Galapagos Verde 2050: An opportunity to restore degraded ecosystems and promote sustainable agriculture in the Archipelago.

GALAPAGOS REPORT 2013-2014

BIODIVERSITY AND ECOSYSTEM RESTORATION

GALAPAGOS VERDE 2050: AN OPPORTUNITY TO RESTORE DEGRADED ECOSYSTEMS AND PROMOTE SUSTAINABLE AGRICULTURE IN THE ARCHIPELAGO

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Galapagos Verde 2050: An opportunity to restore degraded ecosystems and promote sustainable agriculture in the Archipelago

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Invasive species constitute the greatest threat to terrestrial biodiversity in Galapagos (Gardener *et al.*, 2010a, 2010b). Currently, there are about 900 species of introduced plants of which at least 131 are already invading natural areas of the Archipelago (Guezou & Trueman, 2009; Jaramillo *et al.*, 2013). The humid zones of inhabited islands have the most degraded ecosystems, largely due to invasive species and agriculture (Gardener *et al.*, 2010a; Renteria & Buddenhagen, 2006).

Conservation and/or restoration of the integrity and resilience of ecosystems represent the most effective strategies for ensuring that Galapagos ecosystems continue to generate environmental services for society (DPNG, 2014). The Galapagos Verde 2050 project, a model of applied science on a regional scale, was designed with these conceptual principles in mind. It seeks to transform an altered socioecological system into a healthy and functional system.

Galapagos Verde 2050 is a multi-institutional, interdisciplinary initiative that seeks to contribute to the sustainability of the Archipelago through ecological restoration and sustainable agriculture, while providing an example of effective sustainable development for the rest of the world (Jaramillo *et al.*, 2014). The objectives of the project are:

1. Contribute to the restoration of degraded ecosystems in order to restore and/or maintain their capacity to generate services for humans;

2. Control and/or eradicate invasive introduced species in areas of high ecological value;

3. Accelerate the recovery process for native and endemic plant species that have slow natural growth;

4. Reduce the risk of introduction of exotic species through sustainable agriculture, which would also contribute to local self-sufficiency;

5. Contribute to economic growth through year-round sustainable agriculture.

All project objectives contribute to the well-being of the human population of Galapagos and their natural environment and are thus aligned with the *Management Plan of the Protected Areas of Galapagos* (DPNG, 2014) and the

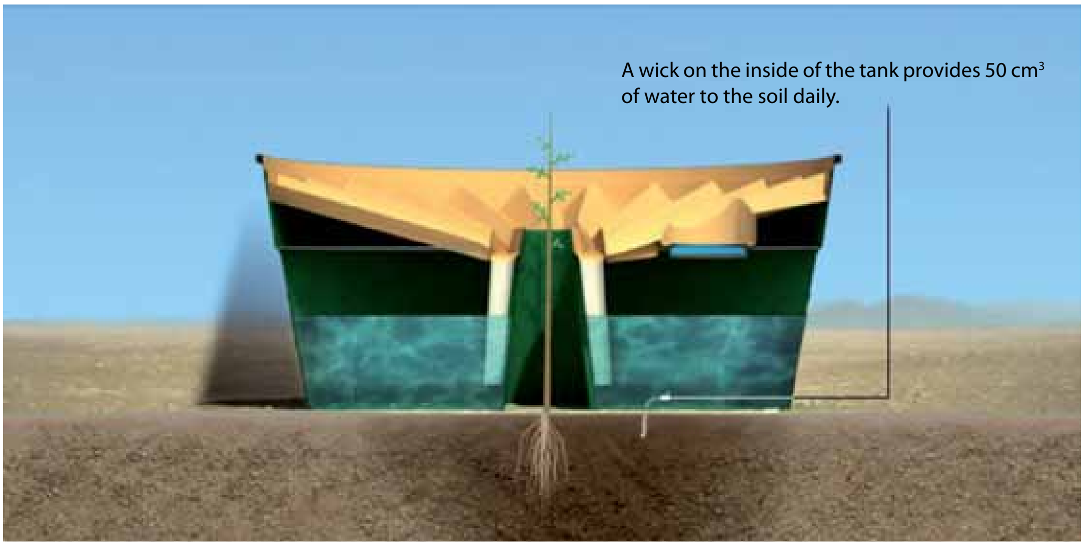

Figure 1. Structure and model of the Groasis Technology, from a vertical cut (taken from www.groasis.com/es).

National Plan of Good Living (SENPLADES, 2013); as well as with the United Nations Millennium Development Goals.

A new technology for water conservation and to enhance plant growth

The Groasis Technology (GT) waterboxx, invented by Mr. Pieter Hoff of the Netherlands and designed by Groasis, is an innovative tool to optimize water use in propagating and cultivating plants (Figure 1). It reduces normal water consumption by 90%, a much greater reduction that seen in other techniques such as drip irrigation. It has been used successfully in more than 30 countries around the world, primarily in arid and desert areas, such as the Sahara Desert (Hoff, 2013). GT has proven effective in increasing survival of seedlings in a variety of environments, including highly eroded land.

The GT waterboxx is designed to provide a permanent supply of water to plant roots through a wick, allowing the roots to grow deeper and more vertically, which ensures the vitality of the plants even after the box is removed. Its use in Galapagos can contribute to restoring ecosystems through the recovery of emblematic native and endemic plant species and to establishing year-round sustainable agriculture.

This article describes the results of a pilot project to test the functionality of GT in Galapagos. These findings were used to develop Galapagos Verde 2050, which from 2014 to 2050 will contribute to the conservation of vulnerable ecosystems, primarily in the humid zones (DPNG, 2014; Jager *et al.*, 2007; Renteria *et al.*, 2006; Trusty *et al.*, 2012; Tye *et al.*, 2001; Jaramillo *et al.*, 2014) and to the development of sustainable agriculture. Sustainable agriculture in Galapagos can help to reduce imports of plant products from mainland Ecuador, thus reducing the threat of introduction of invasive species (FEIG, 2007; Martinez & Causton, 2007; Trueman *et al.*, 2010; Trueman & d'Ozouville, 2010). Sustainable agriculture also contributes to food security for the human population, which is a stated goal of the *National Plan for Good Living* (SENPLADES, 2013).

Methods

The pilot project was based on an agreement between the Fundación Fuente de Vida (FFV) of Ecuador, representing Groasis (a Dutch company), and the Charles Darwin Foundation (CDF), and close collaboration with the Galapagos National Park Directorate (GNPD). The project also involved the Decentralized Autonomous Government of Floreana, the Provincial Directorate of the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries (MAGAP – Spanish acronym), the Galapagos Ecological Airport (ECOGAL – Spanish acronym), and the port captaincy of Puerto Ayora.

Ecological restoration

GT was used for restoration work on Floreana, Baltra, and Santa Cruz. In Floreana 300 waterboxxes were used at a model farm located in the humid zone. In Baltra 19 waterboxxes were located in a highly degraded area located in the abandoned garbage dump to grow six native and endemic species. In Santa Cruz, five waterboxxes were used with three endemic species in a small area at Los Gemelos, a visitor site in the highlands. In addition, invasive introduced plants were eliminated from the facilities of the Puerto Ayora port captaincy and were replaced with endemic species using GT to promote the use of native and endemic plants in urban areas. Several waterboxxes with endemic plants were also located within the premises of the GNPD and CDF to showcase the technology.

Sustainable agriculture

Experiments in sustainable agriculture were carried out on Floreana and Santa Cruz, with community support. Waterboxxes were used in 21 family vegetable gardens (18 on Floreana and three on Santa Cruz) in both the humid and the arid zones. At the Safari Camp resort in Santa Cruz, this technology was tested with cacao, tomato, and cucumber plants.

Plant species used

The pilot project involved 52 species (native, endemic, introduced, and cultivated plants) of which 60% were intended for ecological restoration and 40% for sustainable agriculture in vegetable gardens and farms (Table 1). The selection of species for ecological restoration was based on the IUCN Red List (Jaramillo *et al.*, 2013), focusing primarily on emblematic and threatened species from each island. In the case of sustainable agriculture, most species were fruit trees. Several ornamental and endemic species were also tested at the request of community members in Floreana.

The species selected for both ecological restoration and sustainable agriculture were distributed in eight different substrate types and four vegetation zones (Table 2). For each species, two controls (no GT) were established. Due to the extreme shortage of water in Floreana and Baltra, the amount of water used for the operation of the boxes was decreased to 70% and 50% of the normal volume of water required.

Table 1. Classification of the species used in the pilot project on the three islands.

Island	Objective	Family	Species	Common name	Origin*
Baltra	Ecological restoration	Mimosaceae	*Acacia macracantha* Humb. & Bonpl. ex Willd.	Acacia	N
		Burseraceae	*Bursera malacophylla* B.L. Rob.	Incense tree	E
		Simaroubaceae	*Castela galapageia* Hook. f.	Castela	E
		Cactaceae	*Opuntia echios* var. *echios* Howell	Prickly pear cactus	E
		Caesalpinaceae	*Parkinsonia aculeata* L.	Jerusalem thorn	N
		Asteraceae	*Scalesia crockeri* Howell	Crocker's scalesia	E
Santa Cruz	Ecological restoration	Amaranthaceae	*Alternanthera echinocephala* (Hook. f.) Christoph.	Spiny-headed chaff flower	N
		Amaranthaceae	*Alternanthera filifolia* (Hook. f.) Howell	Thread-leafed chaff flower	N
		Verbenaceae	*Clerodendrum molle* Kunth	Glorybower	N
		Combretaceae	*Conocarpus erectus* L.	Button mangrove	N
		Malvaceae	*Gossypium darwinii* G. Watt	Darwin's cotton	E
		Convolvulaceae	*Ipomoea pes-caprae* (L.) R. Br.	Beach morning-glory	N
		Celastraceae	*Maytenus octogona* (L'Hér.) DC.	Maytenus	N
		Melastomataceae	*Miconia robinsoniana Cogn.*	Galapagos miconia	E
		Cactaceae	*Opuntia echios* var. *gigantea* Howell	Prickly pear cactus	E
		Fabaceae	*Piscidia carthagenensis* Jacq.	Piscidia	N
		Rubiaceae	*Psychotria rufipes* Hook. f.	White wild coffee	N
		Asteraceae	*Scalesia affinis* Hook. f.	Radiate-headed scalesia	E
		Asteraceae	*Scalesia helleri* ssp. *santacruziana* Harling	Heller's scalesia	E
		Asteraceae	*Scalesia pedunculata* Hook. f.	Tree scalesia	E
	Sustainable agriculture	Cucurbitaceae	*Cucumis sativus* L.	Cucumber	C
		Solanaceae	*Solanum lycopersicum* L.	Tomato	C
		Sterculiaceae	*Theobroma cacao* L.	Cacao	C

Floreana	Ecological restoration	Amaranthaceae	*Alternanthera filifolia* (Hook. f.) Howell	Thread-leafed chaff flower	N
		Burseraceae	*Bursera graveolens* (Kunth) Triana & Planch.	Incense tree	E
		Verbenaceae	*Clerodendrum molle* Kunth	Glorybower	N
		Boraginaceae	*Cordia lutea* Lam.	Yellow cordia	N
		Asteraceae	*Darwiniothamnus tenuifolius* (Hook. f.) Harling	Lance-leafed Darwin's shrub	E
		Asteraceae	*Lecocarpus pinnatifidus* Decne	Wing-fruited lecocarpus	E
		Verbenaceae	*Lippia salicifolia* Andersson	Narrow-leafed lippia	E
		Plumbaginaceae	*Plumbago zeylanica* L.	Ceylon leadwort	N
		Rubiaceae	*Psychotria angustata* Andersson	Pink wild coffee	N
		Asteraceae	*Scalesia affinis* Hook. f.	Radiate-headed scalesia	E
		Asteraceae	*Scalesia pedunculata* Hook. f.	Tree scalesia	E
		Aizoaceae	*Sesuvium portulacastrum* (L.) L.	Sea purslane	N
		Solanaceae	*Solanum quitoense* Lam.	Purple solanum	I
		Sterculiaceae	*Waltheria ovata* Cav.	Waltheria	N
		Rutaceae	*Zanthoxylum fagara* (L.) Sarg.	Cat's claw	E
	Sustainable agriculture	Anacardiaceae	*Mangifera indica* L.	Mango	
		Apocynaceae	*Nerium oleander* L.	Oleander	
		Lamiaceae	*Ocimum campechianum* Mill.	Wild sweet basil	
		Lauraceae	*Persea americana* Mill.	Avocado	
		Alliaceae	*Allium fistulosum* L.	Welsh onion	
		Annonaceae	*Annona cherimola* Mill.	Cherimoya	
		Cannaceae	*Canna indica* L.	Indian shot	
		Solanaceae	*Capsicum annuum* L.	Cayenne pepper	
		Caricaceae	*Carica papaya* L.	Papaya	
		Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsun. & Nakai	Watermelon	
		Rutaceae	*Citrus reticulata* Blanco	Mandarin orange	C
		Rutaceae	*Citrus x limetta* Risso	Sweet lemon	C
		Rutaceae	*Citrus x limon* (L.) Osbeck	Lemon	C
		Rutaceae	*Citrus x sinensis* (L.) Osbeck	Orange	C
		Solanaceae	*Solanum lycopersicum* L.	Tomato	C
		Euphorbiaceae	*Jatropha curcas* L.	Barbados nut	C
		Arecaceae	*Cocos nucifera* L.	Coconut	C
		Cucurbitaceae	*Cucumis melo* L.	Muskmelon	C
		Fabaceae	*Phaseolus lunatus* L.	Lima bean	C

* N = native; E = endemic; I = introduced; C = cultivated.

Table 2. Vegetation zones, soil types, and the origin of the plant species used in the pilot project on Baltra, Santa Cruz, and Floreana (N = native, E = endemic, C = cultivated).

Island	Project	Zone	Substrate	Species origin			Total Species
				N	E	C	
Baltra	Ecological restoration	Arid	Clay	2	4	0	6
		Littoral	Clay	0	1	0	1
Floreana	Sustainable agriculture	Arid	Clay	0	0	13	13
			Humus	0	0	6	6
			Humus-clay	0	0	15	15
			Humus-rocky	0	0	8	8
			Rocky	0	0	3	3
			Rocky-clay	0	0	6	6
		Humid	Clay	0	0	1	1
			Humus	0	0	6	6
	Ecological restoration	Arid	Clay	5	4	0	9
		Humid	Humus	0	1	0	1
			Humus-clay	1	1	0	2
			Humus-rocky	2	4	0	6
			Rocky-clay	0	1	0	1
			Humus	3	5	0	8
			Humus-rocky	2	4	0	6
		Littoral	Clay	2	1	0	3
			Rocky-clay	2	2	0	4
Santa Cruz	Sustainable agriculture	Transition	Clay	0	0	2	2
			Humus	0	0	1	1
			Humus-rocky	0	0	1	1
	Ecological restoration	Humid	Humus	0	4	0	4
		Littoral	Clay	3	0	0	3
			Sandy	3	4	0	7
			Humus	2	1	0	3
			Rocky	2	1	0	3
			Rocky-sandy	2	1	0	3

Results

Ecological restoration

Preliminary results for the arid zone in Baltra indicated that the growth rate of seedlings planted using GT was significantly greater than those without GT, and that the growth rate of certain species, especially *Opuntia echios* var. *echios*, was particularly rapid. The same results were seen in Floreana and Santa Cruz (Figure 2). *Opuntia* species normally grow an average of 2 cm per year (Colonel, 2002; Hicks & Mauchamp, 2000; Estupiñan & Mauchamp, 1995), in contrast with the registered monthly growth of 1.5 cm with this new technology, which could result in an annual growth of more than 10 cm (Figure 3).

However, the growth and survival of seedlings in Baltra were affected by the physical characteristics of the soil (high levels of clay), evidenced by the stress of the control seedlings, and soil compaction caused by anthropological activities (airport, transport of heavy equipment, etc.). Signs of herbivory by land iguanas were also noted, as some species included in the project are part of the iguanas' natural diet. This observation demonstrates the importance of the project to restore the natural dynamics of degraded ecosystems in order to ensure food sources for native fauna.

In Floreana as in Baltra, positive results were obtained in three vegetation zones (literal, arid, and humid), using 14 native and endemic species. The greatest success was observed in the humid zone.

Sustained growth was also observed for the majority of the 14 native and endemic species used in Santa Cruz.

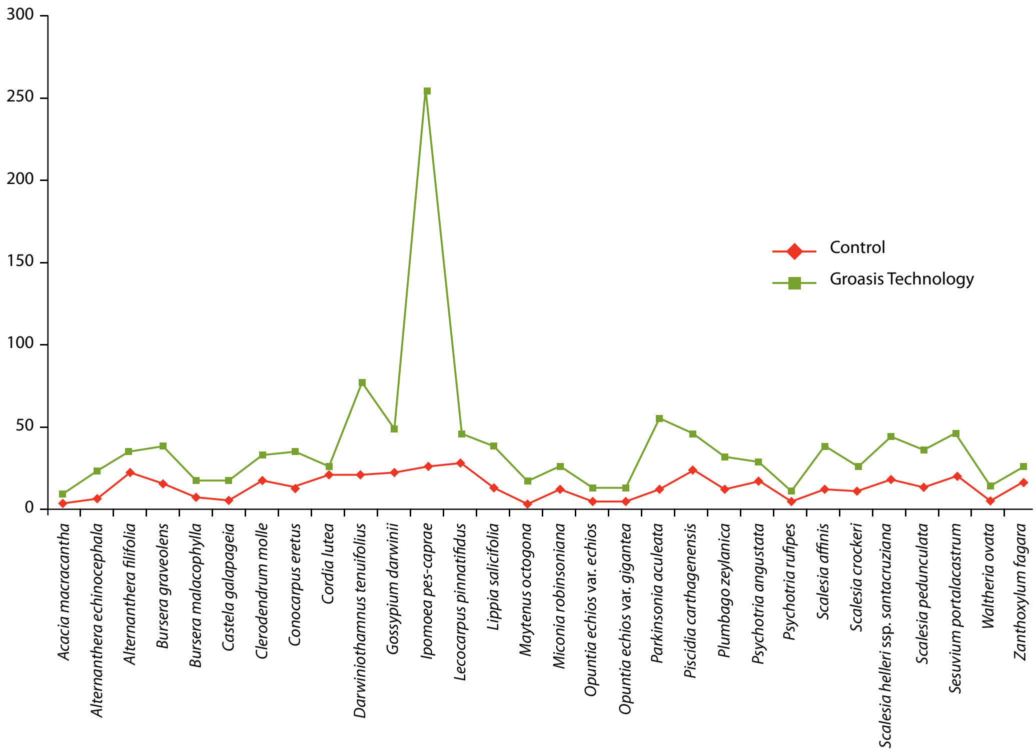

Figure 2. Average growth rate of the 30 species used in the pilot project for ecological restoration (using GT and control without GT) on Baltra, Floreana, and Santa Cruz Islands.

Figure 3. a) *Opuntia echios* var. *echios* near the Baltra airport, July 29, 2013; **b)** the same plant, November 17, 2013, after almost four months of monitoring, and **c)** the same plant without the box after 6 months, January 27, 2014.

An exceptional case was the high growth rate of *Scalesia pedunculata*, in both Floreana and Santa Cruz (at Los Gemelos), much like *Opuntia echios* var. *echios* in Baltra (Figure 4).

Sustainable agriculture

Preliminary results in sustainable agriculture in both Floreana and Santa Cruz were positive for the 22 cultivated species included in the experiment. However, in the case of tomatoes (*Solanum lycopersicum*) and watermelon (*Citrulus lanatus*), growth rates were more rapid than was observed for the other species (Figure 5).

Galapagos Verde 2050: Steps towards the future

Results of the pilot project in both restoration and sustainable agriculture indicate that GT works in Galapagos under different climatic and ecological conditions. Based on these results, Galapagos Verde 2050 was launched. This three-phase project began in January 2014 and will end in 2050.

Figure 4. *Scalesia pedunculata* in Floreana Island ready to grow naturally; Aníbal Altamirano, GNPD ranger, and Adrián Cueva, CDF field assistant, demonstrate how the box is extracted without causing damage to the plant.

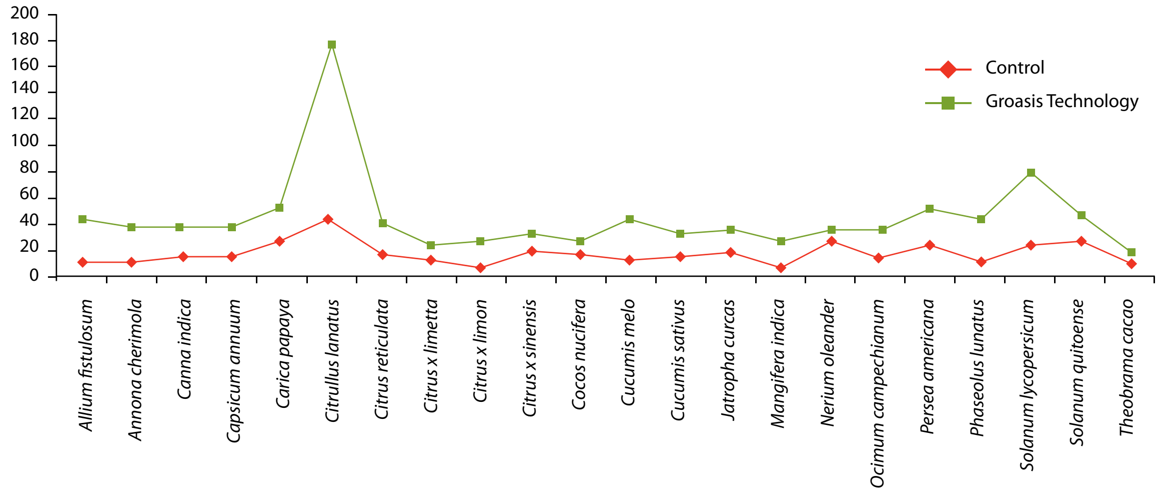

Figure 5. Average growth rate of 22 species used for sustainable agriculture (with GT and control without GT) in Floreana and Santa Cruz Islands.

Phase 1 (January 2014 to December 2016). Phase I includes ecological restoration on Baltra, Santa Cruz, South Plaza, and Floreana Islands. On Baltra the project focuses on land iguana nesting areas. On Santa Cruz, two small populations (1 ha) of *Scalesia affinis*, an endangered species, will be restored in the areas of El Mirador and Garrapatero (Figure 7). On South Plaza the work will focus on the restoration of the *Opuntia echios* var. *echios* population throughout the island (13 ha). On Floreana the efforts will focus on the restoration of a degraded area in the Black Gravel mine and supporting MAGAP's efforts to achieve adoption of sustainable agricultural practices on 25% of the farms. It is expected that some agricultural areas on Floreana will be designated for agro-ecological production according to MAGAP's Bioagriculture Plan for Galapagos, which promotes integrated production systems (Elisens, 1992).

Phase 2 (January 2017 to December 2018). During Phase 2, ecological restoration will occur in degraded ecosystems on Floreana that have been defined as priority areas by the GNPD. Work will be conducted on Española Island to achieve the repopulation of at least 20% of the area where *Opuntia megasperma* var. *orientalis* existed historically. In terms of sustainable agriculture, according to plans established by MAGAP, this phase of the project will strive to involve 100% of farms on Floreana in agro-ecological production.

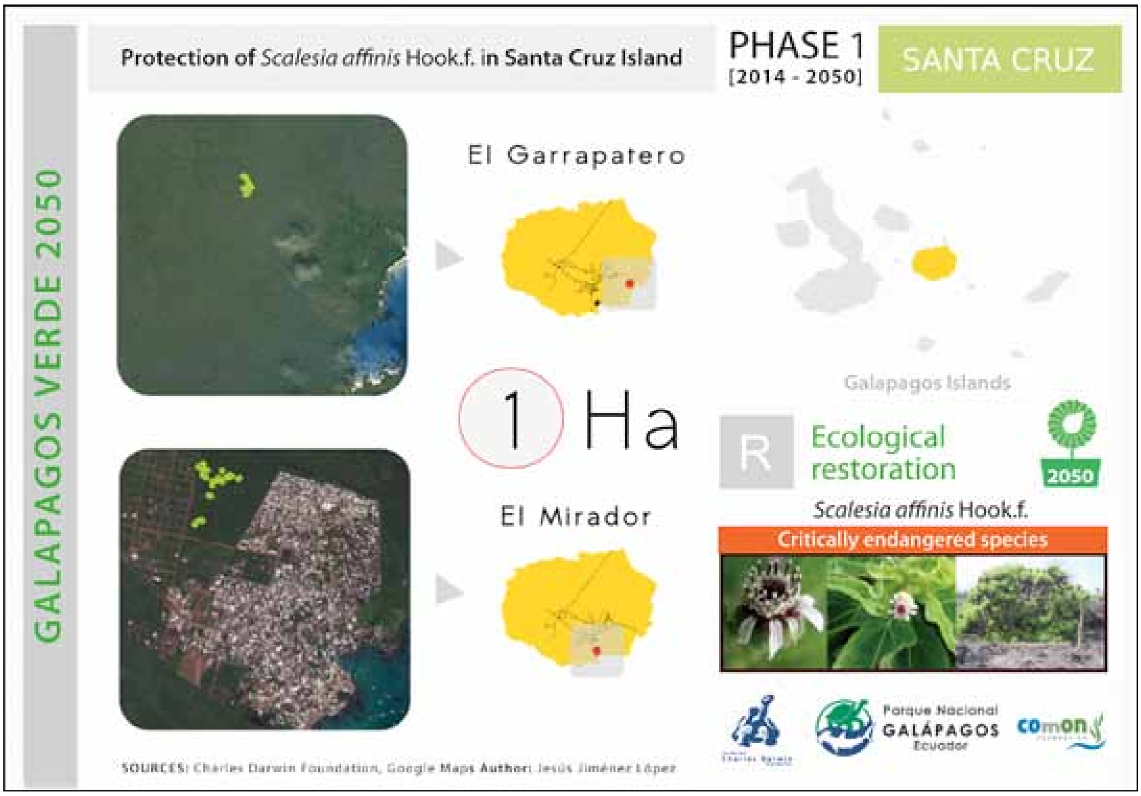

Figure 6. Fenced areas in El Mirador and Garrapatero to protect the last remnants of Scalesia affinis, a critically endangered species on Santa Cruz Island.

Phase 3 (January 2019 to December 2050). During this extended period the use of GT will be expanded to restore priority ecosystems and species identified in the GNPD's *Management Plan for the Protected Areas of Galapagos*. This work will take place on populated islands as well as on Santiago, where invasive plant and animal species have caused degradation, and on Española Island, where the goal is complete recovery of the cactus population (*O. megasperma* var. *orientalis*), based on available information regarding its historical distribution. In terms of sustainable agriculture, GT will be used to help achieve the goals of MAGAP regarding the implementation of the new model of agricultural production in the Islands.

Each phase of the project will involve establishing a timeline for completing specific goals for each island or species, as in the example of *Scalesia affinis* on Santa Cruz Island (Figure 7).

Conclusions and recommendations

The Groasis Technology (GT) pilot project in Galapagos resulted in the following conclusions:

- The use of GT is viable in Galapagos for both large-scale ecological restoration and sustainable agriculture.
- Some transplanted control plants (cultivated without GT) did not survive the stress from transplanting, while those that used GT not only survived but demonstrated accelerated growth. This indicates that GT offers protection for endemic Galapagos plants and minimizes the stress of transplanting, ensuring and increasing their survival rate.
- Despite certain externalities, such as herbivory and damage caused by domestic animals and humans, it is clear that GT stimulates growth and is effective with agricultural species.
- Growth acceleration occurred in restoration activities and sustainable agriculture, even in very arid zones where it was necessary to significantly reduce the normal amount of water required by the Groasis waterboxx. This result indicates that GT is an effective technology, even in extreme drought conditions.

The following recommendations are based on the conclusions of the pilot study:

- Expand the use of GT for ecological restoration on additional islands.
- Expand the use of GT in agriculture to increase production in Galapagos.

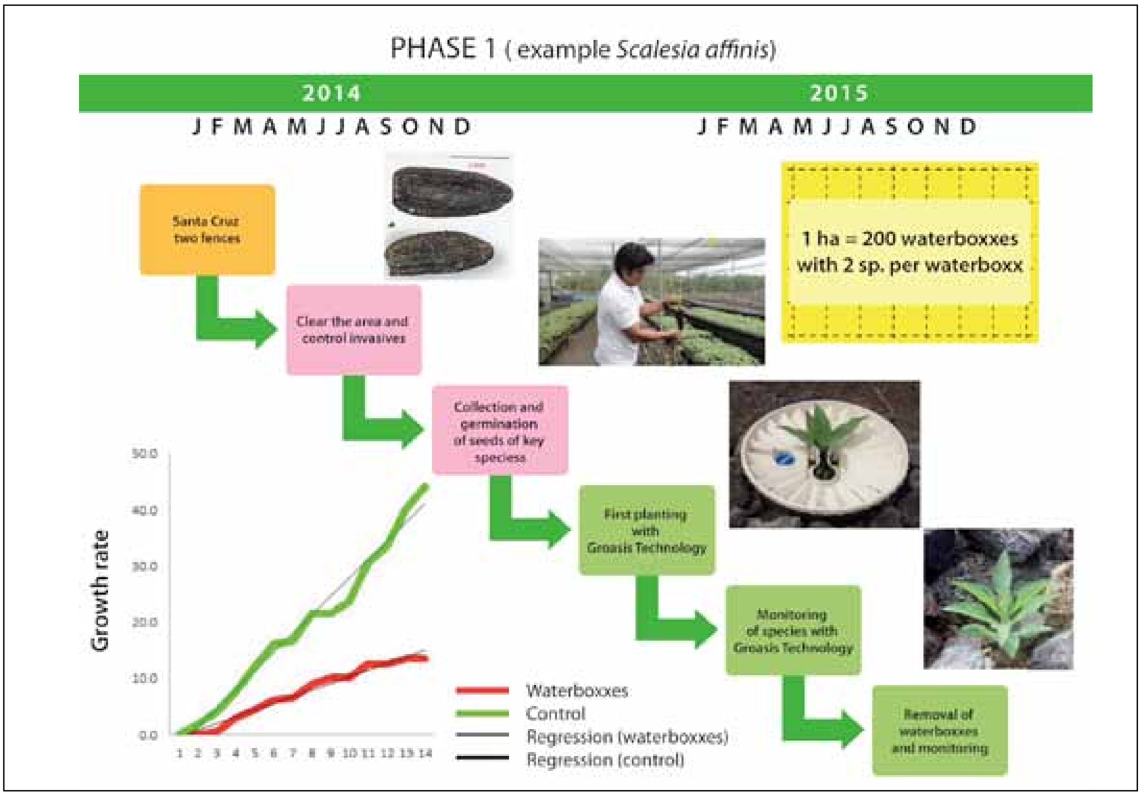

Figure 7. Example of work with Scalesia affinis to restore 1 ha in two areas on Santa Cruz Island during Phase I of the project.

- Expand inter-institutional coordination of restoration and agriculture projects to ensure project success and to incorporate new eco-friendly technologies, such as GT.

The ability of GT to overcome water constraints makes it an important tool for restoring threatened ecosystems and species and improving agricultural production. By 2050, it is expected that this project, implemented through coordinated and cooperative efforts of Galapagos stakeholders, will result in significant contributions to ecosystem restoration, sustainable agriculture, and a more sustainable archipelago.

Information about the Galápagos Verde 2050 Project is available at: www.darwinfoundation.org/es/ciencia-e-investigacion/galapagos-verde-2050/.

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