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Enhancing restoration success of rare xeric plants through water-saving technologies: A case study of *Scalesia affinis* ssp. *affinis* in the Galapagos Islands

Esme Plunkett [1] , **Luka Negoita** [1] , **Christian Sevilla** [2] , **Patricia Jaramillo Díaz** Corresp. [1, 3]

[1] Charles Darwin Foundation, Puerto Ayora, Galapagos Islands, Ecuador

[2] Galapagos National Park Directorate, Puerto Ayora, Galapagos Islands, Ecuador

[3] Department of Botany and Plant Physiology, Universidad de Málaga, Malaga, Spain

Corresponding Author: Patricia Jaramillo Díaz
Email address: patricia.jaramillo@fcdarwin.org.ec

Arid tropical archipelagos, such as the Galapagos Islands, host a high concentration of endemic plant species, many of which currently require restoration to recover from past environmental degradation. Water-saving technologies have potential for hastening restoration by addressing the primary limiting factor for rare xeric plants – water availability – yet whether such technologies provide any advantage over that from ambient precipitation inputs remains unclear. This study examined response by the endemic plant species *Scalesia affinis* ssp. *affinis* to the implementation of water-saving technology during early stages of ecological restoration. Survival of 374 individuals planted across six sites on Santa Cruz Island, Galapagos (326 with technology and 48 as controls) was monitored. A mixed-effect logistic regression that modelled plant survival as a function of total precipitation, standardized precipitation index, and technology treatment revealed that short-term increases in ambient precipitation increased plant survival, longer-term excess in rainfall increased mortality, and use of Groasis Waterboxx water-saving technology increased survival from 8% to 53%. We conclude that water-saving technologies can enhance survival of rare plants such as *Scalesia affinis* ssp. *affinis* in restoration programs in dry tropical archipelagos.

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Esme Plunkett[1], Luka Negoita[1], Christian Sevilla[2], Patricia Jaramillo Díaz[1, 3]

[1] Charles Darwin Research Station, Charles Darwin Foundation, Santa Cruz, Galápagos, 200102, Ecuador.

[2] Galapagos National Park Directorate, Galapagos, Ecuador,

[3] Department of Botany and Plant Physiology, Málaga University, Málaga, 29071, Spain.

Corresponding Author:

Patricia Jaramillo Díaz [1, 3]

Email address: patricia.jaramilllo@fcdarwin.org.ec

Abstract

Arid tropical archipelagos, such as the Galapagos Islands, host a high concentration of endemic plant species, many of which currently require restoration to recover from past environmental degradation. Water-saving technologies have potential for hastening restoration by addressing the primary limiting factor for rare xeric plants – water availability – yet whether such technologies provide any advantage over that from ambient precipitation inputs remains unclear. This study examined response by the endemic plant species *Scalesia affinis* ssp. *affinis* to the implementation of water-saving technology during early stages of ecological restoration. Survival of 374 individuals planted across six sites on Santa Cruz Island, Galapagos (326 with technology and 48 as controls) was monitored. A mixed-effect logistic regression that modelled plant survival as a function of total precipitation, standardized precipitation index, and technology treatment revealed that short-term increases in ambient precipitation increased plant survival, longer-term excess in rainfall increased mortality, and use of Groasis Waterboxx water-saving technology increased survival from 8% to 53%. We conclude that water-saving technologies can enhance survival of rare plants such as *Scalesia affinis* ssp. *affinis* in restoration programs in dry tropical archipelagos.

Introduction

Despite occupying just < 5% of the global terrestrial area, oceanic islands are home to > 20% of the planet's terrestrial plant and vertebrate species (Courchamp *et al.,* 2014) and experience high levels of degradation and species extinction (Gillespie et al. 2013). The Galapagos archipelago and its flora is no exception: 37% of plant taxa are endemic and loss of the archipelago's dry forest has been substantial (Tye & Francisco-Ortega 2011). The Galapagos flora is currently the focus of major restoration activities (Jaramillo *et al.* 2020). Water-saving technology (WST) could potentially accelerate these xeric species' restoration, given that water availability has been identified as a key driver of seeding survival of xeric plants (Tapia *et al.* 2019; Negoita *et al*. 2021) both in Galapagos and similar arid tropical zones elsewhere (Jaramillo *et al*. 2020).

We focused on *Scalesia affinis* ssp. *affinis* as a model taxon to investigate the effect of WST on accelerating species restoration. In 2013, the Charles Darwin Foundation (CDF), via the Galapagos Verde 2050 (GV2050) project, began an initiative to restore populations of *Scalesia* spp., with a particular focus on *S. affinis* ssp. *affinis* on Santa Cruz Island. *Scalesia* (Asteraceae) is the largest of seven endemic genera of the Galapagos, with 15 species and more than 20 taxa, and a prominent example of adaptive radiation (Adsersen & Svendsen 1986; Tye 2003) from colonizing barren lava fields, to forming a forest canopy (Hamann 1979a; Itow 1995; Kelager & Philipp 2008; Atkinson et al. 2009; Watson et al. 2009). Many *Scalesia* spp. are threatened by anthropogenic habitat changes, introduced species, and the changing climate (Lawesson 1986; Caujapé-Castells et al. 2010). The population of *Scalesia affinis* ssp. *affinis* on Santa Cruz Island has dramatically declined (Atkinson *et al.* 2009). By the year 2000 the population within the main town of Puerto Ayora dropped to five individuals (Nielsen 2004; Kelager & Philipp 2008), and in 2007 it was reported that all areas with previously large populations of *S.affinis* ssp. *affinis* had seen population decline (Jaramillo 2007). *Scalesia affinis,* provides food and shelter for many birds, land iguanas, and insects (Nielsen 2004) and is the preferred nesting site for the endemic carpenter bee (*Xylocopa darwini*) — the primary pollinator in Galapagos (McMullen 1989).

Through regular monitoring over six years, GV2050 collected data on the survival of *S. affinis* ssp. *affinis* plantings using WST, as well as data on other associated environmental conditions (Jaramillo *et al*. 2020). Our goal was to inform future restoration efforts by evaluating the effect of water-availability on *S. affinis* ssp. *affinis* survival in Galapagos. By extension, we can better understand how WSTs may benefit programs to restore rare xeric plant species elsewhere in the arid tropics.

Materials & Methods

Study area, sites, and target species

Our studies occurred on Santa Cruz Island (-0.6394, -90.3372) — the second largest island of the Galapagos archipelago (Helsen *et al.* 2009), which also hosts the largest human population of the archipelago (Watson et al. 2009; INEC 2015). We studied *S. affinis* ssp. *Affinis,* a species for which all subpopulations are under some level of threat (Itow 1995; Nielsen 2004; Jaramillo *et al.* 2018a), including on Santa Cruz Island where it has dramatically declined (Atkinson *et al.* 2009). We studied *S.affinis* ssp. *affinis* at six sites which totaled an area of one hectare and were all locations where *S. affinis* ssp. *affinis* had been historically found, locations that were confirmed by samples in the CDF Herbarium (Jaramillo et al. 2018b), observations, and photographs (Jaramillo 2007; Atkinson *et al*, 2009) (Fig. 1). The first was an enclosed area of national park land in an area called 'Garrapatero' in the southeast of the island and the second 'Mirador' on public land in Puerto Ayora (Jaramillo *et al,* 2018). The other four sites, all small gardens located in Puerto Ayora, are the gardens of the Galapagos Biosecurity Agency (ABG), the Galapagos National High School, the offices of the Galapagos National Park Directorate (GNPD), and the Charles Darwin Research Station (CDRS) (Fig. 1).

Plantings, water-saving technology, and precipitation data

S. affinis ssp. *affinis* were germinated in the CDRS laboratories from seeds collected from naturally occurring individuals and were monitored for 12 weeks before being planted across the study sites. From 2014 to 2018, 374 individuals were planted at six different study sites: Garrapatero (*n* = 180), Mirador (*n* = 128), and across the four gardens (*n* = 66) (ABG garden (*n* = 31), CDRS garden (*n* = 25), Galapagos National School (*n* = 4), and GNPD garden (*n* = 6)). Individuals were planted either using WST Groasis Waterboxx (Groasis) technology or without (controls). The Groasis is a donut-shaped polypropylene tub with a lid designed to collect rainwater and stores it within the tub (Groasis® 2019). The bottom of the tub has a section of rope that wicks water to the area of the plant roots via capillary action. The box reduces evaporation of surface water and the growth of weeds around the plant (Jaramillo *et al*. 2020). Each Groasis received 20 litres of water at the time of planting and controls were planted directly into the ground with 5 litres of water. Following planting, control plants were not provided with water other than by natural means, whereas the Groasis technology were filled with 15 litres of water every three to four months. In total between all sites, 326 plants were planted with Groasis, and 48 were planted as controls.

Each individual plant was given a unique code and its survival monitored every three-to-four month after planting. The Groasis was removed at the point just before each plant had grown too large to fit through the center Groasis hole. Monitoring of an individual was terminated after it died. Although the monitoring is ongoing, data presented here are from the first six years of monitoring: 2014 - 2020.

Ambient water inputs were determined from daily precipitation data 1970 - 2020 available from the CDRS weather station (Charles Darwin Foundation 2020) in Puerto Ayora, Santa Cruz Island. These data were used to calculate indices of total precipitation and standardized precipitation. The Standardized Precipitation Index (SPI) is a relative index of water availability that can be used to indicate periods of drought and excessive rainfall as a measure of precipitation deviation from the historic mean (World Meteorological Organization 2012) and was calculated using the 'SPEI 'package in R (Vicente-Serrano et al. 2010) with all available precipitation data from 1970 through 2020 given a seven-month rolling window that generated a SPI closely correlated with local estimates of the standardized Normalized Difference Vegetation Index (NDVI) anomalies (data not shown in Fig. S1) and hence an indicator of precipitation conditions relative to plant growth (Lotsch 2003; Haverkamp *et al.* 2017). The median SPI value was extracted for each monitoring interval for each individual planting. Total precipitation (cm) across each monitoring interval was also calculated as a measure of short-term water availability, in contrast to SPI which reflects the longer-term availability of water.

Data analysis

Effect of treatment (Groasis or control) was initially visualized using Kaplan-Meier survival curves for each treatment. Subsequently a regression modeling approach was used to test the effect of watering treatment and precipitation on plant survival. This was done by with a repeated-measures mixed-effect logistic regression with the 'lme4' package (Bates et al. 2015), to model the plant survival status at each monitoring date as a function of water availability. Separate models were used to test the effect of each precipitation index (median SPI and total precipitation), modeling survival as a function of treatment, precipitation index, the interaction between treatment and precipitation index, and plant age, with plant identifier as a random effect (to account for the non-independent repeated measures). Survival describes whether a plant is alive or dead at the time of monitoring, treatment is the type of WST (either Groasis (n = 326) or no-WST control [(n = 48]), precipitation index is either median SPI or total precipitation since the last monitoring, and plant age in days since planting is also included in the model to account for any changes in mortality due to age. Precipitation indices and plant age were each standardized by subtracting their mean and dividing by twice their standard deviation to aid with model convergence and make model coefficients comparable as relative effect sizes. The interaction between treatment and precipitation indices was included since WSTs are expected to be more effective when water is not already plentiful. Our purpose was to test the effect of precipitation indices (total precipitation and median SPI) and treatment (Groasis) and any interactions between the two on *S. affinis* ssp. *affinis* survival. To do this, a series of likelihood ratio tests (LRT) were used to test 1) the overall effect of each precipitation index, 2) the overall effect of treatment within each model, and 3) the interaction of each precipitation index with treatment. The first test was performed by using an LRT to compare the full model to a ‘null’ model where precipitation index was removed. The second test was the same but removing the treatment effect. The third test compared the full model to one where only the interaction term was removed. Finally, models were constructed based on the results of these tests (keeping only significant and null-model terms) and coefficient summary outputs were extracted. All statistical analyses were conducted using the R statistical language version 3.6.2 (R Core Team 2019).

Results

Plants grown with Groasis generally had a 10x greater survival rate than those grown without Groasis, with a median survival of 455 days (335 to 569 95% CI) for Groasis compared to 46 days (42 to 95 95% CI) for controls (Fig. 2, Fig. 4). This difference in survival was driven most by the first two years of growth in which Groasis showed 53% survival (2.7% s.e.) and controls at 7.7% survival (3.9% s.e.) after one year of growth. At four years of growth, Groasis had 21% survival (2.3% s.e.) and controls remained at 7.7% survival (3.9% s.e.). By five years, both treatments had levelled off, with Groasis at 16% survival (2% s.e.) and controls at 5.1% survival (3.3% s.e.) (Fig. 2).

Both median SPI and total precipitation were predictors of *S. affinis* ssp. *affinis* survival (SPI model = (χ^2(df=2, *n*=374) = 11.57, $p < 0.01$) and Precip model = (χ^2(df=2, *n*=374) = 9.91, $p < 0.01$), Table 1, Fig. 3). WST treatment was also associated with survival in both models where it was tested (SPI model = (χ^2(df=2, *n*=374) = 44.34, $p < 0.0001$) and Precip model = (χ^2(df=2, *n*=374) = 55.95, $p < 0.0001$), Table 1). The interaction between treatment and median SPI was not a significant predictor of survival (χ^2(df=1, *n*=374) = 0.20, *n.s.,* Table 1) whereas the interaction between treatment and total precipitation was (χ^2(df=1, *n*=374) = 9.79, $p < 0.01$, Table 1, Fig. 3).

Two models on the effect of WST on survival were supported (Table 2). The first model included treatment, total precipitation, and the interaction between treatment and total precipitation, whereas the second model only included treatment and median SPI, but no interaction effects. Both models were fit using a generalized mixed-effect logistic regression after standardizing total precipitation and plant age. In the precipitation model, total precipitation had a positive effect on *S. affinis* ssp. *affinis* survival with an odds ratio – 1 of 24.58 and using Groasis had a positive effect on survival with an odds ratio – 1 of 1.26 (Table 2). The interaction between total precipitation and Groasis was negative, with an odds ratio – 1 of -0.96 (Table 2). In the SPI model, median SPI had a negative effect on *S. affinis* ssp. *affinis* survival with an odds ratio – 1 of -0.34, but as with the Precip. model, treatment had a positive effect on survival with an odds ratio – 1 of 3.24 (Table 2).

Discussion

Our results suggest that water availability is an important factor for the early-stage survival and restoration of *S. affinis* ssp. *affinis*. We found that short-term water availability through precipitation increases the survival of this species (Fig. 3a), and the use of Groasis consistently improved survival (Fig. 4; Tables 1 & 2). However, survival was not substantially different between control and Groasis plantings after two years (Fig. 2). This discrepancy may in part be due to the importance of the interaction between Groasis with total precipitation, in which Groasis maintained the survival of *S. affinis* ssp. *affinis* where low precipitation was predicted to decrease the survival of control plants (Fig. 3a). Longer periods of sustained rainfall as estimated through the SPI, however, led to decreased survival of *S. affinis* ssp. *affinis* under both treatments (Fig. 3b).

The hot season rainfall principally determines dry-zone species' annual productivity in Galapagos, as the cold season generates little to no rainfall in the dry zone, cooler temperatures, and less solar input (Snell & Rea 1999; Trueman & d'Ozouville 2010; Larrea & Di Carlo 2011). Therefore, it is not surprising that a dry zone species such as *S. affinis* ssp. *affinis,* shows increased survival in response to short-term water availability, such as that which occurs during hot season rainfall. The effect of precipitation on *S. affinis* ssp. *affinis* survival varied according to the use of the Groasis, such that the plants with Groasis were more likely to remain alive in the periods of short-term drought (Fig. 3a), as are the conditions of the cold season. This suggests the value of such technologies in the ecological restoration of *S. affinis* ssp. *affinis,* as the variation in precipitation in Galapagos has less of an effect on the survival of the individuals planted with this technology. Overall, individuals planted with Groasis showed up to a three-fold increase in survival at each monitoring interval compared to control plantings (Figs. 4).

Individuals of *S. affinis* ssp. *affinis* exhibited resilience in their survival during extended periods of reduced water-availability. Having evolved with regular drought, arid-zone species such as *S. affinis* ssp. *affinis* may be resilient to such conditions (Hamann 1979b; Riedinger et al. 2002). The Galapagos archipelago's location within the ENSO region makes it subject to drought and rainfall cycles that are especially pronounced during strong el Niño/la Niña events. Many plant species in Galapagos, including *Scalesia* spp., benefit from a short-term increase in rainfall associated with el Nino (Tye & Aldáz 1999), which is followed by a large spike in mortality from long-term exposure to water via precipitation. Hamann (2001) also described an increase in mortality of two dry zone *Scalesia* species in response to El Niño rainfall.

These patterns support those seen in GV2050's *S. affinis* ssp. *affinis* individuals, with increased survival in response to short-term water availability (Fig. 3a), but decreased survival in response to periods of long-term excessive precipitation (Fig. 3b). The adaptations of these arid-zone species can make them susceptible to prolonged wet periods that cause water-logging as well as the increased competition from other species, including introduced species that flourish with prolonged rainfall (Snell & Rea 1999). The link between long-term water availability and other *Scalesia* species mortality has been attributed to root rot, high winds and vine overgrowth (Tye & Aldáz 1999; Hamann 2001; Larrea & Di Carlo 2011), however, the precise causal link with *Scalesia affinis* in particular is not always clear. Beginning in 2016, the population of *S. affinis* ssp. *affinis* that were planted experienced a period of high mortality that followed a particularly wet period (Fig. S1). Around this time, we noted an increase in insect herbivory on *S. affinis* ssp. *affinis* individuals (*pers. obs.,* Table S1). This suggests that other factors such as insect herbivory may also lead to mortality of *S. affinis* ssp. *affinis* and that this herbivory may be related to water availability. Future work should measure the levels of herbivore damage and the potential relationship between *Scalesia* species, insect populations, and El Niño events.

Research on *S. pedunculata* has shown that large-scale, rainfall-induced mortality makes way for the next cohort of young plants (Itow & Mueller-Dombois 1988; Itow 1995; Tye & Aldáz 1999; Hamann 2001; Larrea & Di Carlo 2011; Jäger *et al.* 2017). Rainfall, especially during extreme weather events, may thus influence the natural regeneration cycles of related species. Similar patterns, though less pronounced, have been found in the mortality and regeneration of five dry-zone *Scalesia* species in response to the high rainfall of El Niño events (Tye & Aldáz 1999; Hamman 2001; Larrea & Di Carlo 2011). Our study only applies to the first few years of growth in young *S. affinis* ssp. *affinis*, a period less than both the species life expectancy and an ENSO oscillation; therefore, future research should consider longer-term demographic changes in response to water-availability in *Scalesia affinis* ssp. *affinis*.

Galapagos arid-zone rainfall is largely determined by sea-surface temperatures and global climate change is expected to create a wetter and warmer climate in the Galapagos (Trueman & d'Ozouville 2010; Larrea & Di Carlo 2011). It is more important to understand how these changes may affect endangered species in the Galapagos, especially by examining the effect of water availability on their survival and growth. This study gives insight into the effects of water availability on the early growth of *S. affinis* ssp. *affinis* and shows promise in the use of water-saving technologies to improve survival in the face of climatic fluctuations. However, there is a need for further investigation into the life cycles of *S. affinis* ssp. *affinis* in relation to the short-term and long-term fluctuations in water availability in order to fully elaborate restoration plans for this species.

Conclusions

The restoration of endemic species in dry forest ecosystems is needed to prevent the continued degradation of these habitats (Gillespie *et al.* 2013). Water-saving technology has the potential to be a leading tool in the restoration of dry forest plant species, such as *Scalesia affinis*. This study has investigated *Scalesia affinis*' relationship with a key recovery-limiting abiotic factor, water availability, and from this has been able to determine the effectiveness of WST on its survival. Application of similar experimental efforts using WST on endangered dry forest species could produce similar success and ultimately contribute to the recovery of a globally threatened ecosystem.

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Table 1 (on next page)

Likelihood ratio tests (LRT) results of SPI and precipitation, the effect of removing treatment from the full models and the effect of removing the interaction terms from those models.

Likelihood ratio tests (LRT) results of full Standardized Precipitation Index (SPI) and precipitation logistic mixed-effect models (including interaction terms) against ‘null’ models with those precipitation index terms removed (first two rows). LRT results testing the effect of removing treatment from the full models (middle two rows). Finally, LRT results testing the effect of removing the interaction terms from those full models (last two rows). Full models also include plant age as a fixed effect and plant ID as a random effect. Statistically significant tests ($P > 0.05$) are shown in bold.

Table 1. Likelihood ratio tests (LRT) results of full Standardized Precipitation Index (SPI) and precipitation logistic mixed-effect models (including interaction terms) against ‘null’ models with those precipitation index terms removed (first two rows). LRT results testing the effect of removing treatment from the full models (middle two rows). Finally, LRT results testing the effect of removing the interaction terms from those full models (last two rows). Full models also include plant age as a fixed effect and plant ID as a random effect. Statistically significant tests (*P* > 0.05) are shown in bold.

Likelihood ratio test model	χ^2	*df*	***P*-value**
(full SPI model test) SPI + SPI*Treatment	11.57	2	0.00308
(full Precip model test) Precip + Precip*Treatment	9.91	2	0.00704
(SPI treatment test) Treatment + SPI*Treatment	44.34	2	< 0.0001
(Precip treatment test) Treatment + Precip*Treatment	55.95	2	< 0.0001
(SPI interaction term test) SPI*Treatment	0.20	1	0.65211
(Precip interaction term test) Precip*Treatment	9.79	1	0.00175

Table 2 (on next page)

Scalesia affinis ssp. *affinis* survival as a function of 1) the effect of precipitation and the interaction between precipitation and treatment, and 2) the effect of SPI.

Summaries of logistic mixed-effect models on *Scalesia affinis* ssp. *affinis* survival as a function of 1) the effect of precipitation and the interaction between precipitation and treatment, and 2) the effect of Standardized Precipitation Index (SPI).

Table 2. Summaries of logistic mixed-effect models on *Scalesia affinis* ssp. *affinis* survival as a function of 1) the effect of precipitation and the interaction between precipitation and treatment, and 2) the effect of Standardized Precipitation Index (SPI).

Model	**Parameters**	**Coef.**	**Std. Error**	***Z*-value**	**Odds ratio - 1**
1) Precip model	total_precip	3.242	1.406	2.306	24.584
	treatmentgroasis	0.817	0.416	1.962	1.263
	plant_age	0.228	0.221	1.033	0.257
	total_precip * treatment (groasis)	-3.275	1.412	-2.319	-0.962
2) SPI model	median_SPI	-0.412	0.121	-3.393	-0.338
	treatment (groasis)	1.445	0.242	5.972	3.244
	plant_age	0.176	0.199	0.885	0.192

Figure 1

Map of *Scalesia affinis* ssp. *affinis* study sites

Map of the *Scalesia affinis* ssp. *affinis* restoration study sites on Santa Cruz Island, Galapagos, that were the focus on this study of the efficacy of water-saving technologies on xeric plant survival in rare species restoration programs. Puerto Ayora is the town in which the four garden study sites were located in.

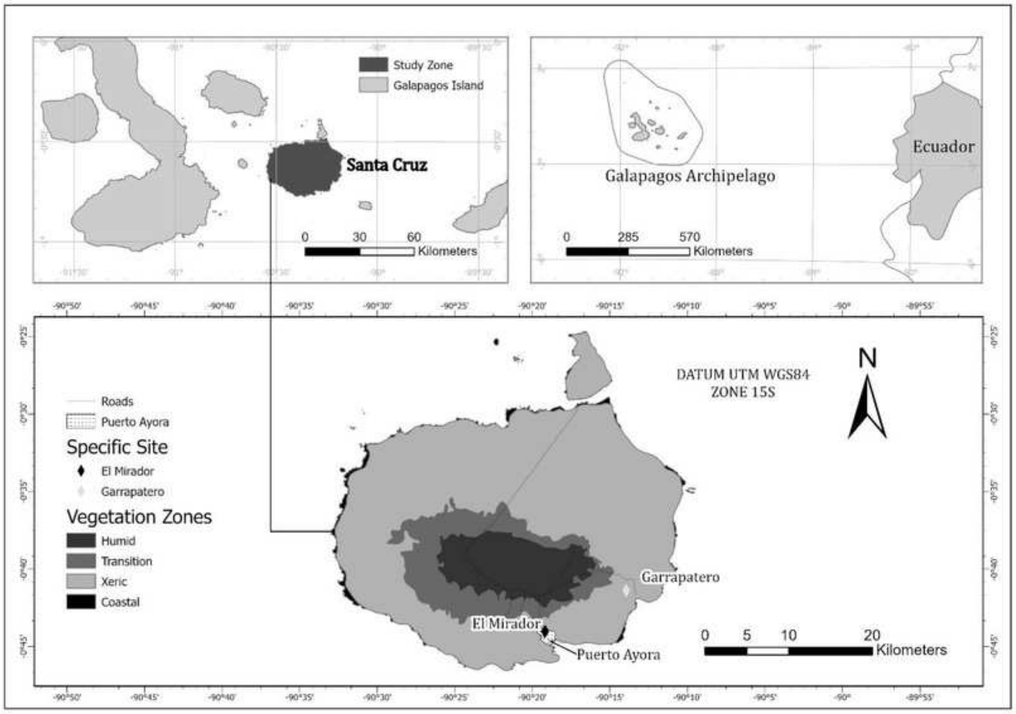


Figure 1. Map of the *Scalesia affinis* ssp. *affinis* restoration study sites on Santa Cruz Island, Galapagos, that were the focus on this study of the efficacy of water-saving technologies on xeric plant survival in rare species restoration programs. Puerto Ayora is the town in which the four garden study sites were located in.

Figure 2

Survival of *Scalesia affinis* ssp. *affinis* individuals planted using Groasis technologies or as controls

Kaplan-Meier survival curves for *Scalesia affinis* ssp. *affinis* individuals planted using Groasis technologies or as controls (no technology) from 2013 to 2020.

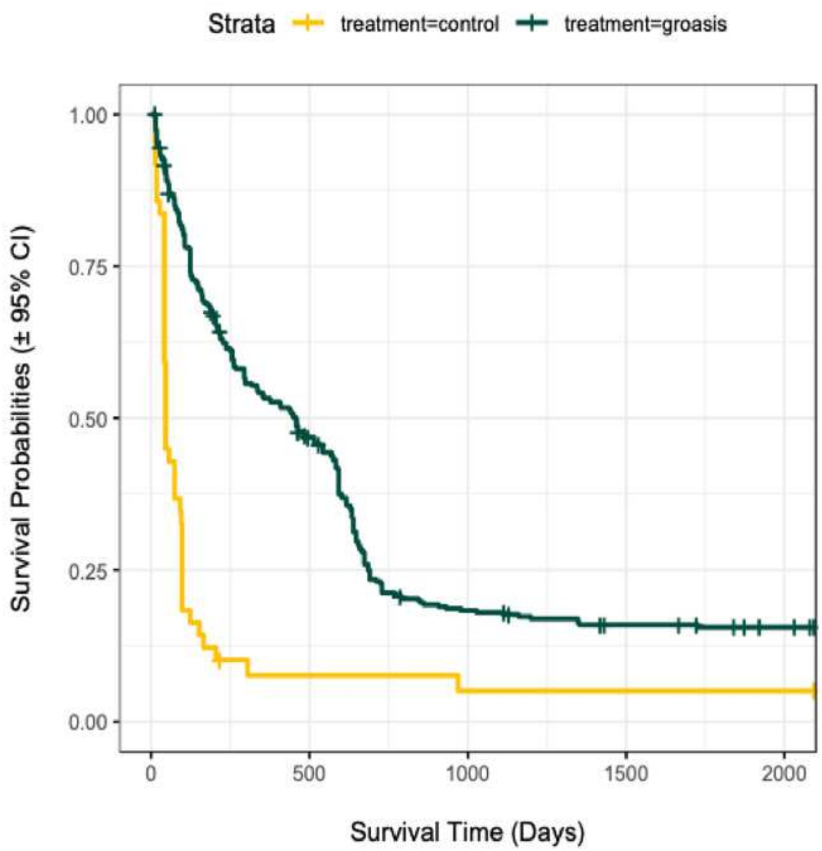


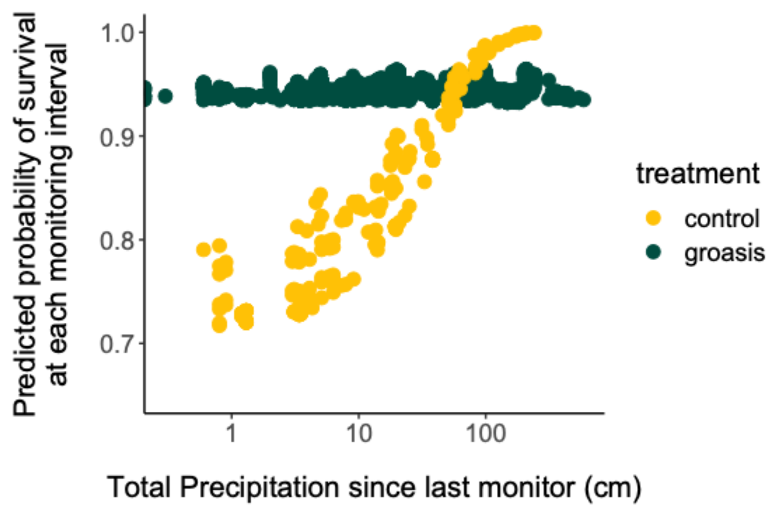
Figure 2. Kaplan-Meier survival curves for *Scalesia affinis* ssp. *affinis* individuals planted using Groasis technologies or as controls (no technology) from 2013 to 2020.

Figure 3 (on next page)

Probability of survival as a function of total precipitation since last monitoring and SPI

Predicted probability of survival as a function of (A) total precipitation since last monitoring (log-scaled axis) and (B) median Standardized Precipitation Index (SPI) since last monitoring. “Control” plants were planted without water-saving technology, and “Groasis” plants were planted with the Groasis Waterboxx technology. Predicted probability of survival in (A) significantly increased with total precipitation (odds ratio – 1 = 24.58) and predicted probability of survival in (B) significantly decreased with increasing median SPI (odds ratio – 1 = -0.34). Note: the interaction effect between treatment and precipitation index was only significant in the total precipitation model (A) ($\chi^2(1, n = 374) = 9.79$, $p < 0.01$).

A.



B.

Figure 3. Predicted probability of survival as a function of (A) total precipitation since last monitoring (log-scaled axis) and (B) median Standardized Precipitation Index (SPI) since last monitoring. "Control" plants were planted without water-saving technology, and "Groasis" plants were planted with the Groasis Waterboxx technology. Predicted probability of survival in (A) significantly increased with total precipitation (odds ratio – 1 = 24.58) and predicted

probability of survival in (B) significantly decreased with increasing median SPI (odds ratio – 1 = -0.34). Note: the interaction effect between treatment and precipitation index was only significant in the total precipitation model (A) ($\chi^2(1, n = 374) = 9.79, p < 0.01$).

Figure 4

Predicted survival of *Scalesia affinis* ssp. *affinis* individuals planted with different treatments at each monitoring interval.

Predicted survival of *Scalesia affinis* ssp. *affinis* individuals planted with different treatments at each monitoring interval. “Control” plants were planted without water-saving technology, and “Groasis” plants were planted with the Groasis Waterboxx technology. Predicted survival in this figure is based on the Standardized Precipitation Index (SPI) survival model, but results are qualitatively similar for the Precipitation model. Test statistics are based on likelihood ratio test when comparing the full model to one where treatment effect was removed.

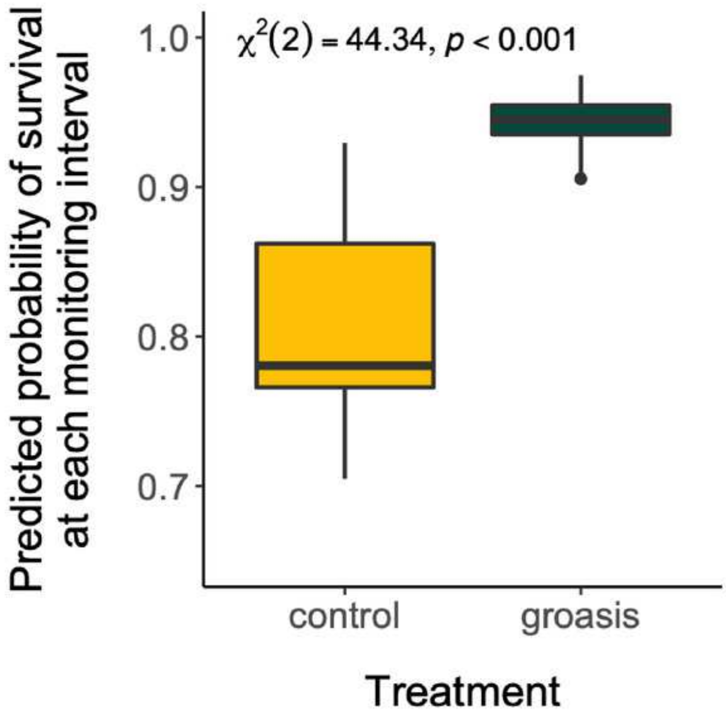


Figure 4. Predicted survival of *Scalesia affinis* ssp. *affinis* individuals planted with different treatments at each monitoring interval. "Control" plants were planted without water-saving technology, and "Groasis" plants were planted with the Groasis Waterboxx technology. Predicted survival in this figure is based on the Standardized Precipitation Index (SPI) survival model, but results are qualitatively similar for the Precipitation model. Test statistics are based on likelihood ratio test when comparing the full model to one where treatment effect was removed.