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Are long-distance dispersal syndromes associated with the conservation status of plant species? The Canary Islands as a case study

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Abstract. Dispersal is the process that allows organisms to reach new suitable territories and expand their area of occupancy. In plants, long-distance dispersal (LDD) of diaspores is related to the presence of morphological structures (dispersal syndromes) that favor mobility by wind (anemochorous), sea currents (thalasochorous) and animals (epizoochorous and endozoochorous). The relationship between these LDD structures and the distribution of plant species is related to characteristics of different archipelagoes. Previous studies in several archipelagoes found that the Canary Islands showed the strongest positive relationship between dispersal syndromes and species distributions. It has been long hypothesized that species without specialized structures for dispersal have more difficulties in expanding their areas of occupancy and consequently these species are more threatened because of limited distribution. Nevertheless, the effect of the dispersal ability of plant species on the degree of threat has never been tested in oceanic archipelagoes. In this study, we selected the 262 lowland endemic plant species of the Canary Islands and evaluated the relationship between the presence/absence of the four LDD syndromes and their threat status. A considerable number of threatened (154 spp.) and non-threatened (108 spp.) species were observed, of which 93 had LDD syndromes and 169 did not. Our analyses failed to find statistically significant differences between the number of threatened species with and without LDD syndromes and their IUCN threatened status. In sum, this study shows a poor contribution of dispersal abilities in the degree of threat of endemic plant species in the Canary Islands.
Keywords: LDD syndromes; Canary Islands; threatened species; IUCN categories.

¿Están relacionados los síndromes de dispersión a larga distancia con los estatus de conservación de las especies vegetales? El caso de las Islas Canarias

Resumen. La dispersión es el proceso que permite a los organismos alcanzar nuevos territorios favorables y expandir su distribución. En plantas, la capacidad dispersiva a larga distancia (LDD, por sus siglas en inglés *long-distance dispersal*) está relacionada con la presencia de estructuras morfológicas (síndromes de dispersión) en sus diásporas que favorecen su dispersión por el viento (anemocoria), las corrientes marinas (talasocoria) y los animales (epizoocoria y endozoocoria). La relación entre estas estructuras LDD y la distribución de las especies de plantas depende de las características de los diferentes archipiélagos. Estudios previos en distintos archipiélagos mostraron que es en las Islas Canarias donde la relación entre la presencia de síndromes de dispersión y la distribución de las especies es más notable y significativamente positiva. Tradicionalmente se ha asociado la menor capacidad de dispersión de las especies, i.e. ausencia de síndromes de dispersión, con un mayor grado de amenaza para su conservación. Sin embargo, el efecto de la capacidad dispersiva de las plantas en su estado de amenaza nunca ha sido analizado en archipiélagos oceánicos. En este estudio hemos evaluado si la capacidad dispersiva de las 262 especies de plantas endémicas de zona baja de las Islas Canarias, considerando la presencia o ausencia de los cuatro síndromes LDD, está relacionada con su grado de amenaza. Entre las especies endémicas estudiadas se encontraban especies amenazadas (154 spp.) y no amenazadas (108 spp.), de las cuales, 93 tenían síndromes LDD y 169 no. Los análisis no mostraron diferencias significativas entre el número de especies amenazadas con o sin síndromes LDD en relación a su estado de amenaza según la IUCN. Este estudio muestra una escasa contribución de las habilidades dispersivas de las angiospermas a su grado de amenaza en las Islas Canarias.
Palabras clave: Síndromes LDD; Islas Canarias; especies amenazadas; categorías UICN.

Introduction

Certain areas of the Earth, known as biodiversity hotspots, hold high levels of biological diversity and are affected by an exceptional loss of habitat. According to Myers & *al*. (2000) and updates made by Conservation International (www.conservation.org/how/pages/hotspots.aspx), several of these biodiversity hotspots are located on islands, despite their limited surface compared to mainland. The high isolation of islands has implications in speciation processes and consequently leads to higher rates of insular endemisms (Whittaker & Fernández-Palacios, 2007). However, island isolation, together with their reduced areas, is also related to a higher extinction

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risk compared to the mainland and makes islands a more challenging territory to preserve (Frankham, 1998). In addition, the majority of species of vertebrates and plants extinctions recorded have occurred on islands (Sax & Gaines, 2008). Therefore, islands are a precious resource for science and should be a conservation priority.

Islands can be divided into two main major groups, according to their connectivity to the mainland: (i) continental islands, which have been connected in the past to the continent; and (ii) oceanic islands, which emerge lifeless from the oceanic floor (normally by volcanic activities) and have never been connected to the mainland (Vargas, 2014). Organisms can only reach oceanic islands overcoming considerable stretches of sea by long-distance dispersal (LDD). Despite colonization also depends on establishment processes, traditionally it has been assumed that species with typical LDD traits were more successful colonizers than those without them (Darwin, 1859; Gillespie & Clague, 2009). Particularly in plants, the presence of morphological features in the diaspores that favor LDD to oceanic islands —i.e. presence of wings or pappus, structures associated with wind dispersal (anemochorous syndrome); with sea currents like corky tissues or air chamber (thalassochorous syndrome); with animal dispersal like hooks or sticky surfaces (epizoochorous syndrome) and fleshy, colored tissues (endozoochorous syndrome) —has been related to island colonization success (Carlquist, 1966). LDD usually brings to mind dispersal from the continent to an island as they are usually separated by long distances. Nevertheless, dispersal between islands within an oceanic archipelago is also considered as LDD; although the distances are shorter, sea barriers have to be overcome. In this work we consider LDD in a biogeographical context, i.e. a biogeographical barrier (e.g. the sea) has to be crossed. Focusing on dispersal within archipelagoes, recent studies found a certain positive relationship between the presence of LDD syndromes and plant distributions within several oceanic archipelagoes (Galápagos, Vargas & *al*., 2014; Azores, Heleno & Vargas, 2015; the Canary Islands, García-Verdugo & *al*., 2017; Arjona & *al*., 2018) indicating that species with LDD syndromes have wider distributions. Although this tendency is observed in all the studied archipelagoes, only in the Canary Islands the relationship between presence of LDD syndromes and wider distributions was statistically strongly supported (Arjona & *al*., 2018).

The Canary Islands offer an ideal framework for conservation studies based on recent floristic data of its entire biota (Arechavaleta & *al*., 2010) and main threats of the endemic biodiversity (Caujapé-Castells & *al*., 2010). In addition, the Canary Islands are floristically related to the Mediterranean Basin, which is one of the world´s hotspot of biodiversity according to Myers & *al*. (2000), and shows the highest concentration of threatened species of the entire Spanish flora (Muñoz-Rodríguez & *al*., 2016). The degree of threat of the species is evaluated by the IUCN (IUCN, 2012) according to several criteria, one of them being the species distribution. The high proportion of threatened plant species in the Canary Islands without LDD syndromes —with narrow distributions in terms of number of islands occupied (Arjona & *al*., 2018)—, which hence are supposed more sensitive to the actual threats for their conservation, may contribute to the high proportion of threatened species of the archipelago. Following this reasoning, our working hypothesis is that species with unspecialized LDD syndromes do not display large distributions and thus they are more abundant into threat categories of the IUCN. Although IUCN has several criteria in addition to distribution range, the relationship between number of islands occupied and LDD syndromes (Arjona & *al*., 2018) lead to think that species with unspecialized diaspores have a higher degree of threat. The main threats that affect Canarian flora are related, among others factors, to anthropic activities or competition (Bañares & *al*., 2004, 2009) but how dispersal traits influence the response of plants to threats has not been previously studied. In this work, we studied the relationship between dispersal traits and threat status to understand the factors responsible for autoecological limitations.

The objectives of the present study are to determine (i) whether plant species without LDD syndromes have a higher number of threatened species in the Canarian endemic lowland flora than species with LDD syndromes; and (ii) whether species without LDD syndromes have a higher degree of threat regarding to the IUCN categories (LC < NT < VU < EN < CR) than those species with LDD syndromes.

Material and Methods

The Canary Islands form a volcanic archipelago located in the North Atlantic, 96 km off northwest Africa. It comprises seven main islands (from east to west: Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro) and several islets. This archipelago is heterogeneous in their habitat representation, since the eastern islands —which are also the oldest ones—, Fuerteventura and Lanzarote, show lower altitudes and a dryer climate than the central and western islands, with higher habitat diversity (Bramwell & Bramwell, 1974). This heterogeneity, together to isolation from mainland, favors the presence of a rich biodiversity in the archipelago and a high proportion of endemic species: the Canaries harbor 1333 angiosperm native species, about 40% of which are endemic (Acebes Ginovés & *al*., 2010).

Some explicit criteria were taken to build the working dataset in this study. (i) Due to the heterogeneous habitat representation in the different islands cited above, we chose only angiosperm species that occur in the lowland xeric habitat, as this is the only habitat that occurs in all islands and then, species colonization is not conditioned by the presence of a certain habitat in an islands (e.g. high mountain vegetation or laurel forest are absent in several islands). In contrast, although habitat is controlled in this study by analyzing only species distributed in xeric areas, some other factors that determine plant distributions and abundance, such as interaction among antagonist and among mutualist species, were not analyzed. (ii) Only endemic species were considered in order to exclude any introduced species. (iii) We considered IUCN categories as assigned by Muñoz-Rodríguez & *al.* (2016). (iv) The IUCN categories were only applied on species (subspecific taxa were not considered). (v) When there were several subspecies we decided to consider the highest category for the whole species (this happened with 23 species); e.g. *Echium strictum* has three subspecies with different IUCN categories: *E. strictum* subsp. *strictum* as NT, *E. strictum* subsp. *gomerae* as VU and *E. strictum* subsp. *exasperatum* as VU; consequently, we assigned VU category for the species *E. strictum*. (vi) Finally, some species were excluded from the analysis because of insufficient data (Table 1). As a result, we worked with 262 lowland endemic species grouped into two groups according to their IUCN category stablished by Muñoz-Rodríguez & *al*. (2016): non-threatened species (which included LC and NT species) and threatened species (including VU, EN and CR species).

Table 1. Species excluded for the analysis and its justification

Species	Exclusion criteria
Allagopappus viscosissimus	Data deficient (DD)
Atalanthus canariensis	Data deficient (DD)
Fumaria coccinea	Data deficient (DD)
Herniaria hartungii	Data deficient (DD)
Kunkeliella psilotoclada	Extinct (EX)
Minuartia webbii	Data deficient (DD)
Patellifolia webbiana	Data deficient (DD)
Phelipanche gratiosa	Data deficient (DD)
Scilla dasyantha	Data deficient (DD)
Vicia chaetocalyx	Data deficient (DD)

In relation to dispersal syndromes categorization we only considered LDD syndromes. We did not considered syndromes related to short distance dispersal, such as barochory, mirmechory, or fresh water hydrochory, because they are less likely to contribute to the formation of new populations in the Canary Islands. Finally, according to representation of LDD syndromes we regrouped the species in two groups: species with LDD syndromes and species without LDD syndromes. Data of syndrome classification and distribution of species diaspores were obtained from Arjona & *al.* (2018).

In order to analyze if there was a higher number of threatened species without LDD syndromes than species with LDD syndromes we employed a Chi-squared test. We performed another Chi-squared test to analyze if either species with or without LDD syndromes showed a higher degree of threat.

Results

The final dataset resulted in a total of 262 species of the endemic lowland flora of the Canary Islands. After combining the list of IUCN categories (Muñoz-Rodríguez & *al*., 2016) and the list of LDD syndromes and species distributions (Arjona & *al*., 2018) we found 108 non-threatened species (51 LC and 57 NT) and 154 threatened species (85 VU, 37 EN and 32 CR) (Figure 1). In the endemic lowland flora of Canary Islands, a high percentage (59%) of species is threatened. In addition, the categorization of the LDD syndromes resulted in 93 species with LDD syndromes (74 anemochorous, 8 endozoochorous, 2 thalasochorous, 1 epizoochorous and 8 diplochorous, i.e. two LDD syndromes according to Vargas & *al*., 2015) and 169 species without LDD specializations (Figure 2). No statistically significant differences were found between threatened and non-threatened species with and without LDD syndromes (Figure 3, Table S1 in Supplement 1, $\chi^2 = 0.55$, 1 df, $p = 0.46$). Likewise, no differences were found among the different IUCN categories regarding the presence of LDD syndromes (Figure 4, Table S2 in Supplement 1, $\chi^2 = 6.35$, 4 df, $p = 0.17$). The proportion of species with and without LDD syndromes grouped into threatened categories (VU, EN, CR) was very similar among them (differences between LDD and unspecialized species were not higher than 5%). The highest differences among IUCN categories were found in NT category, which consisted of 44 species (26%) of unspecialized species and 13 species (14%) of LDD species.

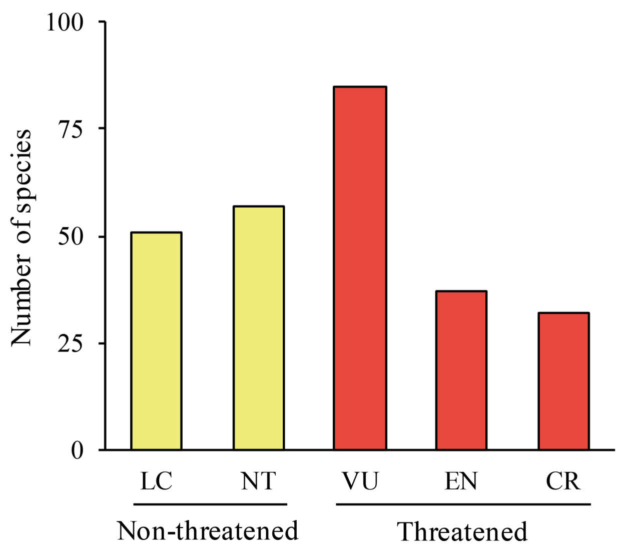

Figure 1. Number of non-threatened (yellow) and threatened (red) species in the endemic lowland flora (262 species). LC: least concern (51 spp.); NT: near threatened (57 spp.); VU: vulnerable (85 spp.); EN: endangered (37 spp.); CR: critically endangered (32 spp.). (Online version in color).

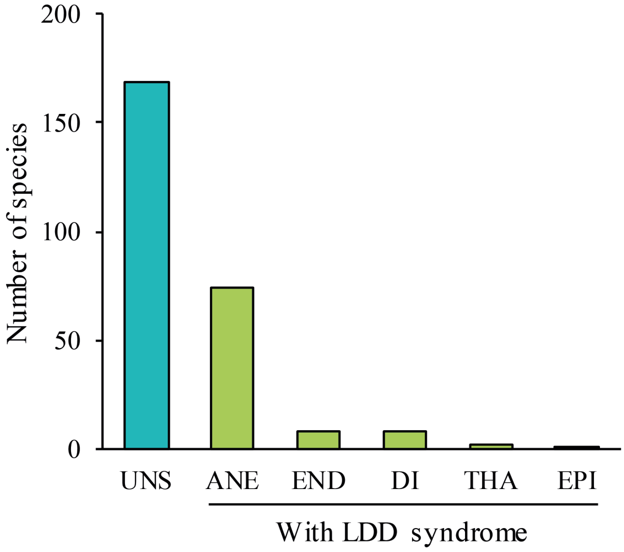

Figure 2. Number of species with (green) and without (blue) LDD syndromes in the endemic Canarian lowland flora (262 species). UNS: unspecialized (169 spp.), ANE: anemochorous (74 spp.); END: endozoochorous (8 spp.); DI: diplochorous (8 spp.); THA: thalasochorous (2 spp.); EPI: epizoochorous (1 spp.). (Online version in color).

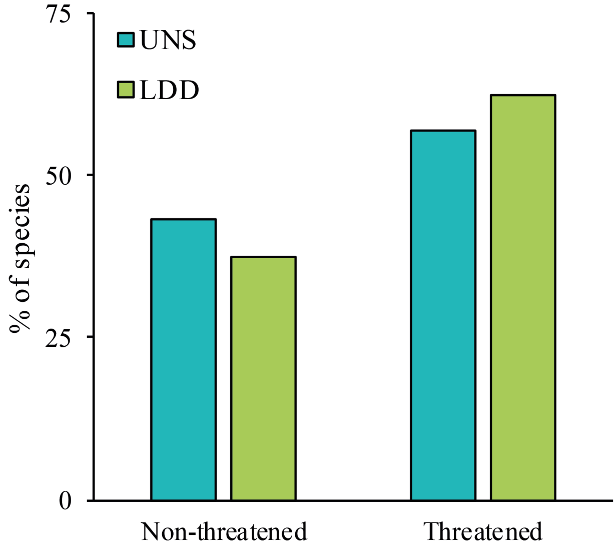

Figure 3. Percentage of threatened and non-threatened species with LDD syndromes (green) and unspecialized (UNS, blue) in the endemic lowland flora of the Canary Islands. χ^2=0.55, 1 df, p=0.46. (Online version in color).

Discussion

In this study we explored the relationship between the representation of LDD syndromes and the degree of threat for the Canarian endemic lowland flora. Our results show that the proportion of threatened species with and without LDD syndromes is not significantly different (Figure 3). In other words, contrary to our expectations, we did not find that a high degree of threat is related to the lack of LDD syndromes, and hence with a lower potential for dispersion. A more detailed analysis revealed that none of the five IUCN categories (LC, NT, VU, EN, CR) had statistically significant differences considering the presence of LDD syndromes (Figure 4).

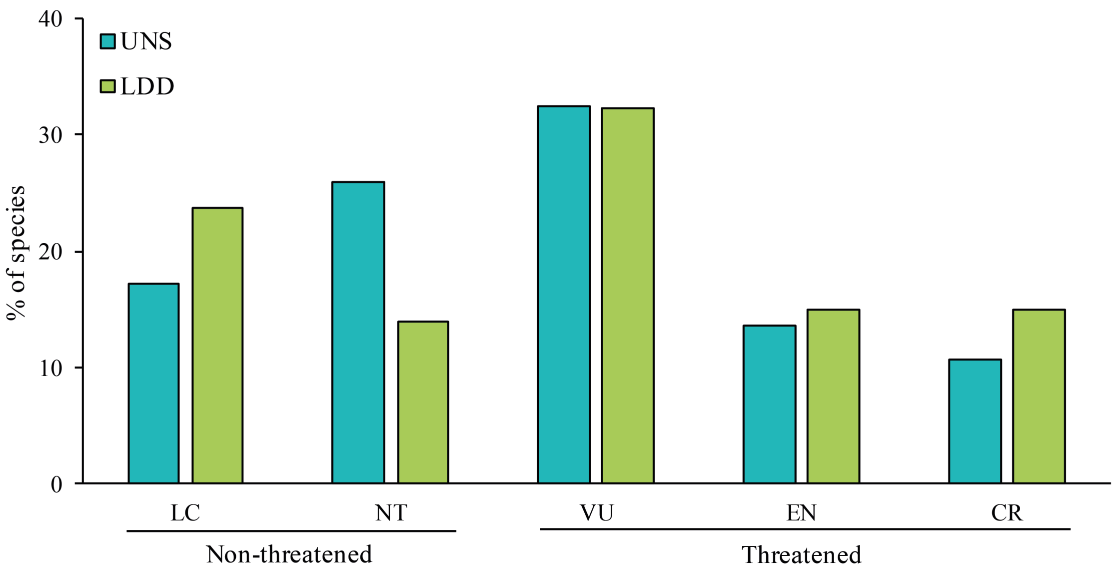

Figure 4. Percentage of species in each IUCN category of species with LDD syndromes (green) and unspecialized (UNS, blue) in the endemic lowland flora of the Canary Islands. LC: least concern; NT: near threatened; VU: vulnerable; EN: endangered; CR: critically endangered. χ^2=6.35, 4 df, p=0.17. (Online version in color).

Failure in finding a relationship between the presence of LDD syndromes and degree of threat could be explained by several causes: (i) The species distribution is not the only criterion used to define the degree of threat. According to IUCN criteria (IUCN, 2012), there are population characteristics such as population dynamics that help to define a more restrictive degree of threat, despite having a wide distribution (e.g. a high demographic reduction of a population determines species categorization). So having a lower dispersal ability could not be sufficient to discriminate between threatened and non-threatened species. (ii) The narrow distribution of some species is not necessary due to a reduction of a past wider area. For instance, recently formed species that are the result of a recent speciation event may not have had enough time to disperse to other territories; therefore, their areas are initially small independently of their syndrome (Vargas, 2007). (iii) Our analysis included a low number of species displaying most LDD syndromes (thalassochorous, epizoochorous, endozoochorous, diplochorous), while a single syndrome (anemochorous) is displayed by a high proportion (80%) of species (Figure 2). Arjona & *al*. (2018) found that anemochorous and unspecialized species had a similar narrow distribution pattern. Indeed, lack of significant differences in our analyses may reflect this imbalance in the LDD syndrome proportions. Future studies employing other techniques will be able to discriminate among LDD syndromes and complete our results. (iv) The use of only endemic species to ensure a native status might bias our results. Future approaches should include the entire native flora of the Canary Islands. (v) Current distributions of species are the result of a two-stage process in which dispersal is followed by establishment (MacArthur & Wilson, 1967). In this study we solely tested the role of dispersal based on current species distributions. Therefore, future studies focused on different factors for establishment such as habitat suitability (using species distribution models) and mutualistic and antagonistic interactions (species interaction networks) are necessary to a better understanding of the factors that modulate the response of the plants to the threats menacing their conservation.

A finding that should be highlighted is that more than a half (59%) of the species of the endemic lowland Canarian flora is threatened (Figure 1). In the same direction, Moreno & *al.* (2008), considering the whole flora of the Canary Islands, found that 247 of the 515 endemic species (48%) are highly threatened, or even extinct, (EN, CR, EX). The high levels of threatened species in the lowland flora of the Canary Islands are worrying because it could translate soon into extinctions due to the past loss of habitat, i.e. caused by the extinction deb (Otto & *al*., 2017). In addition, lowland areas of the archipelago also suffer from high anthropic pressure since the Canary Islands are a main destination for beach and recreational tourism (Moreno Gil, 2003; Ballantyne & Pickering, 2013), among other human activities. Therefore, we call attention of the importance of studying plants not only occurring in fragile habitats (e.g. thermophilous woodlands) but also in expanded areas with intense human pressure.

Conclusions

Considering the lowland endemic flora of the Canary Islands, more than a half (59%) of the species are threatened. Presence of LDD syndromes is not related to the degree of threat of the species. Furthermore, there are no significant differences between species with and without LDD syndromes considering separately different threat categories (LC < NT < VU < EN < CR). Further study is needed in order to extend the analysis to the entire flora of Canary Islands, and to evaluate factors conditioning plant establishment given that not only dispersal is involved in successful colonization. In particular, interaction among antagonist and among mutualist species should be addressed (and considered for IUCN) in future studies for a better understanding of the factors involved in conditioning the threat status of the species.

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Supplementary material

Supplement 1. Table S1: Contingency table of number of species of endemic lowland flora of Canary Islands classified as threatened and non-threatened with and without LDD syndromes". We also corrected the Supplement. Table S2: Contingency table of number of species of endemic lowland flora of Canary Islands classified by IUCN categories and the presence or absence of LDD syndromes.