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Monitoring an endangered and rare plant: population growth and viability of *Lotus kunkelii* (Esteve) Bramwell and Davis (Gran Canaria – Canary Islands)

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Abstract: Species monitoring is a valuable tool that can be used to answer a wide range of questions directly related to species conservation, management, and population improvement. We monitored the only remaining population of *Lotus kunkelii* on a monthly basis over 3 years to reveal important characteristics of the population that could help protect it. In this study, the main hypothesis to be tested is whether the population of *L. kunkelii* is stable or not. The study site is located in Gran Canaria. Monthly censuses of the population recording size (height and diameter), mortality, regeneration, and presence of reproductive structures in each individual were carried out, and this monthly information of variables was correlated with climatic variables. The population is growing (from 105 to more than 200 individuals during the studied time) at a slow pace and is restricted by the environmental conditions of its surroundings (the proximity of the population to the sea that cushions the weather conditions), but we also determined high vulnerability of the species with respect to flooding and heavy rain. However, the population can be considered endangered due to its low number of individuals, and also because it is restricted to a very small area of land. We suggest that to conserve the population new individuals should be protected from grazing where the natural population is found. Finally, the climatic changes predicted by the IPCC in this area should also be considered in future conservation plans.

Key words: Conservation, correlation, global warming, monitoring, protected areas

1. Introduction

Conservation interests usually focus on the protection of endangered species from anthropogenic disturbances (Primack and Ros, 2002) and the analysis of the viability of populations due to threats affecting their natural development (Soulé, 1990). Island populations are particularly vulnerable to anthropogenic disturbances and many species are endangered simply due to their low numbers of individuals or because of their lack of evolutionary ability to respond to disturbances resulting from their isolation (Whittaker and Fernández-Palacios, 2007). Monitoring of population growth, structure, and risk of extinction should be analyzed in order to predict the viability of a population (Salguero-Gómez et al., 2015).

Effective monitoring for managing endangered species must be carefully planned and focused. As defined by Nichols and Williams (2006), targeted monitoring occurs when a monitoring program is based on a priori hypotheses and models of system responses. Carrying out a poorly designed monitoring program can often be more damaging and expensive (time, resources) than simply not having a monitoring program at all. The key feature in a successful program is to have clear, well-defined goals and/or questions before the program begins. Moreover, unless a census is possible, the monitoring design will require the establishment of permanent quadrats sampled over a period of years (Herben, 1996). This not only helps to assure that you will have statistically reliable data (when needed) to answer your questions, it also helps avoid wasting time and resources on collecting superfluous data and limits potential damage to sensitive habitats.

With respect to *Lotus kunkelii*, only one extremely small population is known (less than 100 individuals according to Bañares et al. (2003)) on the eastern coast of the island of Gran Canaria. Moreover, based on recent genetic studies, this population should be considered a distinct species

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to the other species of the same genus (*L. lancerottensis* and *L. arinagensis* (Oliva-Tejera et al., 2006)). This issue is particularly important from a conservation standpoint because the minimum unit for legal protection should be the species. Moreover, the species is included in the *Red List of the Spanish Vascular Flora* (Moreno, 1998) and is classified by the UICN as a critically endangered species (Navarro et al., 2011). In 2009 the regional governments of the Canary Islands developed a Recovery Plan for the species consisting mainly of grazing protection and reintroduction of the species in new areas.

We carried out censuses and monitored the population of *L. kunkelii* monthly for 3 years to reveal important characteristics that could help us understand its population dynamics and conservation requirements such as its regeneration and mortality. Long census periods do form a firm enough basis to enhance conservation assessments (Brigham and Schwartz, 2003). Our main hypothesis is that the population of *L. kunkelii* is stable, based on 3 years of monitoring (regeneration and mortality), but the low number of individuals threatens the population and requires management activities to promote this number. The evolution of the different size classes of the species over this period and its relationship with climatic variability will help us to understand the population and its viability in the coming years and to decide on the main conservation targets for the species.

2. Materials and methods

2.1. Study site

The population of *L. kunkelii* is restricted to the mouth of the ravine known as the Barranco de Jinámar (coordinates WGS 1984 UTM Zone 28N, 460.550,3.101.052; Figure 1). This area, where the species was first cited, was disturbed (and the species eventually disappeared) when it was used as a rubble dump during the urbanization of nearby areas and the construction of a main road on the island (Kunkel, 1973). After 1972, on a small, adjacent slope, covered with rubble and sand, a small population of this species became reestablished. Consequently, the area was protected in 1991 by the Canarian Government (Site of Scientific Interest of Jinámar).

The population is located at an altitude of between 10 and 35 m on an approximately 20%–30% slope facing the ocean. The surface area where the whole population is located is around 15,000 m^2 (25–150 m from the shore). Precipitation (mainly during winter periods) barely reaches 200 mm/year and usually accumulates over short periods of the year. Yearly average temperature is 22 °C and average humidity over 70% (Table 1). Ocean spray is very frequent in this area as it is facing NE tradewinds. The soils are classified as sodic and saline (Rodríguez and Mora, 2000) with a dominance of sands with poor water retention capacity, highly salinity, and poor nutrient content.

Plant communities are coastal shrubs dominated by *Astydamia latifolia*, *Frankenia capitata*, *Limonium pectinatum*, *Crithmum maritimum*, *Chenoleoides tomentosa*, *Suaeda mollis*, *Schizogyne sericea*, and *Tetraena fontanesii*.

One of the main problems for native flora in the Canary Islands is grazing by rabbits and goats (Gangoso et al., 2006), although other authors do not consider it a main threat (Arévalo et al., 2007). Consequently, since 2014, the Cabildo de Gran Canaria (Island Council) has been implementing rabbit eradication programs in the area that still continue at the present time.

2.2. The species

Lotus kunkelii (Esteve) Bramwell and Davis is a taxon of the *Lotus* sect. *Pedrosia* and is endemic in the eastern Canary Islands. It is a pseudo-creeping woody plant that can reach 30 cm in height with a gray cotton cover. It presents sessile-succulent leaves with yellow inflorescence of 3–4 flowers. The species is heliophilous and halophilous, related to coastal and semidesert environments with sand and sediment accumulation and poor soil development.

The flowering period occurs from November to April and only has an effect on the largest individuals. The fruit is a legume with 8–18 seeds on average. The fruit production is abundant and mainly occurs from February to June. We have found that the dispersion is mainly barochoric and by ants (personal observation). At the beginning of the study, around 100 individuals were found in the area. The plant is classified based on its conservation status as critically endangered following the UICN classification rules (Navarro et al., 2011).

2.3. Sampling design

We performed monthly censuses of the population in the area over 3 years. Plant numbers were recorded along with height and two diameters (the largest one and the plant's perpendicular one) projected by the plant, which allowed the calculation of the total biovolume of the species. We also noted the following information: number of flowers, number of fruits, grazing evidence, damage from other causes (human or animal trampling, accidental falling rocks…), and mortality (loss of individuals from one sampling to another). The new individuals were also mapped and incorporated into the population censuses and considered as seedlings (regeneration). Based on the biovolume information (Fernández-Palacios and de los Santos 1996), we classified the individuals as seedlings (<0.001 m^3), juveniles (0.001–0.05 m^3), adults (0.05–0.025 cm^3), and seniors (>0.25 cm^3).

2.4. Statistical analyses

Mortality, regeneration, and total number of reproductive structures in the population were correlated (and

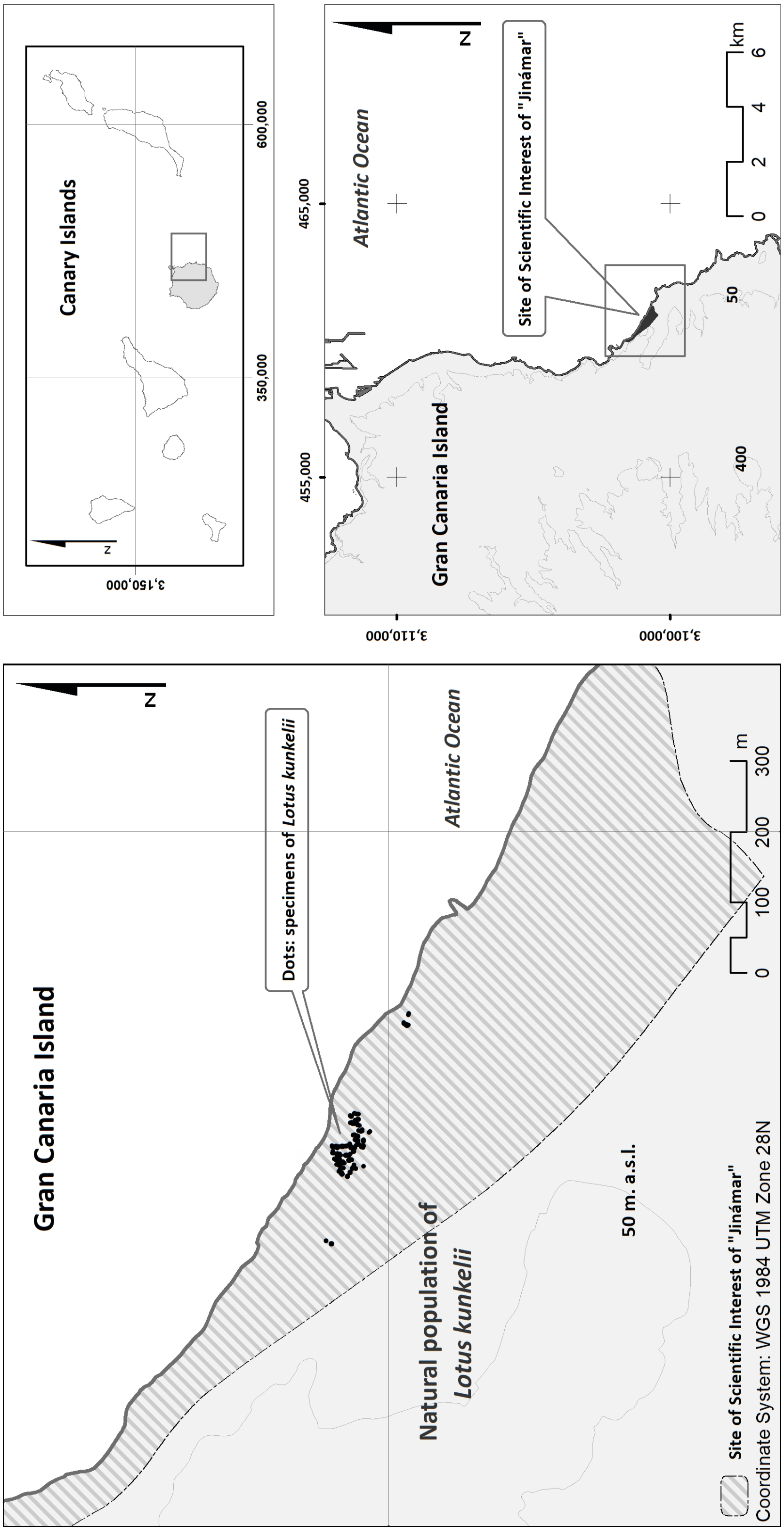

Figure 1. Location of the study site and the protected area "Site of Scientific Interest of Jinámar". The initial individuals of the population are indicated by black dots.

Table 1. Climatic variables in the area of the population monitored daily over 3 years (Pre: monthly precipitation; Tmean: Monthly average temperature; Tmean/max: Monthly average maximum temperature; Tmean/min: Monthly average minimum temperature; mean%Hum: monthly average humidity).

Month	Pre (mm)	Tmean	Tmean/max	Tmean/min	mean%Hum
Mar_2013	17.3	21.56	27.42	15.71	68.37
Apr_2013	0.7	23.25	29.27	17.22	62.93
May_2013	2.7	23.77	30.18	17.36	58.91
Jun_2013	0.2	24.37	30.10	18.64	62.53
Jul_2013	0.0	26.86	33.38	20.35	64.18
Aug_2013	1.3	27.81	33.86	21.75	65.72
Sep_2013	5.5	26.10	31.52	20.68	68.39
Oct_2013	1.6	23.88	27.74	20.02	72.93
Nov_2013	13.4	21.04	23.91	18.17	77.21
Dec_2013	20.5	18.09	20.86	15.33	80.07
Jan_2014	17.9	16.50	19.02	13.97	83.63
Feb_2014	27.0	17.19	20.16	14.22	82.12
Mar_2014	4.4	24.43	30.90	17.96	70.80
Apr_2014	1.9	23.24	30.05	16.43	65.16
May_2014	1.9	24.43	30.90	17.96	64.16
Jun_2014	0.0	26.30	33.61	18.98	61.45
Jul_2014	0.0	26.99	33.42	20.55	63.33
Aug_2014	0.0	27.19	32.82	21.57	67.05
Sep_2014	0.2	26.10	31.52	20.68	68.39
Oct_2014	6.5	24.41	29.05	19.77	71.82
Nov_2014	45.1	20.60	23.51	17.69	80.56
Dec_2014	24.0	18.09	20.86	15.33	80.07
Jan_2015	1.9	16.50	19.02	13.97	83.63
Feb_2015	8.7	17.19	20.16	14.22	82.12
Mar_2015	17.6	19.05	23.27	14.82	70.80
Apr_2015	0.0	22.42	29.09	15.75	65.18
May_2015	0.0	25.68	33.34	18.02	64.18
Jun_2015	0.0	24.71	30.68	18.73	63.62
Jul_2015	0.0	27.16	33.83	20.48	63.14
Aug_2015	4.6	27.63	33.67	21.59	67.27
Sep_2015	8.2	27.15	32.92	21.39	66.91
Oct_2015	113.7	23.98	28.32	19.64	73.49
Nov_2015	4.6	20.79	23.58	18.00	78.42
Dec_2015	3.5	18.09	20.86	15.33	80.04
Jan_2016	5.3	16.50	19.02	13.97	83.63
Feb_2016	47.3	17.33	20.37	14.29	81.59
Mar_2016	8.7	19.89	24.96	14.82	69.26
Apr_2016	0.3	23.10	29.50	16.69	64.99

their significance was tested with Pearson's correlation coefficient) with monthly precipitation, average temperatures, average humidity (%), average minimum temperatures, and average maximum temperatures. Humidity and temperature data were obtained hourly from our data logger located in the center of the population, at around 28 m altitude and soil level, avoiding inferences in the sensors (HOBO Pro v2 logger U23-00x). With respect precipitation we used the information from the pluviometer Gran Canaria-Aeropuerto (C6491), at 24 m altitude and 10 km southwards by the coast (other pluviometers nearer the natural population presented important loss of information for several months and also different altitude). We also correlated density of the class seedlings with mortality. Because we conducted multiple tests, we performed Holm's procedure, a global test of significance, in order to determine whether there was any significant value at all. In addition, standard statistical methods following those of Legendre and Legendre (1998) were implemented using SPSS (SPSS, 1997).

3. Results

As expected, the class of seedlings was the most variable over the 3 years, with some important increases (>100 individuals in this class) during 2015 (Figure 2), which then started to decrease at the beginning of 2016. The classes of adults and juveniles started to increase at the beginning of 2016, revealing some transfer of individuals from seedlings to juveniles and adults. On the other hand, the senior class remained constant over these years with low variability, just some temporary minor changes probably due to the sampling process and the characteristics of the biovolume variable. The seed bank of the species might be active for several months after dispersal at least as long as there is important natural regeneration in the area without flowering of fructification in the previous months (June 2013 and January 2014).

With respect to the reproductive structures for the whole population, there was a remarkable increase at the end of the sampling period. In general, it remained mostly constant from the beginning of the study period with some increases in the spring–summer seasons (Figure 3a). Mortality remained low until the summer of 2015 (Figure 3b). It is worth noting that 90% of mortality was restricted during this season to seedling and juvenile classes, and no evidence of extrinsic disturbance was found during the study period (Figure 3b).

There was a significant positive correlation between mortality and precipitation over the periods and also a significant negative correlation between reproductive structures and the average minimum temperatures (Pearson's correlation coefficient $R = -0.544$, $n = 36$, $P < 0.01$ and $R = -0.352$, $n = 36$, $P < 0.05$ respectively; Table 2). For the remaining variables analyzed, we did not find significant correlations. The correlation of seedling and mortality was revealed also nonsignificant (Pearson's correlation coefficient = 0.038; $n = 36$, $P > 0.05$).

4. Discussion

Addressing problems of endangered species successfully is a complex task that involves knowledge of the problem itself and its context (Wallace and Clark, 2002). If possible, a complete demographic monitoring of individuals provides most information (Philippi et al., 2001) and monitoring numbers of individuals over time is central to conservation (Alexander et al., 2012). In our case, during the sampling period, the population increased from 105 to 201 individuals, improving the conditions of the population, and even more importantly the senior and adult classes increased (Figure 2). Although we did not

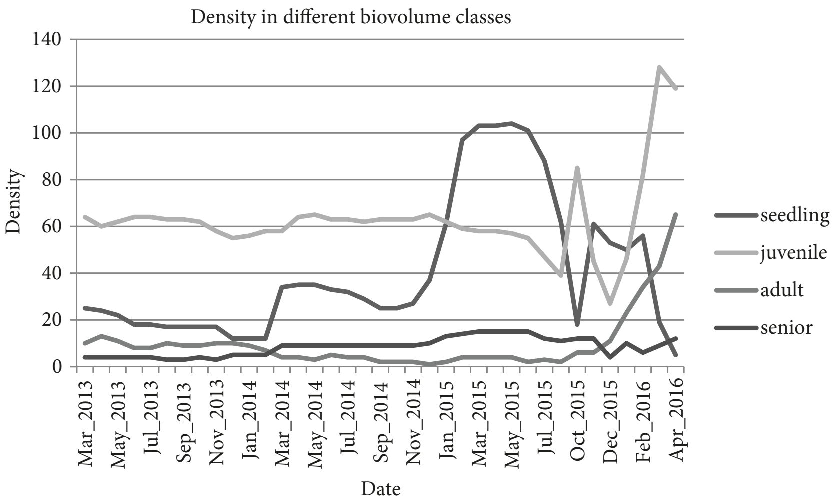

Figure 2. Density of individuals in different classes during the 3 years of the study.

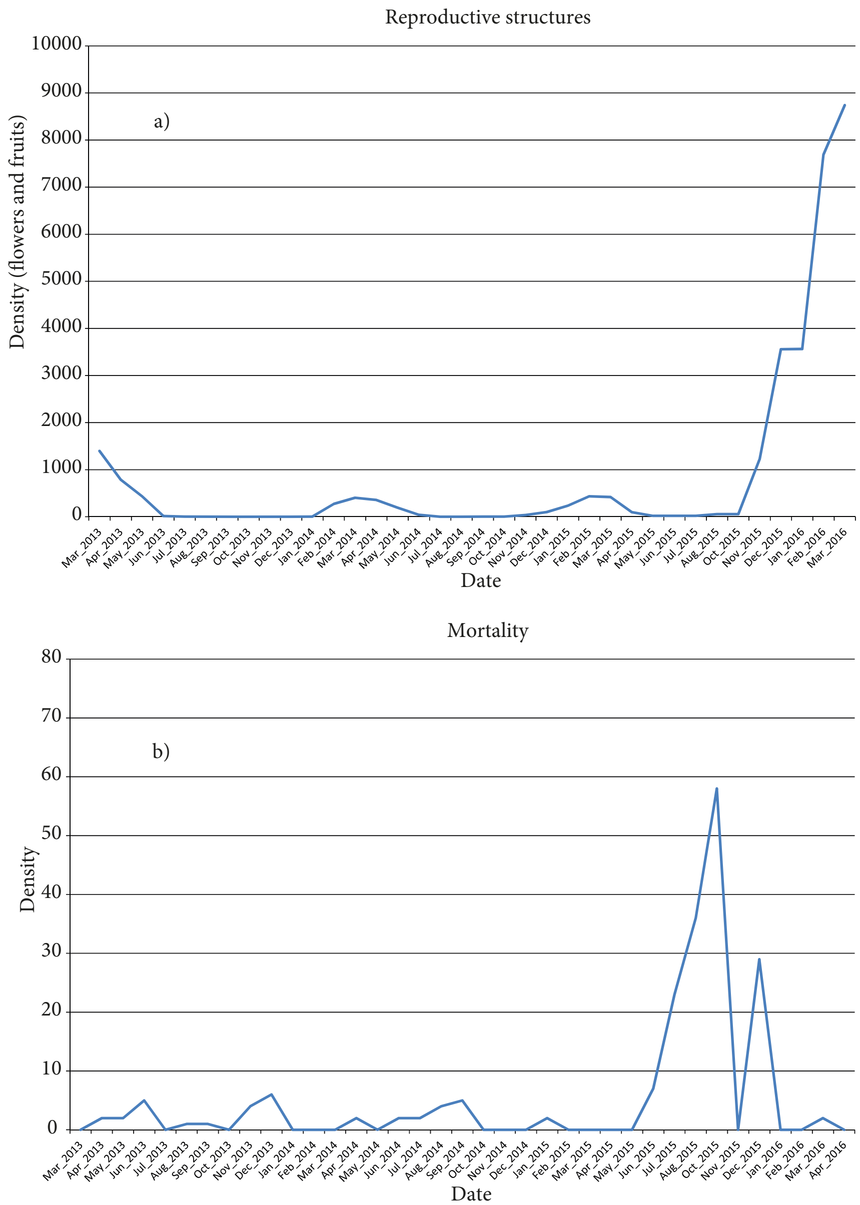

Figure 3. a) Density of reproductive structures (fruits and seeds) and b) density of mortality during the 3 years of the study.

find significant correlation between seedling density and climatic variables, we can note a high rain event in October 2015 that may be related to this increase. Thus, we can affirm that we had consistent growth in the population. We monitored regeneration, as the most sensitive plant size, to environmental changes and disturbances. Regeneration showed great variability, although in the final year, a peak of individuals was found. Mortality, restricted in 95% of cases to juvenile and seedling classes, is also related to the germination peaks of the species (the appearance of new seedlings), which are very sensitive during the frequent dry periods of the year, although the correlation between mortality and seedling density is nonsignificant as long as the effect is restricted to very few months.

One of the causes of mortality was revealed from the positive correlation between mortality and precipitation. The population is located in an area whose slope can reach 40%–45%, facing the ocean and with poor soil development, mainly rubble covered with sand. The seedling and juvenile individuals are very vulnerable to flooding and water runoff during the rainy periods, which are usually concentrated in a few days over the year. For this reason, we found a very significant relationship between precipitation and mortality.

Table 2. Pearson's correlation coefficients (R) and significance level (Sig) for the variables seedlings, mortality, and reproductive structures with the climatic variables (Pre: monthly precipitation; Tmean: Monthly average temperature; Tmean/max: Monthly average maximum temperature; Tmean/min: Monthly average minimum temperature; mean%Hum: monthly average humidity). In bold are indicated the significant correlations.

		Pre (mm)	Tmean	Tmean/max	Tmean/min	mean%Hum
Seedlings	R	–0.177	–0.085	–0.036	–0.179	–0.013
	Sig	0.295	0.615	0.835	0.290	0.937
Mortality	R	**0.544****	0.184	0.130	0.274	–0.014
	Sig	0.001	0.277	0.444	0.101	0.936
Rep. struc.	R	–0.024	–0.227	–0.154	**–0.352***	–0.016
	Sig	0.887	0.177	0.362	0.033	0.927

(*) P < 0.05; (**) P < 0.01

In addition, the number of reproductive structures in the population is negatively related to the monthly average minimum temperatures. Low temperatures can be a stimulant for flowering and fruiting, mainly restricted to the most humid and coldest periods of the year as is likely to occur in hotter areas. It is also true that flowers and fruits are present throughout the year, which is mainly linked to the weather conditions, although becoming more abundant in the winter–spring season. Minimum temperature is also related to germination in many studies (Hanley and Fenner, 1998; Arévalo and Fernández-Palacios, 2008) although we did not find such correlation. We can assume that the environmental and climatic adaptation of the species is related to this result.

We expected stronger relationships with humidity and average temperature, but these were not revealed by the analyses. We suggest that the proximity of the population to the sea is cushioning the weather conditions. Thus, the plant has adapted to an extreme environment, high salinity, and no great temperature variations throughout the year.

The results revealed an increase in the number of individuals in the population for the seedling class, but all this regeneration is located in the natural population as long as the environmental conditions around are highly disturbed and unappropriated for the species. Although we did not detect evidence in this population of rabbit impacts, in introduced populations of this species in other parts of the island, the impact of the rabbits has been devastating (personal observation). Due to the location of this population, facing the ocean winds and with a steep slope, no rabbit impact is expected. In addition, we consider that the eradication programs of rabbits in the area are having a positive effect.

In conclusion, the *Lotus kunkelii* population should be considered endangered due to the low number of individuals and its restriction to very small areas of land. Therefore, we suggest for the population to increase it will be necessary to protect new individuals from grazing (although with low impact in the natural population studied they are more likely to affect new areas of introductions of the species) with fences around the area where the natural population is found and in similar areas where it is planned to be introduced as well as continuing working with quality of nursery plant production for reintroduction in more inadequate areas for the development of the species.

Finally, the climatic change predicted by the IPCC in this area is likely to lead to significant changes in species composition. In fact, even the moderate scenarios of the IPCC predict a severe decrease in precipitation and a rise of 3–4 °C in average temperatures in the Mediterranean region (de Castro et al., 2004), with a similar scenario for Canary Islands based on the newest and most precise IPCC estimations (IPCC 2013). So far, changes detected over the past 70 years have revealed an increase of almost 2 °C in minimum average temperatures (Martín et al., 2012; Arévalo et al., 2017). These concerns about possible climate change should also be considered in future conservation plans. Moreover, we recommend continuing the monitoring of this population to determine its short-term viability (Menges, 2000) in the case of local disturbances in the area.

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