

achieved by pre-labeling flags with species and treatment and placing them haphazardly within a site. Ensuring a balanced design for each site can be done when labeling flags before placement. Similarly, it is important that treatments and species are planted in a random progression. For example, do not the controls or Groasis or a certain species for separate days. There are several reasons for this, but for example if work needs to end early, then the experimental planting will still remain more or less balanced. It will also ensure that certain species or treatments do not receive subconscious preferential treatment.

5) **Plantings will follow the overall experimental design for sample sizes, but also follow guidelines for minimum sample sizes required for each individual planting expedition.** This is important for ensuring reliable results. For example, it is important to plant a minimum of six plants with each treatment in one planting expedition than to plant only one or two plants (Tables 1 and 2).
6) **This experiment can be divided into stages:** Stage one will be considered complete once all species are planted with these protocols and reach the required minimum sample sizes. Stage two will be complete and initial results can be analyzed once two years have passed since stage one was complete. Stage three will be complete once 10 years have passed since stage one was complete or several years have passed since all Groasis Waterboxxes have been removed from surviving individuals.
7) **Plantings for this experiment should be monitored a minimum of every four months until stage two is complete, and then every six months thereafter (twice per year).** This will be important for acquiring sufficient data.
8) **When allocating resources and time towards germinating and growing seedlings for outplanting, priority should be given first to the most abundant species and functional groups (Figure 2, Table 1).** The reason for this is that those species or groups will have the biggest costs when scaling restoration since they are most abundant and those species are a priority for evaluation.
9) **Not all treatments are used with all species in this design in cases where existing results strongly suggest that those technologies are not likely to provide any improvement or value.** For example, hydrogel was excluded from most species because of its general negative effect.
10) **Results thus far suggest that the best survival has been achieved by planting between the months of June and October.** Planting expeditions should be encouraged during this period, but the results are preliminary and this is not a strong rule.
11) **Once overall sample sizes are reached for each species, no further resources are required for planting or germinating more of those species.** It will be better to allocated our limited time and resources towards ensuring a complete sample size of all species in this experiment rather than planting many additional individuals of a species for which we already have sufficient data. In cases where we already have too many seedlings for a particular species, it is important that we establish collaborations with DPNG and other organizations who can plant our additional seedlings using our current best findings. This will be necessary later anyway, so better to begin with these collaborations now so that we can have enough resources for the scientific component of the work.

Table 1. Overall experimental design for evaluating water-saving technologies for Baltra Island restoration.

	Control	Hydrogel	Groasis	Groasis + Hydrogel	Total	Functional Group
Bursera	**50**	**50**	**50**	**50**	**200**	**dominant**
Cordia	**50**	**50**	**50**	**50**	**200**	**dominant**
Castela	**50**	**0**	**50**	**0**	**100**	**dominant**
Opuntia	**50**	**0**	**50**	**0**	**100**	**dominant**
Parkinsonia	**50**	**0**	**50**	**0**	**100**	**n-fixer**
Acacia	**50**	**50**	**50**	**50**	**200**	**n-fixer**
Clerodendrum	**50**	**50**	**50**	**50**	**200**	**n-fixer**
Senna	**50**	**0**	**50**	**0**	**100**	**diversity**
Scalesia	**50**	**50**	**50**	**50**	**200**	**diversity**
Scutia	**50**	**50**	**50**	**50**	**200**	**diversity**
Lycium	**50**	**50**	**50**	**50**	**200**	**diversity**
Croton	**50**	**50**	**50**	**50**	**200**	**diversity**
Maytenus	**50**	**50**	**50**	**50**	**200**	**diversity**
Grabowskia	**50**	**50**	**50**	**50**	**200**	**diversity**
Vallesia	**50**	**0**	**50**	**0**	**100**	**diversity**

Table 2. Required minimum experimental design template for every site during a planting planting expedition. Note that if a species does not require a technology, then those replicates may be omitted.

	Site	Control	Hydrogel	Groasis	Groasis + Hydrogel	Total
Species 1	*Site 1*	**6**	**6**	**6**	**6**	**24**
Species 2	*Site 1*	**6**	**NA**	**6**	**6**	**18**
Etc…	*Etc…*	**6**	**6**	**6**	**6**	**24**
***Minimum 6 plants per species per technology per site in a balanced design during each planting expedition.**						

For example, this may be one example of an experimental design:

	Site	Control	Hydrogel	Groasis	Groasis + Hydrogel	Total
Acacia	*Casa Ojo*	*10*	*10*	*10*	*10*	*40*
Parkinsonia	*Casa Ojo*	*15*	—	*15*	—	*30*
Acacia	*Casa Piedra*	*20*	*20*	*20*	*20*	*80*