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ORIGINAL PAPER

Applying the IUCN Red List criteria to small-sized plants on oceanic islands: conservation implications for threatened bryophytes in the Canary Islands

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Abstract The International Union for Conservation of Nature (IUCN) Red List categories and criteria were applied to small-sized spore-producing plants with high dispersal capacities (bryophytes). The application of some of the IUCN criteria to bryophytes in small and highly environmental diverse islands implies several problems. The criteria applicability increases when the occupancy area is reduced. However, for common species restricted to a single type of vegetation belt, the use of the IUCN criteria is problematic because of inapplicable and/or misleading thresholds. We adapted the IUCN criteria by modifying the occupancy and occurrence area sizes and by specifying the location. This approach allowed us to establish the first Red List for the bryophyte species in the Canaries, which comprises 105 species (67 mosses and 38 liverworts); among them, 7 are critically endangered, 20 are endangered and 78 are vulnerable. Twenty-six species were classified as near-threatened, 245 were considered to be at low risk and 125 were data deficient (DD). Among the DD ones, 19 corresponded to newly reported species (DD-n) and 40 had no records during the last 30 years (DD-va). Our findings show that the freshwater habitats as well as the habitats in the most restricted cloud forests (with *Erica platycodon*) contain the

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majority of the threatened species, followed by other types of laurel forests and high mountain habitats.

Keywords Conservation priority · International Union for Conservation of Nature · Liverwort · Moss · Habitat singularity

Introduction

Small-sized plants, such as bryophytes, are usually ignored in conservation efforts, although the number of publications about them is slowly increasing (Hallingbäck 2007). There is an increasing awareness that the vast majority of extinctions go unnoticed because they occur within small, highly neglected organisms, such as small invertebrates, despite representing the highest proportion (approximately 80 %) of currently described species (Cardoso et al. 2011). This situation is even more dramatic on oceanic islands because island species and/or populations are more prone to extinction than species on the mainland (Paulay 1994; Quammen 1997).

Island organisms may be more sensitive to human disturbances because (i) long-term evolutionary history has often resulted in a high level of endemicity (Whittaker and Fernández-Palacios 2007); (ii) as a consequence of their small size and geographical isolation, insular populations have a lower chance of re-colonisation after catastrophic events (Whittaker et al. 2001; Gillespie et al. 2008); and (iii) regular large-scale disturbances are less frequent on islands because of their isolation (Whittaker 1995; Brooks et al. 2002; Komdeur and Pels 2005), implying that species on islands might be more vulnerable to large-scale human-induced disturbances such as habitat destruction or invasive species (Duncan and Blackburn 2007).

Macaronesia is part of one of the 25 biodiversity hotspots in the world (Myers et al. 2000). Within the Mediterranean Regions of the world, it is one of the most important floristic areas (Médail and Quézel 1997; Vanderpoorten and Long 2006) by its high degree of endemism, especially among vascular plants (e.g., Kim et al. 2008; Reyes-Betancort et al. 2008). The bryophyte flora besides shows high diversity and distinction with respect to the surrounding mainland areas, and it has a 10 % of endemic species, which represents the highest endemicity rate within the Euro Asiatic-Mediterranean Region (Bischler 2004; Vanderpoorten et al. 2011).

The Canary Islands are a biodiversity hotspot part of Macaronesia, and bryophytes contribute significantly to its biodiversity. The bryophyte flora of these islands is characterised by high levels of diversity (140 liverworts, 6 hornworts and 355 mosses according to González-Mancebo et al. 2008a, b; Dirkse and Losada-Lima 2011; Sérgio and González-Mancebo 2009; Dirkse and Brugués 2010) and are located in a territory of approximately 7,500 km^2. A relatively high proportion of bryophyte species have a restricted distribution in the northern hemisphere. In addition to the Canarian and Macaronesian endemics, these species are also restricted to the Euro Asiatic-North African Mediterranean Region and the Mediterranean-oceanic Region.

The International Union for Conservation of Nature (IUCN) Red Lists are well established as a conservation tool at the global level, and their value has been widely propagated (e.g., Rodrigues et al. 2006). In recent years, IUCN Red List categories and criteria (2003) have been increasingly used at national or regional levels, and this has been encouraged by the IUCN with the publication of guidelines for national or regional Red Lists (Gärdenfors et al. 2001). Despite several critics (Possingham et al. 2002), some national Red Lists are considered an appropriate basis for setting conservation priorities and in some countries Red Lists obtained, among which is not Spain, also have legal status.

The IUCN Red Lists are far from being perfect, but the IUCN remains faithful to its original aim of providing the most comprehensive and reliable information regarding the species conservation status (Rodrigues et al. 2006). However, although the IUCN criteria were meant to be applicable to the majority of described species and world areas, different application problems have been noticed and solved with adaptations for different taxonomical groups, such as bryophytes (Hallingbäck et al. 1995, 1996, 1998; Hallingbäck and Hodgetts 2000; Hallingbäck 2007) or invertebrates (Cardoso et al. 2011), and for small areas, such as islands (Martín 2009).

Some of the main issues that explain the absence of Red Lists for small organisms such as bryophytes, despite the applicability guidelines that have been published (Hallingbäck et al. 1998; Hallingbäck 2007), are as follows: (i) the distribution of the described species is largely unknown due to their small size, which caused them to be overlooked; (ii) species abundances and the changes in space and time are unknown; and (iii) the current IUCN criteria are difficult to apply due to the absence of data (especially regarding the number of individuals and prior abundance).

Additionally, the application of the criteria to bryophytes on islands involves several problems because of the different considerations for fragmentation, the occurrence and occupation extent sizes, the distance between locations and the standard high diversity of island habitats. It becomes more difficult to consider the same criteria that are applied to wider regions when determining the ecosystem distribution and size on oceanic islands, especially when a high number of rare species exist (Molloy et al. 2002; Martín Esquivel 2004; Martín et al. 2005, 2009). Therefore, the criteria should be adapted to increase the feasibility of the classifications.

To our knowledge, this work represents one of the few applications of the IUCN criteria to the entire list of bryophyte species on relatively small oceanic islands. In Madeira Island, for instance, only the rarest species (20 % of the total flora) were analysed by Sérgio et al. (1992) and Sim-Sim et al. (2008). Our analyses also allowed us to recognise the main habitats and vegetation belts for threatened species in the Canaries and the singularity of the bryophyte flora at each vegetation belt.

Based on the application of the IUCN Red List criteria, the aims of the present work are as follows: (1) to identify the potential shortcomings of the current criteria when applied to bryophytes located on relatively small islands; (2) to explore alternative adaptations of the existing criteria considering the biological and biogeographical attributes of bryophytes; (3) to elaborate a Canary Islands bryophyte Red List; and (4) to identify the types of vegetation and habitats that harbour for the highest number of threatened bryophytes. Finally, we recommend conservation strategies for the protection of threatened small organisms with high dispersal abilities inhabiting oceanic volcanic islands.

Methods

Study area, habitats and vegetation belts

The Canary Islands are situated in the subtropical zone between 28° and 29° N and between 13° and 18° E within the southern limit of the Euro Asiatic-North African Mediterranean Region (see Fig. 1 of Appendix). Typical features of the study area include a montane topography with elevations that rise 800–1,000 m between valleys and mountain-tops and a maximum altitude of 3,718 m on Tenerife Island. Climatic conditions are highly influenced by aspect and topography in relation to the prevailing NE winds, which produce high humidity (fog precipitation) during most of the year and a moist, temperate oceanic climate in the NE-exposed areas located over 700–1,200 masl. Areas situated below and above this altitudinal range have a drier climate.

Five main vegetation types, which represent different macrohabitats for the species, can be distinguished in the Canary Islands following Del-Arco et al. (2010): inframediterranean scrubs (*Aeonio-Euphorbion canariensis*), thermophilous vegetation (mostly included in *Mayteno canariensis–Juniperion canariensis* and *Salicion canariensis* forests), laurel forest (wide sense) included in the *Ixantho-Laurion novocanariensis*, *Visneo-Apollonion barbujanae* y *Myrico-Ericion arboreae*, pine forest (*Cisto symphytifolii-Pinion canarirensis*) and supramediterranean scrubs (*Spartocytision supranubii*) (see Table 7 of Appendix). The original vegetation located in the humid mountain belt (laurel forests) shows a high reduction of their potential area in the Canaries (18 % of the original area remains with well preserved stage (Fernández-López 2001). Laurel forests also represent one of the most important ecosystems for bryophytes in Europe (Hallingbäck and Hodgetts 2000). For these reasons, laurel forest and open areas (natural and deforested) situated in this bioclimatic belt were considered separately. The small and the floristically species poor oro-mediterranean belt (Del-Arco et al. 2006, 2010) was considered together with the supramediterranean belt.

Because of the characteristic poikilohydric condition of bryophytes, cloud regime variations are very important. Therefore, three different forest types were distinguished among the laurel forests wide sense (see Table 7 of Appendix), according to their different mist precipitation values (Gómez-González and Fernández López 2009): *laurel forests*, situated on the slopes and bottom areas (with less cloud influence), *cloud forest with Erica arborea* (mainly situated in top areas with higher cloud influence or secondary forests) and *cloud forest with Erica platycodon* (situated in the ridges with the highest fog influence). Additionally, the mixed pine forest (with some laurel forest elements, such as *E. arborea*, *L. novocanariensis* and *Ilex canariensis*, according to Del-Arco et al. 2010) was distinguished within the pine forest area. Furthermore, microhabitats where the species are located were also distinguished in these vegetation belts: freshwater habitats, forest habitats (soil banks, forestry soils, rocks, and trees) and soils, rocks and trees in open areas (including pine forest, because it generally is an open forest formation in the Canaries). Classification of different microhabitats was supported by results of previous ecological works for all vegetation types of the Canaries (e.g. González-Mancebo et al. 1991, 2004, 2008b).

In addition to the Canarian and Macaronesian endemics, the Ibero-Macaronesian endemic species were considered and represented by four species, which, in addition to Macaronesia, also occur in a significantly reduced area in the southwest of the Iberian Peninsula.

Database of species and distributions

All taxa were considered at the species level for classification following the last species compilation (Losada-Lima et al. 2010). All species with taxonomical problems were included as data deficient (DD) with the exception of those of the genus *Leucobryum*. Three *Leucobryum* species have been reported in the Canaries (González-Mancebo et al. 2008a) according to Hill et al. (2006). However, in this case, we followed Vanderpoorten et al. (2003) who considered *L. glaucum* and *L. junipeoideum* to be synonymous. In addition, during our surveys (including all populations from these islands), we never reported the species *L. albidum*, for that reason it was excluded from this Red List.

The Red List criteria were applied to the Canary Islands as a whole (approximately 7,500 km^2), although there is heterogeneity in the abundance of some species between the islands. For instance, *Leucodon canariensis* is a Macaronesian endemic species, included in the near-threatened (NT) category; however, in some islands, such as Gran Canaria, this species is nearly extinct (González-Mancebo et al. 2009a). The nomenclature follows Ros et al. (2007) for liverworts and hornworts and Ros et al. (in press) for mosses.

Red List assessment

Despite the existence of criteria to apply IUCN categories at the regional level, some problems persist, especially those related to small islands. For that reason, in addition to the special characteristics guidelines considered by Hallingbäck et al. (1995, 1996, 1998), Hallingbäck and Hodgetts (2000), and Hallingbäck (2007) for bryophytes, some criteria were adapted to obtain better thresholds for evaluation in this small and topographically diverse territory.

The main problems associated with applying IUCN criteria and the adaptations to solve them in this paper are summarised in Table 1. Four aspects of the IUCN criteria were adapted to island conditions (see Table 2). (i) *Area of occupancy* (*AOO*) was reduced (0.25 km^2) (see Tables 1, 2) with respect to those proposed by IUCN (4 km^2) to avoid an overestimation of the size of suitable habitats occupied by species. This square size was also used as the basis for the biodiversity data project of the Canary Islands Government (Martín Esquivel 2004; Martín et al. 2005). Applying the IUCN scaling correction factor to transform our 0.5 km × 0.5 km scale to 2 km × 2 km using the IUCN Standards and Petitions Subcommittee (2011) thresholds and including the bryophyte flora of the Canaries at the maximum precision level for map distribution resulted in the inclusion of 100 % of the species occurring within threatened habitats at the threshold of 2,000 km^2 (vulnerable, VU) and 500 km^2 (endangered, EN). In addition, 32.5 % of the species were located within threatened habitats at the 10 km^2 threshold (critically endangered, CR). As a consequence, the richest habitat for bryophytes (laurel forest wide sense) was a threatened habitat with a total area below the second threshold (500 km^2). Therefore, all restricted laurel forest species could be included in the Red List as EN species, which represents an overestimation of the number of the species in the Red List. The same occurred with bryophytes restricted to thermophilous forests or water habitats, which are also threatened.

When the precision level for the species frequency was reduced, the application of the scaling correction factor resulted as follow: 100 % for VU species, 81.9 % EN and 6 % CR. This means that the IUCN thresholds and the 2 × 2 square grids are more suitable for larger areas (mainland), where it is more difficult to obtain accurate data.

(ii) *To select new AOO thresholds* to this smaller scale (to avoid an overestimation of the species on the Red List), we analysed the distribution of the frequency for the entire species list (excluding DD species with reasonable doubt of their presence in the Canaries). We used the 50th percentile (median statistical) for the species-range size distribution for NT species (80 grid squares), and a progressive reduction of 1/4 for each of the following categories: VU (20 grid squares), EN (5 grid squares) and CR (1 grid square). The IUCN uses a 1/4 reduction in the threshold for AOO; however they use that only for VU (2,000 km^2) to EN (500 km^2) categories. In our case, this proportion was maintained in all cases.

(iii) *Location size*. Although bryophytes are wide-dispersal plants, the occurrence of rare species may be strongly determined by the microsite occurrence and metapopulation behaviour, as suggested by Rydin (2009). For many rare species, especially dioicous, the relative importance of dispersal versus microsite limitation may be significant in determining their distribution. For that reason, the location size was related to the habitat size where the species occurs without fragmentation and the location size could be expressed in terms of number of grid squares.

Table 1 IUCN criteria, shortcomings associated with the small size of oceanic islands, and adaptations considered in the present study for the case of the Canary Islands

IUCN application	Shortcomings	Adaptation
For bryophytes, the *AOO* has been interpreted as the number of grid squares in which a species has been recorded (Hallingbäck and Hodgetts 2000)	According to IUCN Standards and Petitions Subcommittee (2011), AOO is a parameter that represents the area of suitable habitat currently occupied by a given taxon. Thus, the recommended size of the grid squares by IUCN (2 × 2 km^2) is too big for the majority of the habitats where rare species occur in the Canaries. For instance, in one of the grid squares wherein occurs many of the threatened species, total habitat area does not exceed 0.3 km^2	Grid square size used here is 0.5 × 0.5 km (0.25 km^2). The use of small grid size is more cost-effective and makes the assessing of decline or rarity of the species more precise. New thresholds were used to avoid an overestimation of species in the Red List, due to this small grid square size
According to IUCN, *location* defines a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of a given taxon. The size of the location depends on the area covered by the threatening event and may include part of one or many subpopulations	Too ambiguous. The location size and consequently distance between locations it is very difficult to apply, especially for small species with a heterogeneous distribution. In addition the distance between locations depends on the island size (Martín 2009)	The size of the location depends on both the size of the habitat type and the continued presence (i.e., number of square grids of 0.25 km^2). Thus, habitat fragmentation and continuous number of square grids defines the location size influencing distance between locations rather more than island size
Hallingbäck and Hodgetts (2000), following Gärdenfors (1996) and Gärdenfors et al. (1999) indicated that the *area of occurrence* (*EOO*) does not depend on the size of the Red List region	According to the IUCN Standards and Petitions Subcommittee (2011), any species or sub-species with an EOO of 20,000 km^2 or less, and that exhibits two of these three additional requirements (severely fragmented, or number of locations ≤10, suffering extreme fluctuations or being in continuing decline), should be considered as threatened. Due to the small area of most of volcanic islands, all bryophyte species have an EOO less than 20,000 km^2, and most of them even less than 5,000 km^2 (all Canary Islands have 7,500 km^2). In addition, this threshold may exclude discontinuities or disjunctions within the overall distributions of taxa	EOO used here are: ≤5 km^2 (CR), ≤50 km^2 (EN), ≤500 km^2 (VU)

(iv) Because of the small island area, the *extent of occurrence* (*EOO*) thresholds provided by the IUCN criteria enabled us to include in the Red List any species present in threatened habitats regardless of whether it is rare or common. For instance, a common

Table 2 Categories and criteria used in the Bryophyte Red List of the Canary Islands with the adaptations included in Table 1

Criteria	Description	CR	EN	VU	NT
A2	An observed, estimated, inferred or suspected population size reduction over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on: any of the following: (a) direct observation (b) an index of abundance appropriated to the taxon (c) a decline in AOO, EOO and/or quality of habitat (d) actual or potential levels of exploitation (e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites	>80 %	>50 %	>30 %	>20 %
B1	EOO scarce and estimates indicating at least two of a–b: (a) Severely fragmented or number of locations (b) Continuing decline, observed, inferred or projected, in any of the following: (i) EOO (ii) AOO (iii) area, extent and/or quality of habitat (iv) number of locations or subpopulations (c) Extreme fluctuations in any of i–iv	≤5 km^2 1 Location	≤50 km^2 2 Locations	≤500 km^2 3–5 Locations	≤1,000 km^2 5–10 Locations
B2	AOO scarce, and estimates indicating at least two of a–c: (indicated in B1)	1 Grid square	≤5 Grid squares	≤20 Grid squares	≤80 Grid squares
D2	Population with a very restricted AOO (≤5 grid squares) or number of locations			(≤2.5 km^2)	(≤5 km^2)

The criteria A2b and A2d have not been used

CR critically endangered, *EN* endangered, *VU* vulnerable, *NT* near-threatened

laurel forest species present in 100 % of the grid squares of this type of habitat in these islands might occur at a maximum for their current area (101 km^2 for this type of forest, Del-Arco et al. 2010) and the potential area for this type of forest in the Canaries does not rise more than 314 km^2 (Del-Arco et al. 2010, see Table 7 of Appendix). In addition, this is a severely fragmented habitat, and abundant and frequent species might occur in less than 10 locations. To avoid a longer Red List including abundant species in restricted threatened habitats, EOO thresholds were reduced (Tables 1, 2), taking in account the current area of the vegetation belts (see Fig. 1 of Appendix). For VU species the threshold of 500 km^2 represent near 10 % of the total area of the Canary Islands without taking in account areas without significant vegetation (urban, rural, industrial and service areas according to Del-Arco et al. 2010). A progressive reduction of 1/10 for each of the following categories EN (50 km^2) and CR (5 km^2) was used.

We analysed the distribution of each species to determine the number of grid squares (0.25 km^2) in which it was located using published reports, herbaria information and new surveys on all islands. The species were evaluated using both the IUCN Red List criteria (2001, 2003, 2011) as well as our adaptations (Tables 1, 2). In both cases, the adaptations for bryophytes made by Hallingbäck et al. (1995, 1996, 1998), Hallingbäck and Hodgetts (2000), and Hallingbäck (2007) were considered. We distinguished, according to Kučera and Váňa (2003) and Sérgio et al. (2007), the sub-category least-concern attention category (LC-att) for endemic and phytogeographically important species. In addition, we included the distinction of two sub-categories among the DD species defined by Sérgio et al. (2007): DD-va as data deficient-vanished and DD-n as data deficient-new.

A detailed explanation of the categories and criteria and the guidelines for their application have been outlined by the Red List Program Committee when applied at regional levels (IUCN 2003, 2005). The criteria C, D and E (with the exception of D2) were not taken into account due to the absence of data regarding the number of individuals and the probability of death. Therefore, these criteria have been excluded from Table 2, which includes all considered criteria. We include the following abbreviations of Red List categories and subcategories: CR, EN, VU, NT, LC, and DD. According to Hallingbäck et al. (1998) on the basis of the European Red List for bryophytes (ECCB 1995), a species may be considered regionally extinct when it has not been possible to find any individual of that species in a known location during the last 50 years. Some DD-va species included in this Red List, with confirmed herbaria specimens (see Dirkse et al. 1993), might be considered as presumably extinct. However, we did not include any species in this category because those old reports did not have confirmation regarding the locality. A species with no new information available (during the last 30 years) raises a reasonable doubt as to whether the species persist on the Canaries. The historical localities may be absent or insufficiently investigated, or the herbarium material was not adequately revised. For all these reasons, the classification of the selected DD species within a different category requires new researches. DD-n species was applied to species that were recently reported from the Canaries and to species that correspond with old reports that had received new taxonomical treatments. LC-att species are regarded as not threatened but can be endemic or can have particular phytogeographic importance or be threatened in Europe.

To classify the species we used the following criteria:

(i) The D2 criteria were applied only to rare species present in habitats that currently are not threatened. For certain rare species of the supramediterranean belt, the climatic change was not considered, which probably represents an underestimation of the real threat for very rare species (see Martín et al. 2012), especially in the island of La Palma where the high mountain belt is very limited in size and altitude. Therefore, we recommended management for rare species of this bioclimatic belt, even those under the VU category.

(ii) We applied the A2, B1, B2 criteria only for scarce species occurring in severely fragmented habitats or a small number of locations (1–5) that were continuing to decline (observed, inferred or projected) in habitat area or quality. Freshwater habitats represent a good example of threatened habitats because most of them have disappeared in the Canaries, and they nowadays are generally threatened due to human exploitation of the few remaining water courses and other freshwater habitats with natural conditions.

(iii) For a high proportion of species, the application of different criteria (AOO, EOO) resulted in the consideration of the species below the same IUCN category. However, when different criteria allowed us to include the species in a different category, we applied the most restrictive criteria (following the IUCN) such that AOO was the most important criteria considered in those cases.

The SPSS program version 18.0. was used to perform a Chi-squared test (χ^2) to examine IUCN category variations in different vegetation belts.

Results

Red List

A summary of the number of species assigned to each Red List category, using the IUCN criteria with the adaptations shown in Table 1, is presented in Table 3, while Table 8 of Appendix provides the category of the Red List by each species. The Red List of the Canary Islands includes 105 species (7 CR, 20 EN and 78 VU), which represents 21 % of the total bryophyte flora reported for these islands. In addition, there are 26 NT and 125 DD (19 DD-n, 40 DD-va and 66 DD). The number of LC is 245 (14 LC-att), which account for close to 50 % (49 %) of the total bryophyte flora in the Canaries. Among endemic species, 52 % are threatened (16 species), and 13 % (4 species) are included as NT.

In Table 4, a comparison is made between mosses and liverworts (including six hornworts species). The proportion of threatened species is higher among the liverworts (26 %) than mosses (19 %). For the non-threatened species, the main differences were found in the DD groups. The proportion of DD species was higher in mosses (28 %) than in liverworts (17 %), while the other proportions were similar in both phylogenetic groups.

The application of the IUCN criteria without the adaptations of Table 1 results in a total of 189 species on the Red List (38 % of the bryophyte flora of the Canaries): 29 CR (15 % of the total species on the Red List with these criteria), 103 EN (55 %), and 55 VU (29 %). The total number of endangered species increases with the original IUCN criteria from 21 to 38 %, mostly whitin the categories CR and EN.

Table 3 Number of bryophyte species in the IUCN categories using the adaptation proposed in Table 1

IUCN category	Number ofspecies (% of total species in the Red List)	Number of endemics	Percent of total species in the Canaries
CR	7 (6.6)	4	1.3
EN	20 (19.0)	3	3.9
VU	78 (74.2)	9	15.5
Total species in the red list	105	16	20.9
NT	26	3	5.1
DD-n	19	1	3.7
DD-va	40		7.9
DD	66	1	13.1
LC-att	14	10	2.7
LC	231		46.1
Total number of species	501	31	100

Table 4 Number of threatened species of each phylogenetic group (using the adaptation proposed in Table 1)

IUCN category	Number of liverworts and hornworts	Percent of total liverworts	Number of mosses	Percent of total mosses
CR	2	1.3	5	1.4
EN	9	6.1	11	3.1
VU	27	18.4	51	14.3
Total species in the Red List	38	26.0	67	18.8
NT	8	5.4	18	5.0
DD-n	4	2.7	14	3.9
DD-va	7	4.7	33	9.3
DD	15	10.2	52	14.6
LC-att	4	2.7	10	2.8
LC	72	49.3	165	46.4
Total species	146	100	355	100

Vegetation belts and habitats

The highest number of threatened species occurs in the laurel forest (wide sense) with 64 species, which represent 61 % of the endangered bryophyte flora of the Canaries (Table 5). Despite their reduced area (see Table 7 of Appendix), laurel forests, with 218 species, nearly had the highest total number of species (after open areas in the humid mountain belt that accounted 227 species), of which, 46 % were species exclusive of this vegetation belt, and 12 % are endemic. Additionally, the proportion of exclusive species among the threatened species in the laurel forest is the highest (64 %), and 20 % of the threatened laurel forest species were endemic. Among the three types of laurel forest distinguished, those with *E. platycodon* had the highest number of endangered species, and 49 % of them were restricted to this type of laurel forest. Furthermore, among the 64 threatened species of the laurel forest, 23 species grow exclusively in this type of forest with the highest cloud influence. Five of the CR species were restricted to *E. platycodon* forests.

Open areas in the humid mountain belt had even higher number of species (227 species) than the laurel forest (218). However, the proportion of exclusive of this type of habitat (19 %), endemic (5 %) and threatened species (11 %) were substantially lower.

Among the total threatened species 23 % occurs in open areas of the humid mountain belt and 20 % in the supramediterranean scrub vegetation belt. In the supramediterranean, more than half of the threatened species (52 %) were restricted to this vegetation belt, but there was only one endemic threatened species. All of the other vegetation belts had a similar proportion of threatened species (8–14 %) and a very low number of exclusive and endemic species.

Freshwater habitats contained 36 % (27 species) of the threatened bryophyte species, and the laurel forest showed a higher number of threatened species in their freshwater habitats (Table 6). Outside the laurel forest, the rocks situated in the supramediterranean scrub belt represented the habitat that accumulated a large number of threatened species.

There were variations in the proportion of the IUCN categories in the different vegetation belts. The CR species were only found in the laurel forest belt (six species) and thermophilous (one species). The results of the χ^2 show significant differences among the proportions of the other IUCN categories. The proportions of EN and NT species were significantly higher in the laurel forests with respect to the other vegetation belts

Table 5 Number of species at each IUCN categories (using adaptations of Table 1) in the vegetation types distinguished

IUCN categories	CR	EN	VU	Total threatened (exclusive, endemic)	NT	LC	DD	Total species (exclusive, endemic)
Euphorbia scrub		2	7	9 (2, 0)	2	101	20	132 (16, 1)
Thermophilous vegetation	1	4	10	15 (2,3)	6	106	5	132 (4, 5)
Open areas (humid mountain belt)		5	19	24 (8, 4)	6	159	38	227 (44, 11)
Laurel forest (wide sense)	6	12	46	64 (41, 13)	16	104	34	218 (101, 26)
Laurel forest	1	7	30	38 (7, 8)	14	102	30	146 (3, 21)
Cloud forest with *E. arborea*		1	25	26 (0, 7)	14	93	11	118 (0, 20)
Cloud forest with *E. platycodon*	5	9	33	47 (23, 15)	15	91	7	113 (23, 18)
Mixed pine forest		1	9	10 (3, 0)	6	102	6	128 (3, 2)
Pine forest		2	9	11 (3, 0)	6	107	20	144 (12, 1)
Supramediterranean scrubs		2	19	21 (11, 1)	6	73	18	118 (25, 2)

In the humid mountain belt, due to their drastic reduction, the actual area of the cloud forest is treated separately of non-forested areas (open areas). Three forest types are distinguished in the laurel forest according to their different cloud influence: laurel forest, cloud forest wide sense (without *E. platycodon*) and cloud forest with *E. platycodon*. Mixed pine forest (lower altitudinal pine forest areas with *Erica–Myrica* thicket)

(EN: χ^2 48.00, $P < 0.001$ and NT: χ^2 44.57, $P < 0.001$), while the VU species were also significantly different in open areas of humid mountain belt and the supramediterranean legume shrub vegetation (χ^2 182.98, $P < 0.001$). The proportion of LC species was significantly higher in open areas of the humid mountain belt (χ^2 155.32, $P < 0.001$). Finally, the proportions of the DD species were lower in the thermophilous and mixed pine forest (χ^2 47.42, $P < 0.001$).

Discussion

Red List

The results obtained here using the IUCN criteria with our own adaptations to the bryophyte flora of the Canaries (21 %) are comparable to results obtained in other territories, which indicates the suitability of the methodological changes performed to adapt the IUCN criteria to small areas for bryophytes. There are variations in the proportion of the bryophyte threatened species from different countries. For instance, 15 % of the species on the Iberian Peninsula (Sérgio et al. 2007), 37 % in Switzerland (Schnyder et al. 2004), 24 % in the Czech Republic (Kučera and Váňa 2003) and 17 % in Serbia and Montenegro (Sabovljevic et al. 2004) are considered threatened (CR, EN and VU) according to the IUCN criteria.

The application of the IUCN criteria without adaptations to small islands results in an overestimation of the number of threatened species, which represent that common species restricted to one type of habitat, such as *Neckera intermedia* in the laurel forest or *Frullania azorica* in the termophilous, might be considered as threatened.

Notable differences were found when comparing the DD group with other Red Lists. This may be due to both a high number of recent reports (included as DD-n), especially

Table 6 Number of threatened species in the main types of habitats for threatened species in the Canary Islands

Habitats	Laurel forest					Open areas (including pine forest)				
	Freshwater habitat	Deep ravine	Soil bank	Understory	Trees	Freshwater	Soil bank	Soils	Rock	Trees
Euphorbia scrub						4	3	5		
Thermophilous vegetation						11	1	1		1
Humid mountain belt (open areas)						7	2	2	5	5
Laurel forest (wide sense)	27	5	11	15	17					
Mixed pine forest						7				1
Pine forest						4	2	1	4	1
Supramediterranean shrubs						8	1		12	1

regarding mosses, as well as the absence of species in the regionally extinct category, which in the future will most likely include many of the DD-va species. The absence of many important data like a precise locality or taxonomical revision of the herbaria specimens does not allow us to classify some of the DD-va species as regionally extinct.

Theoretically, neither the size of the locations and the grid squares nor the EOO are related to the size of the area for which a Red List is created (Gärdenfors 1996; Gärdenfors et al. 1999; Hallingbäck and Hodgetts 2000). However, this potential shortcoming in practice produces several problems, such as the overestimation of the number of threatened species, as shown in this study. Interestingly, Martín Esquivel (2009) previously discussed the validity of the general thresholds for the IUCN criteria on small oceanic islands. One problem is that smaller countries or regions generally contain smaller populations, which results in longer Red Lists (Martín 2009). Additionally, the method used here for bryophytes, such as smaller grid square size (0.25 km^2 instead of 1 km^2), is especially useful to categorise species with a restricted distribution in a highly diverse territory. This smaller grid square size is especially successful for obtaining more precise data and detecting discontinuity in the distribution. This grid square size is useful for small organisms such as bryophytes, especially in reduced habitats with high heterogeneity such as the laurel forests. The small size in concordance with the location concept applied here represents an adequate method to avoiding an overestimation of the habitat area and, consequently, a better tool to analyse fragmentation on small oceanic islands.

In addition, using the smaller grid square for AOO was also very useful in avoiding the inclusion of common species restricted to one type of vegetation belt on the Red List, especially for laurel forests and high mountain vegetation, which represent the most restricted vegetation belts in the Canaries. This approach results in a more adequate AOO threshold for small and highly diverse islands. In addition, although AOO is the only existing criterion that can be properly applied to most species (Lewis and Senior 2011), the threshold values do not appear appropriate for all types of organisms. According to Cardoso et al. (2011) organisms with small body sizes often require substantially smaller areas than organisms with larger body sizes. Bryophytes typically have smaller sizes than vascular plants, and the use of similar AOO sizes may result in an overestimation of the extinction risk, as has also been discussed for invertebrates (Cardoso et al. 2011). The thresholds used for AOO were calculated based on a 50th percentile of species-range size distribution and may be applied in a comparable way to different areas and organisms, which might be a suitable, efficient approach to be applied on other oceanic islands and organisms.

Vegetation belts and habitats

The interpretation of the distribution of Canarian Red List bryophytes shows a consistent pattern with humid conditions rather than with the altitudinal pattern of the vegetation belts, as was evidenced by the abundance of threatened species in the wetter belts. Thus, bryophytes are widely distributed in all vegetation belts in the Canaries, although they are better represented in terms of number of species in the environments with permanently suitable conditions (i.e. humid and sub-humid belts, including cloud forests and open areas; see Table 5). Therefore, altitudinal distributions appear mainly related to humidity conditions than to temperature. Disjunct altitudinal distributions mainly include species that can grow in all arid ecosystems from the basal *Euphorbia* scrubs to the pine forest and Legume summit shrub but are absent in the humid mountain belt. Restricted distribution is mainly related to the more humid areas, including laurel forests and cloud forests but also thermophilous vegetation. Only a small proportion of the restricted species occurs exclusively in the high mountain belt.

Threatened bryophytes are not randomly distributed along different bioclimatic belts but are mainly concentrated in the laurel forest, freshwater habitats and high mountain habitats, reflecting a rare habitat distribution on the Canary Islands. The abundance of threatened species in the most restricted type of laurel forest suggests that conservation of rare bryophytes in the Canary Islands must be undertaken through the preservation and restoration of rare and high quality habitats, like those found in other geographical areas (Berglund and Jonsson 2001; Heinlen and Vitt 2003; Cleavitt 2005; Söderström and During 2005). The singularity of the laurel forests also explains the higher proportion of threatened liverworts, because most of them are restricted to this type of forest, as determined by Lloret and González-Mancebo (2011).

This differential distribution also occurs with endemic and exclusive species. Laurel forests (wide sense) have the highest levels of both endemism and exclusive species, especially *E. platycodon* forests, and are the wettest on the Canary Islands (Gómez González and Fernández López 2009). However, our results show that drier areas have a lower number of threatened species, with the exception of the supramediterranean belt. Presumably, for species restricted to this bioclimatic belt, temperature is a limiting factor preventing species from spreading to lower areas.

Climatic conditions related to different bioclimatic belts rather than microhabitats appear to better explain the distribution of threatened species. In fact, CR species occur in different types of substrates located in very small sites. For instance, the Macaronesian endemic *Echinodium spinosum* occurs on rocks, soils, or even as an epiphyte in a very small area where the species does not reach 40 m^2 of cover. The same occurs with the CR, the Macaronesian endemics *Radula jonesii* and *Radula wichurae*, which can occur on rock or as epiphytes in a very limited area of *E. platycodon* cloud forest. Even for the very restrictive freshwater habitats, vegetation belts are surprisingly important. There are few widespread species (such as *Rhynchostegium riparioides*) that are restricted to this type of habitat in different bioclimatic belts along the complete altitudinal gradient. However, for most freshwater habitat species, the location is highly restricted depending on the bioclimatic belt, and most of them grow exclusively in freshwater habitats located within laurel forests.

Conservation implications and priorities

Two types of threatened species may be distinguished in the Canaries, those distributed in restricted habitats that were briefly represented in the archipelago by both past human and/or natural causes and those with an estimated or suspected population size reduction due to current threats. The first type of threatened species was mainly classified as VU; while those in the second group were included as CR and EN species.

The main problem for conservation of these threatened species results from the existence of very restricted suitable areas (related to past laurel forest destruction and currently small natural suitable areas, which continue to be threatened by different factors) and current uses. Based on the small area of the laurel forests (wide sense), their high fragmentation rate (e.g., Guimarães and Olmeda 2008) and the high number of threatened bryophytes, we suggest protecting the entire cloud forest ecosystem.

Cloud forests with *E. platycodon* with a current area of 4.73 km^2 (Del-Arco et al. 2010) represent only 1.5 % of the laurel forest area and 0.06 % of the total area of the Canary Islands. Most of *E. platycodon* forests are included in protected areas; however, some of these areas are still EN by cattle (i.e. clearing of forest for grazing and soil disturbance), and all of them are threatened by climate change. The temperatures at these altitudes have increased during the last 70 years at a rate of almost one-tenth of a degree per decade (Martín et al. 2012), and the situation in the top of the mountains might become highly vulnerable to the effects of global warming (Lloret and González-Mancebo 2011). In addition, an apparently increased incidence of destructive storms, explained as an effect of global warming, may threaten species occupying habitats at the highest elevations. Furthermore, the existence of very popular bryological localities has resulted in an over-sampling of particular taxa by bryologists from different countries because the Canaries are still an attractive destination for collectors.

At the habitat level, freshwater biodiversity appears to be much more severely threatened than other habitats and urgent conservation actions are needed. Water courses in these islands have been gradually disappearing due to massive extractions that are currently continuing. In addition, many of the water courses that still remain are contaminated, especially in areas below 700 masl. Moreover, most of the traditional water exploitations such as water galleries and especially water channels, which represent good refugia for freshwater species, now are dessicated or replaced by water tubes. Active management to re-establish the original conditions of water courses has been already suggested for the long-term conservation of the biodiversity of freshwater habitats in laurel forest (Patiño et al. 2010). In fact, several DD-va species are freshwater species that presumably are extinct from the Canaries.

In conclusion, the priority of conservation should be given to freshwater habitats and cloud forests with *E. platycodon* because both environments together contain 63 % of the EN bryophytes in the Canaries. The protection of freshwater habitats and current laurel forests (wide sense, including ericaceous and broad leaved laurel forest) results in the protection of 70 % of the threatened species and 42 % of the endemic bryophytes on these islands. Open areas in the humid mountain belt contain nearly 23 % (24 of a total 105 threatened species) of the threatened species; many of them correspond to laurel forest species that survive in the original sites after forest destruction (González-Mancebo et al. 2009a). For instance, the Macaronesian endemic *Leucodon treleasei* occurs as epiphyte in the laurel forests from La Palma and Tenerife; however can survive as epiphyte of foreign trees as *Castanea sativa*. High mountain habitats also occupy a greatly reduced area and contain nearly 19 % of the total threatened species. These habitats have a naturally restricted area of occupation, mostly in legally protected national parks with appropriate conservation management. However, for some VU species restricted to wet areas in this bioclimatic belt, specific action plans designed for selected species are needed, because climatic change threats have not been considered in this habitat. In addition Martín et al. (2012) recently showed stronger climatic warming effects in this bioclimatic belt than in lower altitude areas of the Canary Islands.

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Appendix

See Fig. 1 and Tables 7 and 8.

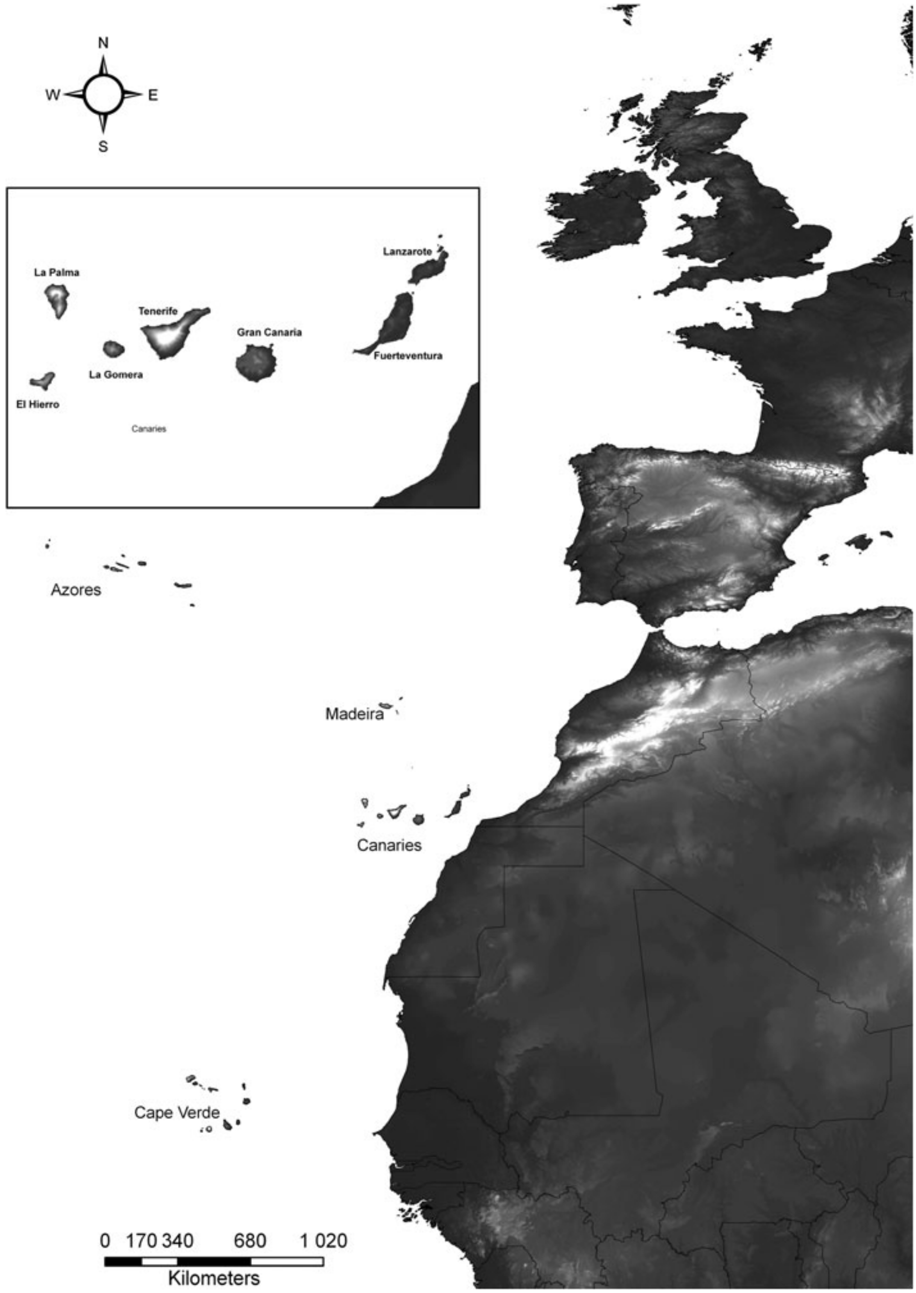

Fig. 1 Location of the Canary Islands

Table 7 Vegetation and bioclimatic belts, altitudinal range and mean temperature in the Canary Islands according to Del-Arco et al. (1996, 1999, 2002, 2006); Del-Arco and Wildpret (1999)

Potential vegetation	Bioclimatic belt (thermotypes)	Estimated actual area (km^2)	Island	Altitudinal range (m)	Mean precipitation (mm)	Mean T (°C)
Euphorbia scrubs and other inframediterranean scrubs	Inframediterranean	490	All islands	0–400 (500) north slopes and until 600–800 m south slopes		19–22
Thermophilous vegetation (sclerophyllous woodlands and thermomediterranean scrubs)	Inframediterranean and thermomediterranean	64	All islands	100–700		16–19
Open areas (*humid mountain belt*), non-forestry areas (natural or deforested)	Humid mountain belt thermomediterranean and lower mesomediterranean with trade-wind clouds	765	All islands	400 (500)–900 (1200)		14–18
Laurel forests wide sense (including *Erica–Myrica* thicket)	Humid mountain belt (thermomediterranean) and lower mesomediterranean with trade-wind clouds)	307	H, P, G, T, (C)	400 (500)–1500 Mainly north slopes		14–18
Pine forest	Dry mountain belt (upper-dry thermomediterranean and dry—humid mesomediterranean)	1126	H, P, G, T, C	900 (1200)–2000 (2300)		10–17
Supramediterranean scrubs A physiognomic similar scrub occurs in Gran Canaria, but in the upper mesomediterranean belt: the oromediterranean belt situated above 2900 m is present only in Tenerife	High mountain belt (supramediterranean and oromediterranean)	189	P, T, (C)	2000 (2200)–3718		7–10

Areas (km^2) were estimated following Del Arco et al. (2010). Brackets indicate a lower representation of the bioclimatic belt in the island. Potential vegetation is indicated for all bioclimatic belts, with the exception of the humid mountain belt, where due their drastic reduction, the actual area of the cloud forest is treated separately of non forest areas (open areas) in this bioclimatic belt. Altitudinal range considered for all the islands and all exposures

Islands: *H* Hierro, *P* La Palma, *G* Gomera, *T* Tenerife, *C* Gran Canaria, *F* Fuerteventura, *L* Lanzarote

Table 8 Red list of the Canary Islands

	Criteria
Critically endangered (CR)	
Cyclodictyon laetevirens	B1, 2, a, b (iii)
**Echinodium spinosum*	A2c, B1, 2, a, b (i, ii, iii)
Racomitrium ellipticum	B1, 2, a, b (iii)
**Radula jonesii*	B1, 2, a, b (iii)
**Radula wichurae*	B1, 2, a, b (iii)
Scopelophila ligulata	B1, 2, a, b (iii)
**Tetrastichium virens*	B1, 2, a, b (iii)
Endangered (EN)	
**Andoa berthelotiana*	B1, 2, a, b (i–iv)
Aphanolejeunea sintenisii	B1, 2, a, b (iii)
Campylopus flexuosus	B1, 2, a, b (iii)
Conocephalum conicum	B1, 2, a, b (iii)
Cratoneuron filicinum	B1, 2, a, b (iii)
Fissidens serratus	B1, 2, a, b (iii)
Marchantia paleacea	B1, 2, a, b (iii)
**Orthotrichum handiense*	B1, 2, a, b (iii)
Philonotis calcarea	B1, 2, a, b (iii)
Plagiochila porelloides	B1, 2, a, b (iii)
Pseudotaxiphyllum elegans	B1, 2, a, b (iii)
Ptychostomum pallens	B1, 2, a, b (iii)
Pylaisia polyantha	B1, 2, a, b (iii)
Racomitrium aquaticum	B1, 2, a, b (iii)
Radula carringtonii	B1, 2, a, b (iii)
Radula holtii	B1, 2, a, b (i–iv)
Riccardia multifida	B1, 2, a, b (iii)
Riella affinis	B1, 2, a, b (i, ii,iii)
Scorpiurium deflexifolium	B1, 2, a, b (iii)
**Telaranea azorica*	B1, 2, a, b (iii)
Vulnerable (VU)	
Acanthocoleus aberrans	B2, a, b (iii)
Andreaea heinemannii	D2
Aneura pinguis	B1, 2, a, b (iii)
Aphanolejeunea microscopica	B1, 2, a, b (iii)
Atrichum angustatum	D2
Atrichum undulatum	D2
Campylostelium pitardii	D2
Campylostelium strictum	D2
Colura calyptrifolia	B1, 2, a, b (iii)
Coscinodon cribrosus	D2
Dicranum scoparium	B1, 2, a, b (i–iv)
Ditrichum pusillum	D2
Dumortiera hirsuta	B1, 2, a, b (iii)

Table 8 continued

	Criteria
Encalypta streptocarpa	D2
**Fissidens coacervatus*	B1, 2, a, b (iii)
**Grimmia curviseta*	D2
Grimmia nutans	D2
Grimmia orbicularis	D2
Habrodon perpusillus	D2
Heterocladium wulfsbergii	B1, 2, a, b (iii)
Homalia lusitanica	B1, 2, a, b (iii)
**Isothecium algarvicum*	B2, a, b (iii)
Jubula hutchinsiae	B2, a, b (iii)
Jungermannia hyalina	B2, a, b (iii)
Jungermannia pumila	B1, 2, a, b (iii)
Leiocolea heterocolpos	D2
Leiocolea turbinata	D2
Lejeunea flava	B2, a, b (iii)
Lepidozia cupressina	B1, 2, a, b (iii)
Leptobryum pyriforme	B1, 2, a, b (iii)
Leptodyctium riparium	B1, 2, a, b (i–iv)
Leucobryum glaucum	B1, 2, a, b (i–iv)
**Leucodon treleasei*	B2, a, b (iii)
Lophozia bicrenata	B1, 2, a, b (iii)
Marchantia polymorpha	B1, 2, a, b (iii)
Marsupella funckii	D2
Metzgeria conjugata	D2
Metzgeria leptoneura	D2
Microcampylopus laevigatus	D2
Myurium hochstetteri	B2, a, b (iii)
Nardia geoscyphus	D2
Neckera menziesii	D2
Oedipodiella australis	D2
Orthodontium pellucens	D2
Orthotrichum pumilum	D2
**Pelekium atlanticum*	B1, 2, a, b (iii)
Philonotis fontana	B1, 2, a, b (i–iv)
**Plagiochila maderensis*	B2, a, b (iii)
Plagiochila stricta	B1, 2, a, b (iii)
Pohlia annotina	D2
Pohlia cruda	D2
Pohlia wahlenbergii	B1, 2, a, b (iii)
Polytrichastrum formosum	B1, 2, a, b (iii)
Polytrichum commune	D2
Pterigynandrum filiforme	D2
Ptychomitrium polyphyllum	B1, 2, a, b (iii)

Table 8 continued

	Criteria
Ptychostomum pseudotriquetrum	B1, 2, a, b (iii)
Ptychostomum rubens	B1, 2, a, b (iii)
Pyramidula tetragona	D2
Racomitrium aciculare	B2, a, b (iii)
Radula aquilegia	D2
Rhamphidium purpuratum	B1, 2, a, b (iii)
**Rhynchostegiella bourgaeana*	B1, 2, a, b (iii)
Rhynchostegium megapolitanum	D2
Scapania curta	D2
Schistidium apocarpum	D2
Sciuro-hypnum plumosum	B1, 2, a, b (iii)
Scleropodium cespitans	D2
Southbya nigrella	D2
Sphaerocarpos michelii	D2
Sphaerocarpos texanus	D2
Telaranea europaea	B1, 2, a, b (iii)
**Tetrastichium fontanum*	B1, 2, a, b (iii)
Thamnobryum alopecurum	B2, a, b (iii)
Tortella alpicola	D2
**Tortella limbata*	D2
Trichodon cylindricus	D2
Tritomaria exsecta	B1, 2, a, b (iii)
Near Threatened (NT)	
Antitrichia californica	
Asterella africana	
Aulacomnium androgynum	
Bartramia pomiformis	
Cephalozia bicuspidata	
Cephaloziella calyculata	
Diplophyllum albicans	
Entosthodon commutatus	
Fissidens crassipes	
Grimmia anodon	
**Heteroscyphus denticulatus*	
Homalia webbiana	
**Leucodon canariensis*	
Nardia scalaris	
Orthotrichum cupulatum	
Oxyrrhynchium hians	
Oxyrrhynchium pumilum	
Philonotis rigida	
Porella obtusata	
Pseudoscleropodium purum	

Table 8 continued

	Criteria
Ptychostomum donianum	
Rhynchostegiella litorea	
**Rhynchostegiella macilenta*	
Rhynchostegiella teneriffae	
Riccardia chamedryfolia	
Tortula revolvens	

[a] Indicate endemic species including Canarian, Macaronesian and Iberian–Macaronesia endemics

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