GEA, FLORA ET FAUNA

Using GIS and MaxEnt to predict global distribution of *Saxifraga catalaunica* (Saxifragaceae)

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Abstract

Knowledge about species occurrence is essential in terms of biogeographical and conservation research. Species distribution models provide basic information so as to predict vulnerability to local or global extinction or design nature preservation policies. GIS technologies and MaxEnt application have demonstrated respectively efficacy in terms of working with explicit spatial data and modelling species distributions. This paper takes advantage of GIS and MaxEnt to generate a global distribution model of a plant endemic to North-eastern Iberian Peninsula: the queen crown (*Saxifraga catalaunica*). This botanical taxon is listed as Near Threatened according with International Union for Conservation of Nature criteria. We produced a consistent model of queen crown distribution by working with only-presence data of target species and a set of five environmental layers. Our prediction reveals deep existing differences between two only known regions with presence of the taxon, as potential distribution is spatially heterogeneous both within and between studied natural parks. Future conservation efforts could focus on most isolated, vulnerable populations of this Iberian endemic taxon.

Key words. Plant ecology, spatial ecology, species distribution models, MaxEnt, conservation biology.

Resum

Predicció de la distribució global de *Saxifraga catalaunica* (Saxifragaceae) mitjançant GIS i MaxEnt

El coneixement sobre la distribució de les espècies és essencial en termes de recerca biogeogràfica i conservació. Els models de distribució d'espècies proporcionen informació bàsica per predir la vulnerabilitat a l'extinció local o mundial, o dissenyar polítiques de preservació de la natura. Les tecnologies SIG i l'aplicació MaxEnt han demostrat, respectivament, eficàcia a l'hora de treballar amb dades espacials explícites i modelar distribucions d'espècies. El present treball aprofita eines SIG i MaxEnt per tal de generar un model de distribució global d'un endemisme botànic del nord-est de la península Ibèrica: la corona de reina (*Saxifraga catalaunica*). Aquest tàxon es classifica com a quasi amenaçat segons els criteris de la UICN. En el present manuscrit produïm un model consistent de distribució de la corona de reina treballant amb dades de presencia de l'espècie objectiu i cinc variables ambientals. La predicció aportada revela diferències profundes entre les dues úniques regions conegudes amb presencia del tàxon, ja que la distribució potencial és espacialment heterogènia dins i entre els parcs naturals estudiats. Esforços futurs de conservació es podrien centrar en les poblacions més aïllades i vulnerables d'aquest tàxon ibèric endèmic.

Paraules clau. Ecologia vegetal, ecologia espacial, models de distribució d'espècies, MaxEnt, biologia de la conservació.

Introduction

Analyzing, understanding, and predicting species distributions involves the core of spatial ecology (Guisan *et al.*, 2017; Fletcher & Fortin, 2018). Concepts of ecological niche and habitat suitability models are essential in order to comprehend and modelling species distributions, as respectively relate a set of environmental variables to the fitness and the likelihood of occurrence of target species (Hirzel & Le Lay, 2008). Modelling ecological niche or modelling species distributions are closely related conceptions, often differentiated if the focus is on environmental space (linked with demographic information) or in geographical space (Fletcher & Fortin, 2018). Species distribution models are a powerful tool in order to select critical conservation sites, determine native habitat management or conduct preservation efforts (Gaston, 1996; Graham *et al.*, 2004; Guisan *et al.*, 2013; Fletcher & Fortin, 2018).

Geographic information system (GIS) technologies provide a basic tool so as to manage and analyze explicit spatial data (Pereira & Itami, 1991; Boitani & Fuller, 2000). In addition, Maxent application is a widely used method in order to predict species distributions (Elith *et al*., 2011). The power of combining both tools have been proved by some examples of predicted distributions in animal (Bombi *et al*., 2009; Moreno *et al*., 2011; Clements *et al*., 2012; Popov, 2015) and plant species approaches (Kumar & Stohlgren, 2009; Reddy, 2015; Yi *et al*., 2016).

Queen crown (*Saxifraga catalaunica* Boiss. & Reut.) is an evergreen saxifrage species endemic to north-eastern Iberian Peninsula (Bolòs & Vigo, 1984; Grassi *et al*., 2006). Its global population is limited to rocky slopes of two protected areas: Montserrat mountain (3.483 hectares) and Sant Llorenç del Munt (13.694 hectares) natural parks (Nuet & Panareda, 1991). According with IUCN criteria, queen crown is listed as a Near Threatened (NT) species (Sáez *et al*., 2010). A recent census of queen crown was conducted in Montserrat mountain natural park, revealing the presence of the taxon in 19 1x1 km UTM grids (Bracho-Estévanez, 2018).

Our objective is to predict the potential distribution of target species using GIS technologies and MaxEnt application while evaluating the habitat suitability of its global range: Montserrat mountain and Sant Llorenç del Munt natural parks.

Materials and methods

Potential distribution modelling of queen crown was carried out in central Catalonia (Fig 1), prelitoral mountain range (Montserrat massif and Sant Llorenç del Munt mountains, 171,77 square kilometers), covering the complete occurrence range of the species (Nuet & Panareda, 1991; Sáez *et al*., 2010). Elevation ranges from 116 to 1236 (Sant Jeroni, Montserrat massif top) and 1104 (La Mola, Sant Llorenç del Munt mountains top) meters above sea level. Mean annual temperature and precipitation are around 10-14 °C and 500-750 liters per square meter, respectively. Most precipitation occurs during autumn and spring. Highest temperatures are recorded during summer (Nuet & Panareda, 1991; Ninyerola *et al.*, 2005; Generalitat de Catalunya, 2016). Previous factors condition typical Mediterranean climate conditions within studied area (Brunet *et al.*, 2007).

We used MaxEnt (Version 3.4.1) (Phillips *et al.*, 2019) Java application in order to predict the geographical distribution of our target species in Montserrat mountain and Sant Llorenç del Munt natural parks (Elith *et al.*, 2011). MaxEnt has been highlighted as one of the best existing approaches when modelling the probability distribution for a species occurrence (Kumar & Stohlgren, 2009). Entropy is a key concept for MaxEnt predictions engineering. According with Shannon (1948) entropy could be understood as «a measure of how much 'choice' is involved in the selection of an event» (Shannon, 1948; Phillips *et al.*, 2006). MaxEnt method provides a probability distribution following maximum-entropy principle, considered an optimal approach to model species geographic distributions with presence-only data (Jaynes, 1957; Phillips *et al.*, 2004, 2006; Ward, 2007). Thus, MaxEnt estimates the cumulative probabilities of occurrence of target species for a set of previously known occurrence locations and a group of environmental layers defined as features (Phillips *et al.*, 2017). There exist great examples of explicit models representing potential distribution of plant species using maximum-entropy principle (Kumar & Stohlgren, 2009; Hosseini *et al.*, 2013; Yang *et al.*, 2013; Reddy, 2015).

Elevation, slope, orientation, precipitation, and temperature were used as environmental layers for potentially predicting the distribution of queen crown. Occurrence locations were obtained from the last updated census of studied species in Montserrat mountain natural park (consisting in a sum of 412 georeferenced locations) (Fig. 1), while elevation and orientation were highlighted as important factors

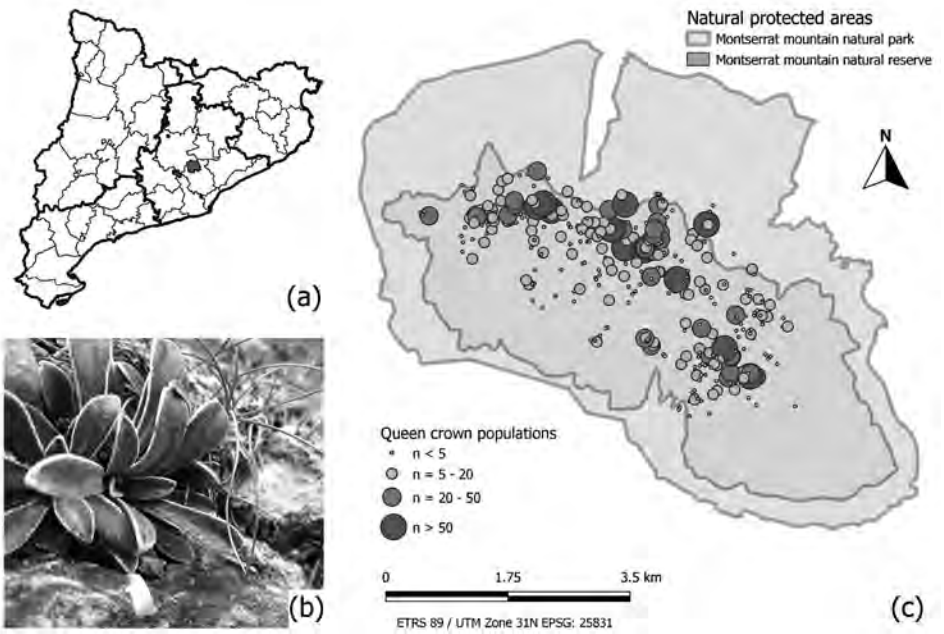

Figure 1. (a) Map of Catalonia provinces and districts. Montserrat mountain and Sant Llorenç del Munt natural parks appear highlighted in red. (b) Queen crown *(Saxifraga catalaunica)* individual in a slope of Montserrat mountain. (c) Representation of last queen crown census conducted in Montserrat mountain natural park (data collected in 2018). Populations of queen crown are scaled by number of individuals. Coordinates are not represented in order to preserve most important locations of studied taxon.

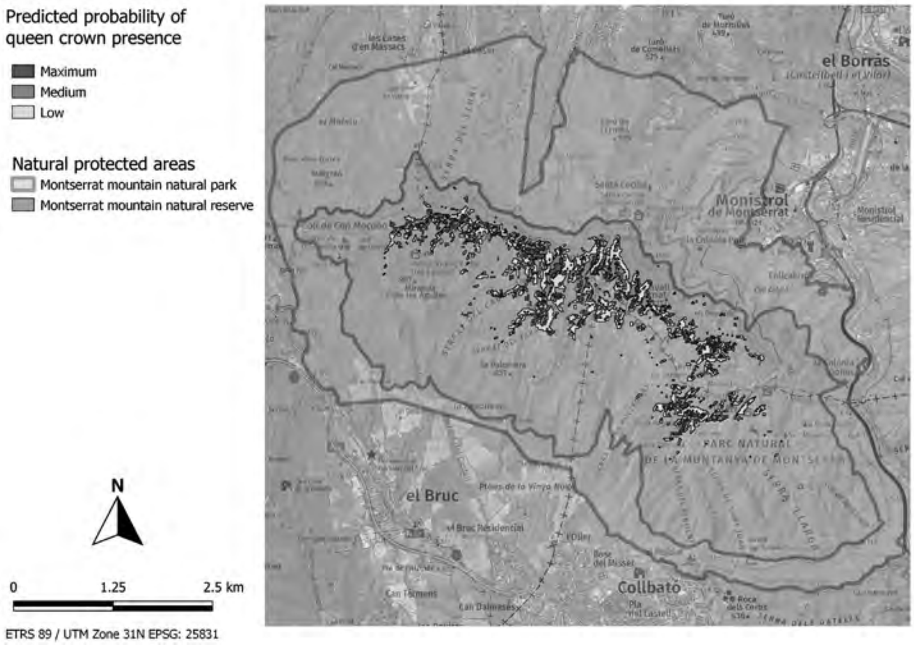

Figure 2. Predicted probability of queen crown presence in Montserrat mountain natural park, scaled in maximum, medium and low categories.

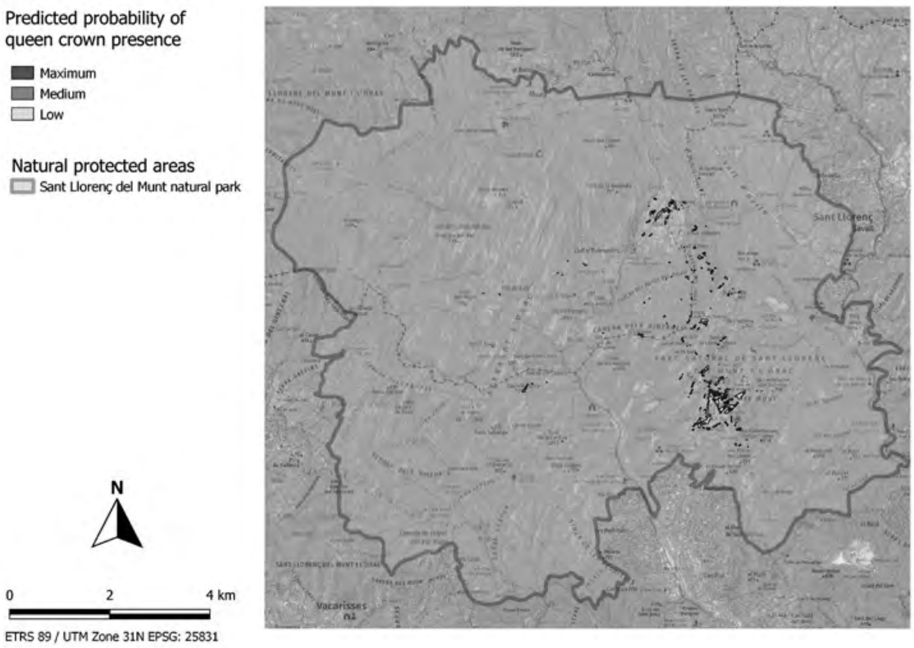

Figure 3. Predicted probability of queen crown presence in Sant Llorenç del Munt natural park, scaled in maximum, medium and low categories.

influencing presence of queen crown in Montserrat protected area (Bracho-Estévanez, 2018). Elevation data was obtained from a 15 × 15m (mean squared error 0,15 m) Digital Terrain Model (DTM) (Terrain, 1978), provided by Cartographic and Geological institute of Catalonia (ICGC), under license CC BY 4.0. DTM raster was uploaded to ArcMap software in order to create slope and orientation raster products, using ArcToolbox Spatial analyst extension (Environmental Systems Research Institute, 2012). We included precipitation and temperature bioclimatic layers in our model. Climatic layers were obtained from the Digital Climatic Atlas of Iberian Peninsula (Ninyerola *et al.*, 2005). Raster cell size, spatial extent and projections were evaluated in order to ensure same properties of all layers before its upload to MaxEnt application.

MaxEnt requires ascii archives to represent continuous environmental layers or features as adequate inputs. Transformation from raster to ascii was obtained by working with ArcToolbox Conversion tools extension. We run MaxEnt application by selecting a logistic output format along with a cross validate replicated run type. 321 presence records were used for training the model, 80 for testing. 10319 points were employed to determine our model distribution (background and presence points). Produced model was uploaded, transformed to raster, and reclassified in ArcMap by using ArcToolbox Spatial analyst and Conversion tools extensions (Environmental Systems Research Institute, 2012). The contribution of each environmental layer was estimated using MaxEnt jackknife test. Maximum-entropy prediction model was reclassified in four classes using natural breaks (jenks) method, consisting in the minimization of intra-group variance while targeting the maximization of inter-group variance data (Simpson & Human, 2008; Balcerzak, 2015). We obtained three classes or groups corresponding to maximum probability (P>0,839), medium probability (0,839>P>0,734) and low probability of queen crown presence (0,734>P>0,484). Last class (P<0,484) was not considered as suitable for our output representations, as holds lowest probability of queen crown occurrence. Final compositions were produced using QGIS software, version 3.6 (QGIS Development Team, 2017).

We also used LecoS v 3.0.0 (Landscape Ecology Statistics) plugin, a QGIS raster tool based on metrics taken from FRAGSTATS. By uploading our MaxEnt model for *Saxifraga catalaunica* we obtained indicative values as patch cohesion index, patch density, fractal dimension index, Euclidean Nearest-Neighbor Distance or landscape proportion for each probability distribution category.

Results

MaxEnt modelling method successfully produced probability distribution outputs of studied taxon in Montserrat mountain and Sant Llorenç del Munt natural parks (Figs 2 and 3). It represents the global distribution range of studied species. Sant Llorenç del Munt output is a great example of how maximum-entropy principle has a potential capability to model target species' habitat requirements and predict its potential distribution, even in areas without available presence data. Test AUC (Area Under the Receiver Operating Curve) of our queen crown distribution model is 0,969. Training AUC is 0,962.

Our model predicts a global of 10,91 hectares with maximum presence probability, 48,58 hectares with medium presence probability and 140,44 hectares with low presence probability of queen crown (Figs 2 and 3). In Table 1 a set of 8 spatial parameters are represented for each natural park, depicted by presence probability categories.

Discussion

AUC is a great trace for a MaxEnt predictive model. The value of our model indicates that it is a great approximation to the potential distribution of queen crown, as this value scores from 0 to 1, values from 0,9 to 1 corresponding to highly data sensitive models (Fielding & Bell, 1997; Swets, 1998). Thus, representations of omission on training samples and AUC strengths consistency of our results, as models with lowest training omission rates and highest AUC (Figs 4 and 5) though spatial autocorrelation could contribute increasing its value (Redon & Luque, 2010).

Elevation is the most relevant variable for our distribution model. Elevation and precipitation contribute with high gains (>1) when tested independently, so provide more useful information than other variables. If excluded, elevation produces considerable losses (>0,3) in terms of model training gain. Elevation relevance is followed by precipitation, temperature, and slope layers (Fig 6). We should consider that variables such as elevation and temperature could be highly correlated, so further approaches may focus on choosing one (as a first approach our decision was to represent all).

Orientation is not that relevant for our model training gain. However, previous approaches have highlighted its importance in queen crown ecology (Nuet & Panareda, 1991; Bracho-Estévanez, 2018). This discordance is probably produced by our geospatial input layers. Within some grids orientation variability is potentially high. Thus, our raster calculator simplifies that complexity to the average orientation of each grid, facing some methodology problems. For instance, in a grid with a southern orientation average (±180 degrees) could exist small areas with northern orientation favorable for studied taxon. Nonetheless, in this case our raster would link target species populations with southern orientations.

Table 1. Values of extension, average patch size, number of patches, patch cohesion index, patch density, fractal dimension index, Euclidean Nearest-Neighbor Distance and landscape proportion (obtained with LecoS QGIS Plugin) in Montserrat and Sant Llorenç del Munt natural parks.

Protected area	*Montserrat natural park*			*Sant Llorenç del Munt natural park*		
Presence probability	*Maximum*	*Medium*	*Low*	*Maximum*	*Medium*	*Low*
Extension (ha)	10,63	46,06	115	0,28	2,52	25,44
Average patch size (ha)	0,08 (±0,16)	0,16 (±0,42)	0,2 (±0,61)	0,02 (±0,01)	0,06 (±0,07)	0,12 (±0,21)
Number of patches	125	232	266	12	40	121
Patch cohesion index	8,3	8,2	9,4	5,9	6,6	8,7
Patch Density	7,0825	0,0001	0,0001	3,6355	0,0001	0,0003
Fractal Dimension Index	1,04	1,06	1,07	1,01	1,03	1,07
Euclidean Nearest-Neighbor Distance	1681	1677	1971	1366	1982	2347
Landscape proportion	0,004	0,009	0,03	0,00008	0,0003	0,003

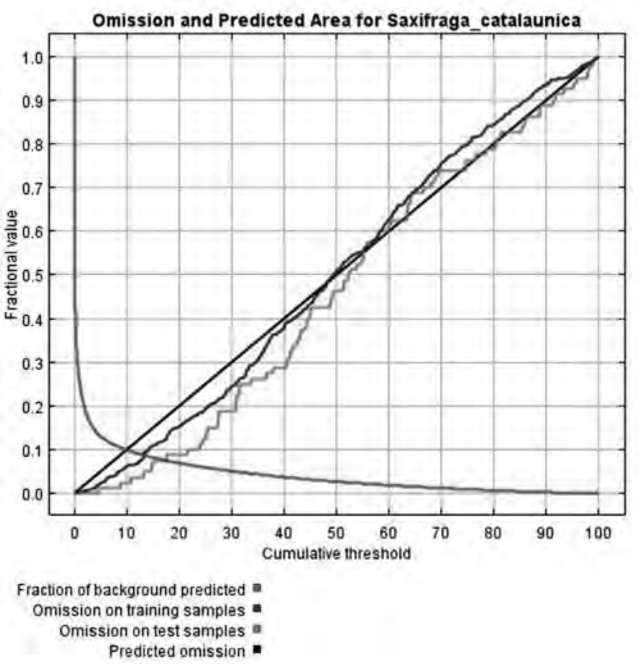

Figure 4. Representation of omission on training samples and predicted area as a function of the cumulative threshold. Omission rate is calculated both on the training presence records and on the test records.

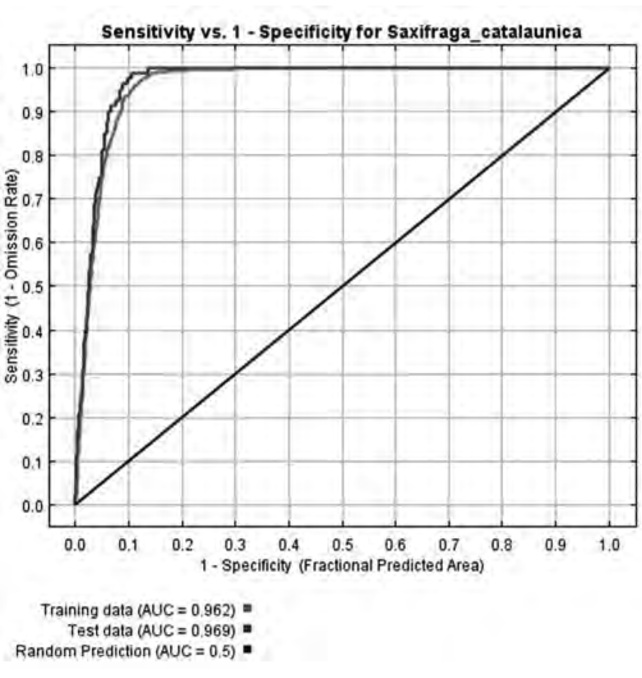

Figure 5. Representation of Area Under the Receiver Operating Curves of our queen crown distribution model. Red line represents the aptitude of our model to the training data. Blue line indicates the aptitude of our model predictions as compares with test data.

Therefore, orientation contribution has been possibly underestimated.

Precipitation is a relevant environmental layer for produced distribution model, followed by temperature. In addition, climate models suggest a trend towards decrease in

Figure 6. Contribution of each environmental variable in modelling global distribution of queen crown. Red bar describes training gain using all variables. Light blue bars indicate gain lost when removing single variable from distribution model. Dark blue bars denote gain contribution of single variable for obtained distribution model.

summer precipitation and increase in annual and summer temperatures for Eastern Iberian Peninsula (Pausas, 2004; Giorgi & Lionello, 2008). Thus, climate change predictions potentially involve reductions in optimal habitat availability for target species, while assuming high uncertainty (Thuiller *et al*., 2005; Randin *et al.*, 2009; Keenan *et al.*, 2011). Future research about how climate change may affect queen crown distribution will be necessary when assessing future preservation measures.

Produced model predicts an almost continuous distribution of studied taxon through septentrional areas of Montserrat mountain natural reserve. Mentioned distribution overlaps with most prominent, north-facing slopes of protected area (Fig 2). Regions as Canal del Migdia, Paret de Sant Jeroni or Paret dels Ecos hold largest patches with maximum potential distribution of queen crown in Montserrat. Our distribution model is clearly different for Sant Llorenç del Munt natural park, with a scattered, discontinuous predicted distribution within protected area, particularly concentrated around La Mola and Montcau peaks (Fig 3). According with our model, Sant Llorenç del Munt natural park holds 0,26 % of maximum, 5,47 % of medium and 22,12 % of low potential distribution hectares comparing with Montserrat mountain natural park. It strongly links with last occurrence estimations of queen crown in Sant Llorenç del Munt protected area: 5 1 × 1 km UTM grids (Sáez *et al.*, 2010), contrasting with 19 1 × 1 km UTM grids in Montserrat protected region (Bracho-Estévanez, 2018). In addition, our model predicts larger patches with maximum, medium and low potential distribution of target species in Montserrat mountain natural park, along with larger patch cohesion index, shorter Euclidean Nearest-Neighbor Distance and greater contribution to landscape proportion than potential distribution patches of Sant Llorenç del Munt natural park (Table 1). Patch cohesion index, patch density, fractal dimension index and landscape proportion are particularly contrasting in maximum presence probability patches. Interestingly Euclidean Nearest-Neighbor Distance is larger for maximum potential distribution patches of Montserrat protected area, according with its dramatically scarce and concentred distribution in Sant Llorenç del Munt natural park.

Sant Llorenç del Munt queen crown populations are more vulnerable to potential environmental disturbances such as climate change. Isolation along with few suitable, available habitat pushes the risk of this taxon in mentioned protected area (Helliwell, 1976; Ellstrand & Elam, 1993; Piessens *et al.*, 2005). So, monitoring population dynamics could be an optimal approach to assess its conservation status (Schemske *et al.*, 1994). Although predicted distribution is more consistent, continuous for Montserrat protected area, some southern and eastern patches appear slightly isolated from core region.

Rock climbing is a potential threat for rocky plant communities (Camp & Knight, 1998; Rusterholz *et al.*, 2004). Many potential distribution hectares coincide with concurred climbing routes. To evaluate possible negative impacts could mean a valuable conservation advance. We suggest focusing conservation efforts on maximum and medium potential distribution hectares, as future preservation measures could safeguard more individuals per unit of effort. Thus, climbing routes coinciding with potential distribution hectares should be carefully analyzed as likely involving negative interference with queen crown.

Produced predictions are relevant given scarcity, endemism and threats involving queen crown conservation, as it means the first approach modelling its global distribution. As shown, combining GIS technologies and MaxEnt predictive distribution outputs is a powerful tool in order to obtain models representing optimal habitat occurrence through spatial dimension. Our research provides two visions of modelling distribution possibilities: assessing potential distribution of target species in a region with availability of occurrence locations (Montserrat mountain) and predicting potential distribution in a region without available occurrence locations (Sant Llorenç del Munt). Thus, with enough representative dataset, MaxEnt distribution predictions have a great applicability when modelling the geographic range of our taxon of interest.

MaxEnt, as a highly intuitive application, supplies researchers and biodiversity management technicians with a practical tool (Phillips *et al.*, 2017). Implications in management of natural resources are potentially high, as previously unknown species distributions could help in focusing conservation efforts, identifying highly valuable areas for taxon preservation, or removing pointless efforts (Kumar & Stohlgren, 2009; Remya *et al.*, 2015; Yi *et al.*, 2016). Combining obtained species distribution model with value of information (VOI) analysis could be an interesting approach in order to assess management and monitoring of target species occurrence (Raymond, 2018; Raymond *et al.*, 2020). VOI analysis represent a competent tool to reduce uncertainty in complex management decisions, particularly underutilized in ecology (Williams, 2011).

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