

Assessing extinction-risk of endangered plants using species distribution models: a case study of habitat depletion caused by the spread of greenhouses

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Abstract The species distribution models (SDMs) are useful tools for investigating rare and endangered species as well as the environmental variables affecting them. In this paper, we propose the application of SDMs to assess the extinction-risk of plant species in relation to the spread of greenhouses in a Mediterranean landscape, where habitat depletion is one of the main causes of biodiversity loss. For this purpose, presence records of the model species (*Linaria nigricans*, a endemic and threatened species) and the greenhouses, a dataset of environmental variables, and different only presence-based modelling algorithms (Bioclim, Domain, GARP, MaxEnt and ENFA) were used to build SDMs for *L. nigricans* as well as for greenhouses. To evaluate the models a modified approach of the area-under-curve ROC was applied. Combining the most accurate models, we generated an extinction-risk model of *L. nigricans* populations, which enabled us to assess the sustainability of the most threatened populations. Our results show that is possible to model greenhouses spreading as a “biological invasion”. The procedure explained and used in this work is quite novel, and offers an objective spatial criterion intended for the management of natural resources and for the conservation of the biodiversity in areas threatened by habitat depletion processes as particular as greenhouses expansion.

Keywords Greenhouses · Habitat fragmentation and depletion · *Linaria nigricans* · Mediterranean landscape · South-eastern Spain · Threatened species

Introduction

Land use change is among the main cause of threat for the biodiversity due to the serious consequences that it is provoking in natural habitats (habitat depletion, fragmentation, and

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destruction) (Soulé 1991; Sala et al. 2000). In a context of global change, one priority is to identify areas with high extinction-risk (Araújo and Williams 2000), in order to model the potential responses of the species to incoming changes (Buckland and Elston 1993), and to apply that knowledge in conservation policies.

The development of the Geographical Information Systems (GIS) and its use in research is improving the design of powerful spatial-analysis methods directly applicable to the conservation of biodiversity and land management. These methods include the species distribution models (SDMs), which can predict the potential distribution of the habitat suitable for a targeted species by analysing relationships between presence records and predictor variables stored as GIS coverages (Guisan and Zimmermann 2000). SDMs are successfully applied to locate new populations of rare and threatened species (e.g. Guisan et al. 2006), to select areas that guarantee the persistence of endangered species (e.g. Araújo and Williams 2000), to predict spatial patterns of biological invasions (e.g. Thuiller et al. 2005a, b; Ward 2007), to identify locations with high extinction-risk (e.g. Araújo et al. 2002) and to evaluate potential effects of global change in species distribution (Thuiller et al. 2005a, b). In fact, SDMs can be used in plant conservation planning to introduce objective and quantitative criteria for decision making.

In 1999 an estimated 682,000 ha were occupied by greenhouses throughout the world, especially in China (380,000 ha), followed by Mediterranean countries (161,300 ha in France Italy, Spain, Greece, Turkey, Morocco, and Algeria (Takakura and Fang 2002). The spreading of greenhouses usually implies habitat depletion and an overexploitation of scarce natural resources such as water or soil. In fact, the spread of greenhouses is the main threat against the outstanding biodiversity in south-eastern Iberian peninsula (Martínez-Fernández and Esteve 2004), and it frequently signifies the occupation of natural habitats of european interest (Habitat Directive of the European Union, Anon 1992), mainly affecting communities of *Periploca*, *Ziziphus*, and *Maytenus* (Mota et al. 1996), which harbour protected species (Anon 2003), and many other plant species, like *Androcymbium gramineum*, *Narcissus tortifolius*, *Euzomodendron bourgaeum*, *Cynomorium coccineum* or *Linaria nigricans*.

The aim of this work is to propose a methodology based on SDMs capable of predicting, in spatial terms, the extinction-risk associated to natural populations of species, in relation to the spread of greenhouses. The case study is the spread of greenhouses in south-eastern Iberian peninsula, and the model species chosen is *L. nigricans*, a rare endemic and threatened species of this area. For this aim, we have applied different species distribution models to select the most accurate ones; also, we have combined the best models to built the extinction-risk model to evaluate the sustainability of the populations of *L. nigricans* in relation to greenhouses spreading. This is intended as a framework that could lead to an objective spatial criterion for improving conservation and management plans.

Materials and methods

Study area, model species and greenhouses

The study area is located in south-eastern Iberian peninsula (Fig. 1) (2.9–1.6°W and 36.6–37.5°N). The climate is Mediterranean, with average annual rainfall of 200–300 mm (frequently torrential), high evapotranspiration, and mean annual temperatures of 16–17°C, with warm, dry summers and temperate winters (Mota et al. 2004). The landscape is dominated by a mosaic of shrubs and chamaephyte plant communities (with *Ziziphus lotus*,

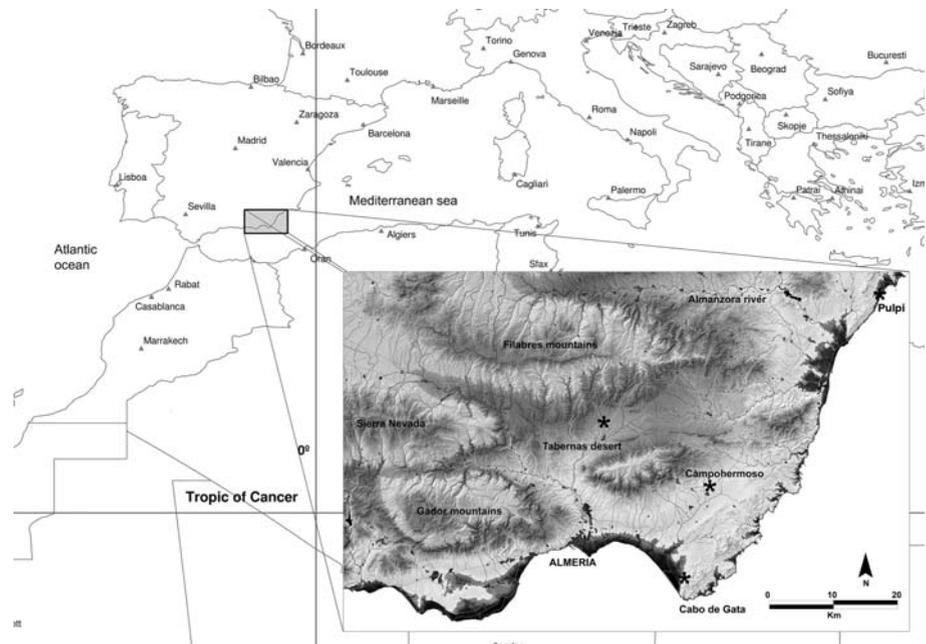


Fig. 1 Situation of the study area and geographical context. Marked localities in Tabernas, Pulpí, Campohermoso and Cabo de Gata, supports known populations of *L. nigricans*

Thymus spp., *Helianthemum* spp., *Rosmarinus* spp., etc.), xerophytic grasslands with large patches of *Stipa tenacissima* (called “espartales”), and varied communities of ephemeral annual plants (Mota et al. 2003).

As model species we have selected *L. nigricans*, because it characterizes diverse communities included in the Habitat Directive of the European Union (92/43/CEE; “2230 *Malcolmietalia* dune grasslands” and “6120 Xeric sand calcareous grasslands”, priority habitat, Anon 1992), and is threatened by the spreading of greenhouses. *Linaria nigricans* is a short-lived therophyte, restricted to four localities of south-eastern Spain (Fig. 1, Campohermoso, Tabernas, Pulpí, and Salinas). It occupies flat areas with arid and sandy soils, and does not tolerate alterations in its habitat (e.g. compaction or changes in the soil properties). The plant has been catalogued as “Endangered” (EN) (Cabezudo et al. 2005) and is protected by the “Law of Flora and Fauna” of Andalusia (Anon 2003). *Linaria nigricans* inhabits annual grasslands with a great number of accompanying mesogean taxa, such as *Leysera leyseroides*, *Iflora spicata*, *Ammochloa palaestina*, *Lobularia lybica*, *Filago* spp., and other species with narrow biogeographical ranges (e.g. *Silene littorea* subsp. *adscendens*, also a locally endemic species; *Asphodelus tenuifolius*; *Eryngium ilicifolium*; *Ononis sicula*).

For more than 30 years, greenhouses have been spreading in SE Iberian peninsula, and are currently occupying a vast area of the plains near the coastline. This spread has been encouraged in recent years by the construction of new infrastructures intended to guarantee the water supply for the intensive agriculture in the region. In our framework, to model the potential distribution of greenhouses, they were considered to behave in a way comparable to a biological species in terms of topographical, climatic, and geographical requirements,

with a great capacity of adaptation to relatively adverse conditions by virtue of technological innovations that improve productivity.

Sampling and environmental data

For 2 years, field surveys were conducted in the area occupied by *L. nigricans* to obtain presence records using GPS devices (ensuring at least 40 m between two nearby presence records), resulting in 500 points. To work with equal sample sizes, 500 presence records of greenhouses were taken on a Landsat image (year 2000) by a random stratified sampling using the same minimum distance criterion. Each group of presence records was randomly split into two groups: 300 points as training dataset and 200 points as the evaluation dataset (Guisan and Zimmermann 2000). The real area occupied by greenhouses was mapped by landcover analysis with neural network over a Landsat image (year 2000) by means of the MLP module (Multi-Layer Perceptron Classifier) included in Idrisi Andes (Clark Labs, Clark University; Eastman 2006).

Topographical variables (as slope, aspect, and potential solar radiation) to be used in the modelling framework were derived from a digital-elevation model (20 m resolution). The climatic coverages of the period 1999–2005 (means, minimum, maximum, and range of temperature, air moisture, and rainfall) were computed according to the interpolation techniques described by Ninyerola and Pons (Ninyerola et al. 2000) using climatic records of the Andalusian Agroclimate Information Network. The coverages of distances from water resources (reservoirs and desalination plants), dams, roads, and urban centres were computed using distance modules of the Idrisi Andes software and land-use coverage as the data source. To avoid multicollinearity in the dataset, a selection process based on the Pearson's correlation index was applied, using Biomapper 3.0 (Hirzel et al. 2004). Variables were eliminated sequentially until achieving a maximum correlation index lower than 0.70, leaving a total of 12 variables (Table 1).

Table 1 Environmental variables used to model the potential distribution area of *L. nigricans* and greenhouses

Type	Variable	Units	<i>L. nigricans</i>	Greenhouses
Topography	Elevation	m	×	×
	Slope	Degrees	×	×
	Direct radiation (yearly maximum)	Wh/m ²	×	×
	Direct radiation (yearly average)	Wh/m ²	×	×
	Direct radiation (yearly range)	Wh/m ²	×	×
Climate	Rainfall (annual)	mm	×	×
	Temperature (yearly maximum)	°C	×	×
	Temperature (yearly minimum)	°C	×	×
	Temperature (yearly range)	°C	×	×
	Air moisture (yearly maximum)	%	×	×
	Air moisture (yearly minimum)	%	×	×
	Air moisture (yearly range)	%	×	×
Distances	To desalination plants	m		×
	To dams	m		×
	To human populations	m		×
	To any roads	m		×

Species distribution models

SDMs are designed to compute the spatial distribution of the suitable habitat for a given species, using as inputs presence records and a set of predictor variables with influence on the distribution of the species, or correlated with other variables that do (Barry and Elith 2006). Since different methods of habitat modelling offer different results from the same data (Thuiller 2003; Segurado and Araújo 2004; Elith et al. 2006), we built models of *L. nigricans* and greenhouses using six different only presence-based algorithms: Bioclim (Farber and Kadmon 2003) Domain (Carpenter et al. 1993), ENFA using mean (ENFA-M) and geometric mean (ENFA-GM) algorithms (Hirzel et al. 2002), GARP (Stockwell and Peters 1999), and MaxEnt (Phillips et al. 2006). Each algorithm was calibrated using the settings recommended by the authors, the presence samples and the selected variables (Table 1).

Evaluation and selection of models

To test the model's accuracy, we applied the area-under-curve (AUC) ROC method (Fielding and Bell 1997), widely used to evaluate distribution models (Arntzen 2006; Elith et al. 2006), but introducing a variation to work with only presence datasets, replacing absence records by 10,000 samples of 200 completely random plots, which were then compared one by one with the evaluation sample (200 presence records) to compute 10,000 AUC values. For a given model, with the random selection of a presence record and a random plot, the mean of the 10,000 AUC values (AUC_m) expresses the probability that the suitability value of the presence record will be higher than the suitability value of the random plot. This method is similar to the AUC test implemented in the MaxEnt software, and it provides a common frame of comparison between models. To detect significant differences in model performance between algorithms, AUC values were normalized using arcsine transformation to apply a repeated measures ANOVA test, using the algorithm as factor (Segurado and Araújo 2004). Models with higher AUC_m were selected as the most accurate ones. Differences in model performance between groups (*L. nigricans* and greenhouses) were explored by ANOVA test.

Postprocessing of distribution models

The *L. nigricans* model selected (called "POTENTIAL L.n. HABITAT") was masked, assigning zero values to the land-uses incompatible with the survival of the plant, resulting in the model "CURRENT L.n. HABITAT". The same masking operation was applied to the model of the greenhouses (called "POTENTIAL Greenhouses HABITAT"), assigning zero values to cells in which there were greenhouses and other land uses not available for new greenhouses (occupied by roads, cities, etc.), resulting in the model "CURRENT Greenhouses HABITAT", which shows the distribution of suitability to build new greenhouses (potential areas to build new greenhouses in the future).

Extinction-risk model

The extinction-risk model for *L. nigricans* populations is based on the idea that higher habitat suitability values of *L. nigricans* and greenhouses concur for the same cell, and thus the greater is the probability that in each cell the plant would exist and be destroyed by a future greenhouse construction. To test our idea, we constructed a model called "POTENTIAL EXTINCTION-RISK", by combining the "POTENTIAL L. n. HABITAT"

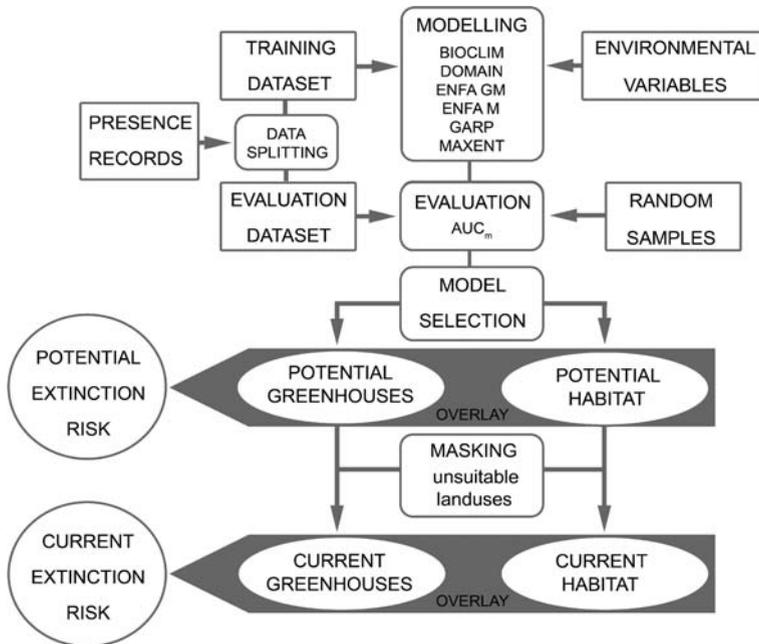


Fig. 2 Flowchart showing the steps followed in the model construction. Rectangles indicate input data, rectangles with round corners indicate procedures, ellipses show intermediate results, and circles final results

and the “POTENTIAL Greenhouses HABITAT” coverages, multiplying them and scaling the result to values of 0–100 in order to provide a relative extinction-risk scale. We evaluated the success of the coverage “POTENTIAL EXTINCTION-RISK” by predicting the destruction of suitable habitat for *L. nigricans*, calculating the percentage of cells really occupied by greenhouses (using the map of greenhouses obtained from the Landsat image analysis) for each extinction-risk level. The relationship between the invasion of greenhouses and extinction-risk level was tested by curve fitting in order to find a mathematical function describing the behaviour of the model.

Afterwards, we built a new model combining “CURRENT L. n. HABITAT” and “CURRENT Greenhouses HABITAT” in order to generate “CURRENT EXTINCTION-RISK”, which shows the areas with the highest possibilities of spatial conflict between the plant populations and the greenhouses in the future (see Fig. 2). This model was analysed to establish the relative risk level of the known populations of *L. nigricans*.

Results

The ANOVA tests confirmed significant differences between algorithms in terms of AUC values (*L. nigricans*: $f = 134,102$, $P = 0.00$; greenhouses: $f = 58,831$, $P = 0.00$). Domain was the best algorithm to model the distribution of *L. nigricans* ($AUC_m = 0.996 \pm 0.00010$) and the greenhouses ($AUC_m = 0.950 \pm 0.00003$) (see Fig. 3). The ANOVA results of the comparison between groups shows a significantly better performance of the models corresponding to *L. nigricans* ($f = 372,290$, $P = 0.00$).

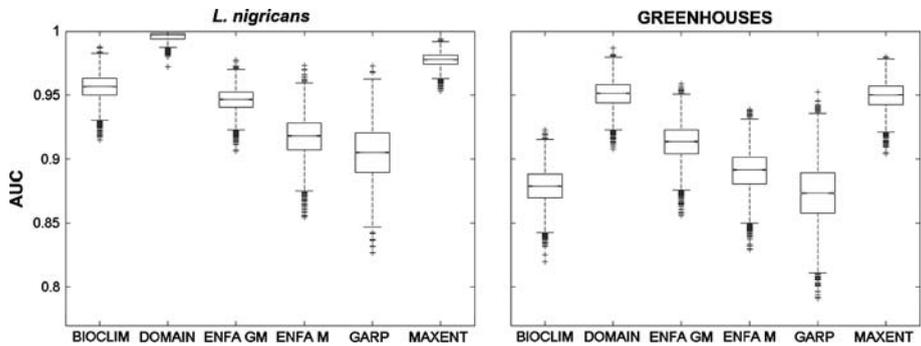


Fig. 3 Results of model evaluation. The boxplot represents the mean (*centre lines*), standard error (*knots*), standard deviation (*box*), range (*dot lines*) and outliers (*crosses*) of the 10,000 AUC values computed for each model

Figure 4 shows the coverage selected to build the EXTINCTION-RISK models. Note that the “POTENTIA L. n. HABITAT” coverage (Fig. 4a) represents the potential distribution of the plant without taking into account the land uses, while the “CURRENT L. n. HABITAT” (Fig. 4b) represents the current distribution, restricted by the land uses incompatible with the survival of the species populations. The “POTENTIAL Greenhouse HABITAT” coverage (Fig. 4c) represents the suitability of the territory for greenhouses, and “CURRENT Greenhouse HABITAT” (Fig. 4d) shows the suitability for new greenhouses (potential spreading areas in the future). The curve fitting analysis applied to the “POTENTIAL EXTINCTION-RISK” model indicates a robust polynomial relationship (3rd order; $R^2 = 0.9655$; RMSE = 3.807) between the relative extinction-risk level and the percentage of cells occupied by the greenhouses.

The model “CURRENT EXTINCTION-RISK” (Fig. 5, combining “CURRENT L. n. HABITAT” and “CURRENT Greenhouse HABITAT”) shows the areas with the highest possibilities of spatial conflict between the plant populations and the greenhouses in the future.

Of the 500 *L. nigricans* presence records available, 40% remained above the risk level 80, corresponding to a single population situated in Campohermoso (see Fig. 1), and 25% between the risk levels 20 and 40 (population of Tabernas; see Fig. 1). The remaining 35% are not in danger from greenhouse construction because they inhabit protected areas (Cabo de Gata-Níjar Natural Park) or other places not suitable for greenhouses.

Discussion

Modelling and model selection

Many works have compared the success of different modelling algorithms in order to identify those that offer the best results (Elith et al. 2006; Segurado and Araújo 2004). Although there are methods that generally perform better than others, it is not possible to determine a priori which ones will be the most appropriate to work with a particular species and a given set of environmental variables. Therefore, taking into account the nature of our dataset, we used different only presence-based algorithms in order to select the best model possible in each case. The differences in terms of the results given by the different

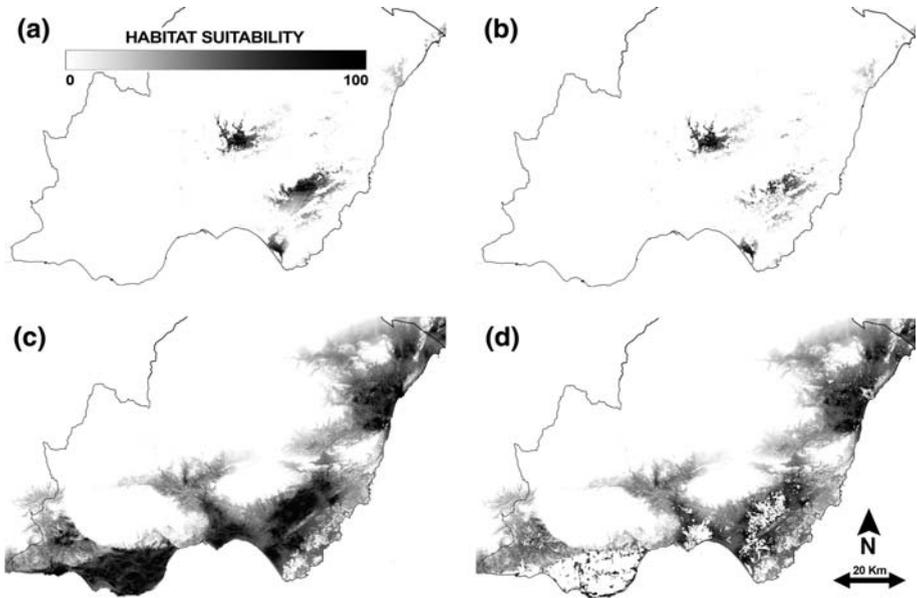


Fig. 4 Selected SDMs for *L. nigricans* and greenhouses. **a** “POTENTIAL *L. nigricans* HABITAT”; **b** “CURRENT *L. nigricans* HABITAT”; **c** “POTENTIAL Greenhouse HABITAT”; **d** “CURRENT Greenhouse HABITAT”

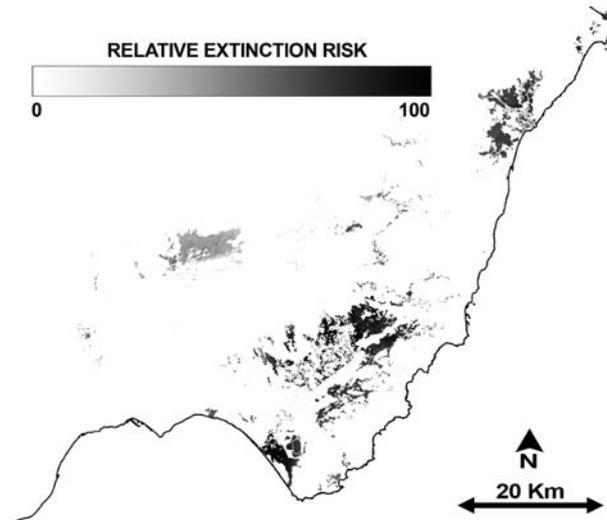


Fig. 5 “CURRENT EXTINCTION-RISK” for *L. nigricans* caused by greenhouses expansion. The areas with higher values indicate suitable habitat for *L. nigricans* with higher probability to be occupied by greenhouses

algorithms roughly coincide with those reported elsewhere (Loiselle et al. 2003; Elith et al. 2006; Ward 2007), observing that Domain and MaxEnt amply surpass Bioclim and GARP in their AUC values.

But the evaluation of only presence-based models is still under discussion and there is no single method appropriate to assess them (Hirzel et al. 2006). To evaluate only presence-based models using the AUC method, some authors have solved the lack of absences by generating random plots to be used in the confusion matrix as absences, calling them “pseudo-absences” (Zaniewski et al. 2002; Engler et al. 2004), or “random instances” (Phillips et al. 2006). Our evaluation method follows these guidelines, but it is slightly different, because during the initial phase of our work, we confirmed that two models tested with two different single random samples could offer significantly different AUC values, changing the choice of the best model according to the spatial distribution of the random sample. We solved this inconsistency in model selection using 10,000 different random samples to evaluate each model. This bootstrapping approach poses a problem in the possibility of generating random instances in suitable habitat areas, but working with large presence samples neutralizes the negative effect that this circumstance can provoke (Engler et al. 2004).

The ANOVA test between groups shows that greenhouse models offered a worse fitting index than did those of *L. nigricans* (Fig. 3), probably because the greenhouses have still not completely occupied their potential distribution area. In addition, some greenhouses have a greater ecological tolerance range than the mean, favoured by technological innovations (heating, refrigeration, double- and triple-layered plastic, rigid roofs, etc.) implemented to achieve greater productivity. This group of unidentified outliers may add unexplained variance to the SDMs corresponding to the greenhouses. Another element that adds variation to the greenhouse model is the human factor, which acts in the form of territorial and urban planning, or in the form of decisions of landowners to use the space for greenhouse construction or not. One of the most noteworthy results of this work is that, despite these drawbacks, it is possible to determine the potential distribution of greenhouses, as a “biological invasion”, using modelling methods normally applied to organisms. This opens a new field of applicability for species distribution models, as long as the factors determining the distribution of the entity to model are known and can be spatially represented in GIS coverages.

The “CURRENT *L. n.* HABITAT” coverage represents the current habitat distribution of the plant restricted by land uses, including areas where the presence of *L. nigricans* was not confirmed in the field sampling. This can have at least two causes: (1) a well-known behaviour of the presence-only based algorithms, which tends to overestimate the potential distribution area, because the models represent the distribution of the fundamental niche (not the real one) of the species (Zaniewski et al. 2002); and (2) the environmental variables do not cover all the factors that influence the distribution of the species (Guisan and Zimmermann 2000; Costa et al. 2007), and therefore the distribution of *L. nigricans* can be influenced by physiological factors or biotic interactions such as soil compactness or competitive exclusion, which cannot be reflected as GIS layers. Nevertheless, the model is useful as an objective spatial criterion for analysis in biodiversity conservation.

Extinction-risk model

The results of the curve fitting analysis applied to the “POTENTIAL EXTINCTION-RISK” are interpreted as a significant trend of the areas with greater relative extinction-risk to be really occupied by greenhouses, so this model is capable of predicting the destruction of *L. nigricans* populations caused by the construction of greenhouses. Though this result cannot be applied directly to the “CURRENT EXTINCTION-RISK” model, it would be expected to work similarly; that is, the areas with higher relative extinction-risk may have a

higher probability of being occupied by greenhouses. A visual comparison of the “CURRENT EXTINCTION-RISK” (Fig. 5) with the “CURRENT *L. n.* HABITAT” (Fig. 4b) shows that a large part of the potential distribution of the plant is situated in areas suitable for greenhouses in the future.

In the locality Campohermoso (see Fig. 1), the growth of the surface area occupied by greenhouses since the 1960 s is estimated at 100 ha per year (authors’ unpublished data). Consequently, the habitat is being directly destroyed by greenhouse construction and degraded by intense fragmentation. In Tabernas the preservation of the species has been compatible with traditional cultivation techniques based on leaving the ground fallow; however, currently these traditional systems are being abandoned and some greenhouses are being established in the zone, although they do not yet directly affect the plant populations. The greenhouses constitute the main cause of the destruction of the habitat of *L. nigricans*. Up to 65% of the known populations of *L. nigricans* are at risk of extinction and thus require management and protection plans for habitats that take into account the spreading of the greenhouses.

The success of the extinction-risk model depends on the rate of spreading of the greenhouses. Up to now, this spread could be limited by the scarcity of water resources, but the construction of new desalination plants and water channels may encourage continued expansion. If so, there is a major risk that numerous populations of *L. nigricans* will disappear, and thus the important accompanying species and habitat. To recalibrate the risk model, upgraded potential distribution models of greenhouses can be computed including information about new desalination plants in order to estimate changes in the risk of habitat destruction, especially in areas currently assigned to low risk levels.

The building of extinction-risk models based on SDMs generates predictions based on solid and objective criteria. These predictions are useful for conservation plans because they enable us to identify potential trends of threatened plant populations and establish the necessary corrective measures. This modelling framework offers an interesting tool applicable to Environmental Impact Assessments, for the management of natural resources and the conservation of biodiversity.

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