A narrow endemic plant: evaluating population dynamics and conservation strategies

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Abstract *Iberodes littoralis* subsp. *gallaecica* (Laínz) M. Serrano, R. Carbajal & S. Ortiz is a small annual plant endemic to dune systems in the north-west Iberian Peninsula. It is categorized as Endangered on the IUCN Red List and is a priority taxon under the EU Habitats Directive. Nevertheless, the only comprehensive census of this subspecies was conducted in 2009. Here we present the results of a new survey conducted in 2023 that adds a new location to its known range. Comparison with the previous census suggests that both the total population and area of occupancy have increased. However, these changes were not uniform across the range of the subspecies, with populations increasing at the northern and southern extremes and populations at central sites remaining stable or decreasing. Spatial differences in climate, anthropogenic pressures, plant performance and/or random fluctuations may explain these interpopulation variabilities. Given that the majority of populations are already located within the EU Natura 2000 network, we recommend that the current level of protection be maintained and that the plant be reintroduced into dune systems from which it has recently disappeared. Despite the increase in the total population, we recommend that the plant be recategorized as Critically Endangered given that its area of occupancy is small. Further censuses over time will be needed to provide information on population dynamics, trends, fluctuations and responses to environmental variables.

Keywords Area of occupancy, biogeography, coastal dune system, Iberian Peninsula, *Iberodes littoralis gallaecica*, narrow endemic, plant conservation, threatened species

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Introduction

Narrow endemic plant species (i.e. species characterized by a limited range) are the focus of significant conservation efforts because of their isolated, threatened and reduced populations (Fenu et al., 2011; Martinell et al., 2011; Ballesteros et al., 2013; López et al., 2015). *Iberodes littoralis* subsp. *gallaecica* (Laínz) M. Serrano, R. Carbajal & S. Ortiz is a small annual plant that is an example of a narrow endemic (Carbajal et al., 2009). Formerly known as *Omphalodes littoralis* subsp. *gallaecica*, it was recently transferred to a new genus of strictly annual plants in which narrow and geographically distant endemics predominate (Serrano et al., 2016; Otero et al., 2022). It occurs only in a few coastal dune systems in the north-west Iberian Peninsula, having disappeared from an undetermined number of locations during the second half of the 20th century (Serrano & Carbajal, 2004). More recently, the number of locations occupied by this plant has been expanded by the reintroduction of c. 700 individuals to a site (Corrubedo) where it had been present until recently (Fig. 1; Retuerto, 2022).

Previous studies show that the plant has low genetic diversity, with most of the variability occurring between locations and intra-location genetic variation almost non-existent (López et al., 2015). This pattern could be related to factors such as self-fertilization, recurrent genetic bottlenecks and its highly fragmented distribution. The lack of gene flow indicates that each location is a genetically distinct group. This differentiation sometimes leads to phenotypic differences in traits such as flowering phenology and size at maturity, even when grown under similar garden conditions (López et al., 2015). Additionally, both the number of individuals and the area of occupancy (AOO) have fluctuated significantly over time (Serrano & Carbajal, 2004).

Iberodes littoralis subsp. *gallaecica* has been categorized as threatened and/or of conservation concern by international, national and local listings (Bern Convention, 1982; Ministerio de Agricultura, Pesca y Alimentacion, 1990; Council Directive 92/43/EEC, 1992; Domínguez Lozano, 2000; Serrano & Carbajal, 2004; Decreto 88/2007, 2007; Ley 42/2007, 2007; Moreno, 2008, 2011; Ministerio de Medio Ambiente & Medio Rural y Marino, 2011). It is categorized as Endangered on the IUCN Red List as its population undergoes extreme fluctuations and continues to decline (Serrano & Carbajal, 2006; as *Omphalodes littoralis* subsp. *gallaecica*). However, the Red List assessment reports

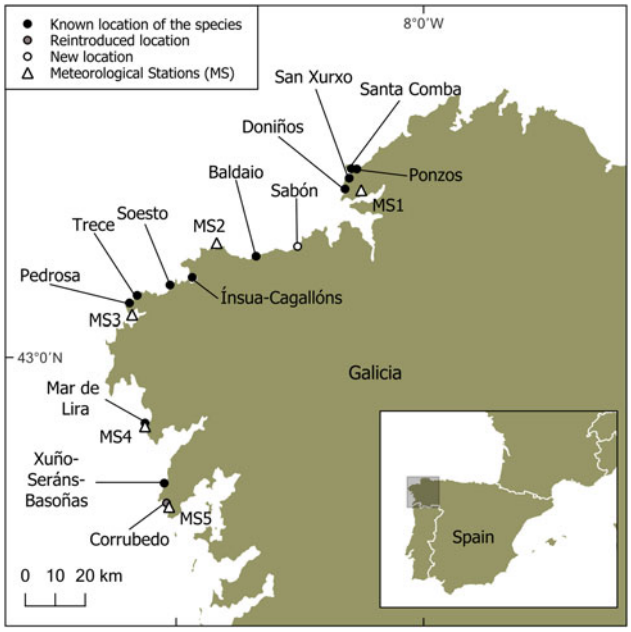

FIG. 1 All known locations of *Iberodes littoralis* subsp. *gallaecica* in Galicia, Spain, showing the 12 previously known locations, the newly found location, and the the locations of the nearest meteorological stations (MS1, CIS Ferrol; MS2, Malpica; MS3, Camariñas; MS4, Lira; MS5, Corrubedo).

a small AOO (< 10 ha) that would have warranted categorization as Critically Endangered. Listing by national and international bodies requires regular monitoring of conservation status and the factors that may affect species now and in the near future (Council Directive 92/43/EEC, 1992; Comisión Estatal para el Patrimonio Natural y la Biodiversidad, 2012). However, the only comprehensive census for *I. littoralis* subsp. *gallaecica* was conducted in 2009. Here we provide an updated survey of the population across its geographical range, together with an assessment of the potential threats facing the subspecies, propose conservation measures, and recommend recategorization on the IUCN Red List.

Study area

Previously, we were aware of only 11 wild locations of the subspecies and of one site where it had been recently reintroduced, along < 200 km of the coastline of Galicia (north-west Iberian Peninsula; Fig. 1; Martínez Cortizas & Pérez-Alberti, 1999). The climate in the area is predominantly oceanic, with a mean annual temperature of c. 13 °C, humid conditions, mean total annual precipitation of 1,000–1,200 mm and marked seasonality (Martínez Cortizas et al., 1999; Álvarez et al., 2011).

Dune systems are common along the Galician coastline, with dune formations varying according to the prevailing wind and wave conditions (Pérez-Alberti & Paz, 2011). Waves, currents and wind engender a morphologically unstable setting, in which vegetation contributes to sand accumulation, dune elevation and volume enhancement (Hernández et al., 2023). Despite their typically thin configuration, coastal dune systems are environmentally complex because of a pronounced wind and salt spray gradient that creates a range of habitats, each with distinctive vegetation: mobile foredunes, relatively stable inland (or grey) dunes and seasonally flooded slacks within depressions amongst the latter. *Iberodes littoralis* subsp. *gallaecica* is typically found within the sparse perennial grasslands of small plants that colonize extensive portions of the grey dunes. Being pioneer communities, these grasslands eventually disappear if the dunes are taken over by larger shrubs. However, physical disturbance and other stresses often impede shrub colonization, and these grasslands typically persist for decades in the open spaces between shrubs (Oubiña et al., 1997; Lomba et al., 2008).

TABLE 1 Number of random quadrats and quadrat size (m^2) used for the survey of *Iberodes littoralis* subsp. *gallaecica* in various patch sizes in Galicia, Spain (Fig. 1), in 2023.

Size of patch (m^2)	Number of quadrats	Quadrat size (m^2)
> 100,000	30	4
10,000–35,000	25	4
100–10,000	25	1
65–100	19–24	1
40–65	13–18	1
10–39	5–12	1
< 10	Direct count	

Methods

We conducted two surveys during April–May 2023 in each location where the subspecies had been found in 2009. In the first survey we checked each UTM 1-km grid square for presence of the subspecies. When present, we used GPS tracks to delimit the occupied patches and then estimated the AOO with *QGIS 3.30.0* (QGIS, 2023). In the first survey we also found a locality (Sabón) where the plant had not previously been reported (Fig. 1).

In the second survey we revisited the occupied patches to estimate abundance. In small patches (< 10 m^2) where the plants were sparse we counted every individual after tagging them to avoid double counting. For large and/or high-density patches we used a random sampling procedure following Albert et al. (2003), with random sampling points generated in a number proportional to the area of each patch, implementing this approach in *QGIS* (Table 1). We validated this method by comparing it with direct counts in some patches. We conducted counts using 1 × 1 m quadrats, except for patches > 10,000 m^2, for which we used 2 × 2 m quadrats. We recorded the number of individuals present within each quadrat along with a brief description

of the habitat. We combined the mean density per patch with patch size to estimate total abundance per patch. We calculated confidence intervals using generalized linear models in *R 4.3.0* (R Core Team, 2023).

We obtained whole-year time series data of monthly mean, maximum and minimum temperatures and monthly precipitation from MeteoGalicia (Xunta de Galicia, 2023) for weather stations close to the subspecies' locations. We used these data to assess temperature and precipitation trends between the two censuses (2009 and 2023). We fitted generalized additive models with a cyclic cubic regression spline for factor month using the package *mgcv 1.8.42* in *R* (Wood, 2017).

We identified pressures (acting now) and threats (likely to have an impact in the near future) based on the list of pressures and threats available from the reference portal for reporting under Article 17 of the EU Habitats Directive (EEA, 2023). We also consulted the list of conservation measures available, from the same portal, to assess the status of each patch of *I. littoralis* subsp. *gallaecica* relative to the Special Areas of Conservation under the EU Habitats Directive (EEA, 2023).

Results

We identified a global population of c. 5 million individuals of *I. littoralis* subsp. *gallaecica* occupying a total area of 80.38 ha (Fig. 2). This population includes c. 16,000 individuals in an area of 0.19 ha at the newly discovered Sabón location plus 31 surviving plants reintroduced at Corrubedo. Both abundance and AOO varied markedly between localities. In particular, three sites at the northern end of the subspecies' range (Ponzos, Santa Comba and San Xurxo) contributed most to the total population, accounting for almost 80% of the individuals and 61% of the AOO. Three locations at the southern end of the range (Xuño, Seráns and Basoñas) and one at the northern end (Doniños) also contributed an appreciable, although smaller, number of individuals (5% and 3% in the north and south, respectively) and to the AOO (13% and 15% in the north and south, respectively). Density per patch also varied across locations, with mean densities ranging from 2.2 individuals/m^2 in Mar de Lira to 13.9 individuals/m^2 in Trece (Supplementary Fig. 1). However, density per patch within locations also varied significantly, with some patches exceeding 20 individual/m^2 and one patch reaching 60 individuals/m^2. Overall, the plant exhibited a clear preference for areas where the soil was physically disturbed to some degree and competition with other plants was minimal, such as human footpaths and animal burrows. Additionally, we found some high-density patches close to car parking areas in two of the northernmost localities (Doniños and San Xurxo). The AOO extended to elevations of up to 90 m in San Xurxo, Soesto and Ínsua-Cagallóns.

The analysis of temperature records during the period between the two censuses indicates a warming trend across the study area, in particular with respect to monthly means and monthly maxima (Supplementary Fig. 2). As a result, and depending on the weather station, monthly means increased by 0.3–1.0 °C on average, and maxima increased by 0.3–1.9 °C on average. Despite some variability amongst weather stations, the warming trends showed no obvious geographical pattern. We did not detect any trend for the precipitation data.

The analysis of the distribution of *I. littoralis* subsp. *gallaecica* in relation to the Natura 2000 network revealed that the majority of the population of this endemic plant occurs in Special Areas of Conservation. Exceptions are the patches in San Xurxo and Doniños, which were partially or entirely outside the Natura 2000 areas. From the EU Habitats Directive list of pressures and threats to local populations we only identified threats in these areas, related to infrastructure development and climate change (Tables 2 & 3; EEA, 2023).

Discussion

Our data indicate that the total number of individuals (330% greater than in 2009), the AOO (160% greater) and the total number of localities (with a new wild population that was not recorded in 2009) of *I. littoralis* subsp. *gallaecica* all appear to have increased since the last survey (Carbajal et al., 2009). However, these increases were concentrated in a few localities at the limits of the narrow distribution range of the subspecies. Populations in the middle of the range displayed little change or even signs of decline (Baldaio, Soesto, Pedrosa and Trece). Therefore, although the global population appears to have been maintained since the last census in 2009, understanding the factors underlying this uneven trend amongst local populations will be relevant to the effective management of this threatened plant.

Both intrinsic and extrinsic factors may influence the uneven behaviour of local populations. In particular, local populations can exhibit large annual variations in abundance (Serrano & Carbajal, 2004). Such intrinsic variability could have contributed to the differences between the 2009 and 2023 censuses.

Differences in individual plant performance could be an additional factor contributing to demographic changes. Previous reciprocal transplant experiments with a subset of populations suggested a genetic basis for the superior growth and seed production in one of the northern populations (López et al., 2015), and this was one of the populations that was markedly larger in 2023 compared to 2009. Further research is needed to confirm whether this also applies to other populations that were larger in 2023.

We found no conclusive evidence linking temporal trends in temperature and precipitation to the variations

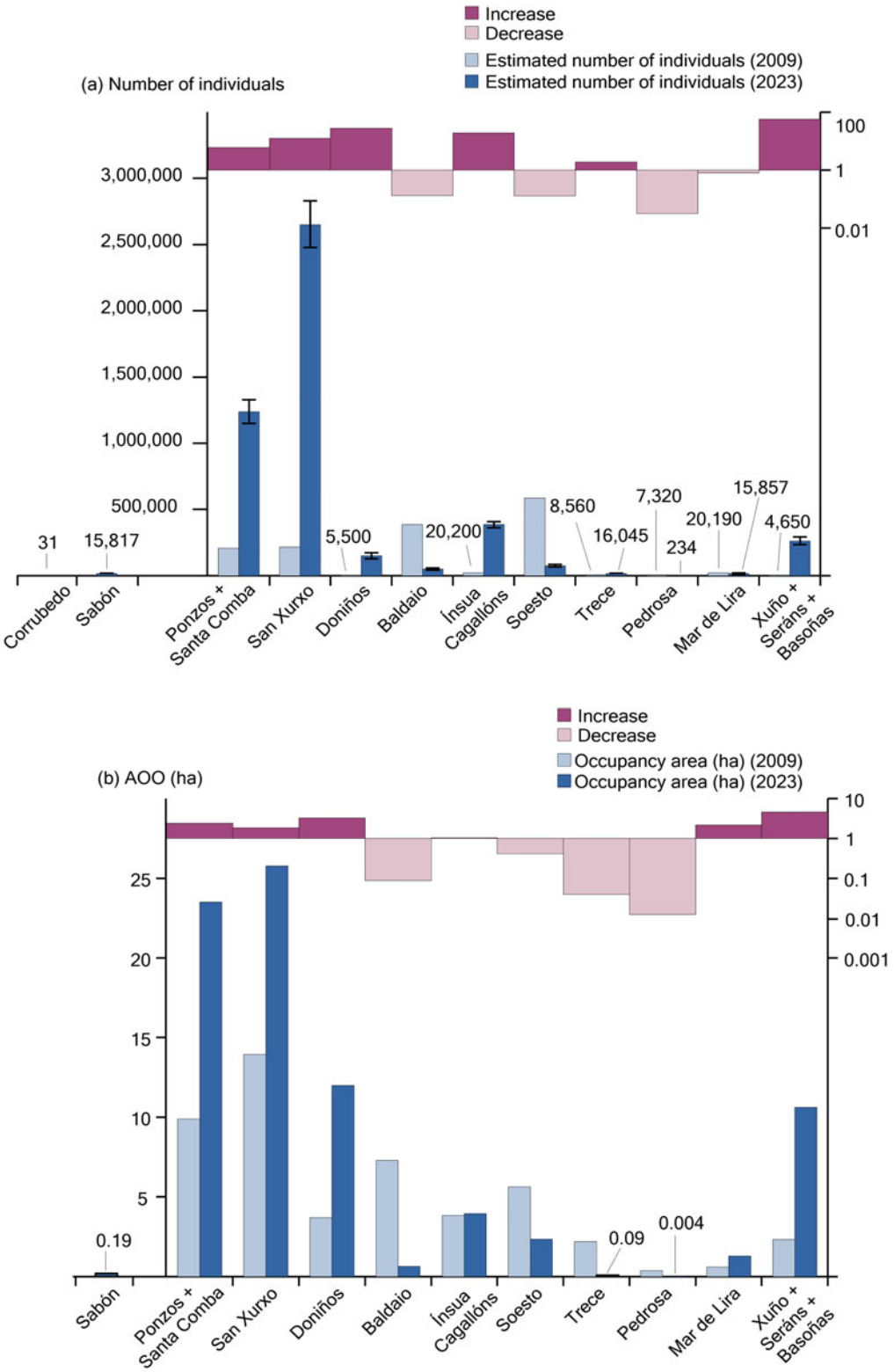

FIG. 2 (a) Number of *I. littoralis* subsp. *gallaecica* individuals in Galicia, Spain (Fig. 1), with confidence intervals, and (b) area of occupancy (AOO) in 2009 and 2023, with relative increases or decreases in 2023 compared to 2009, on a logarithmic scale. Abundances at locations where the plant was discovered (Sabón) or reintroduced (Corrubedo) after 2009 are shown to the left. We combined some sites to facilitate comparison with the 2009 estimates.

TABLE 2 Potential threats from infrastructure development and climate change (and explanation of how each threat could act) in each of the 12 locations in which we found *I. littoralis* subsp. *gallaecica* in Galicia, according to the list of pressures and threats from the EU Habitats Directive (EEA, 2023).

Threat (explanation)	Ponzos	Santa Comba	San Xurxo	Doniños	Sabón	Baldaio	Ínsua-Cagallóns	Trece	Pedrosa	Mar de Lira	Xuño, Seráns, Basoñas	Corrubedo
Infrastructure development												
PF03 Construction or development of infrastructure for sport, tourism or leisure (could require more car parking, thereby compromising nearby populations)		X	X	X		X				X	X	
PF04 Development & maintenance of the beach area for tourism & recreation (could lead to harsher beach maintenance, with machinery, potentially altering habitat geomorphology & influencing AOO & abundance)	X	X	X	X	X	X				X	X	
PF05 Sports, tourism & leisure activities (excessive trampling could modify habitat geomorphology)	X	X	X	X	X	X	X	X		X	X	
Climate change												
PJ01 Extreme temperature changes (could cause population decline during germination)	X	X	X	X	X	X	X	X	X	X	X	X
PJ03 Changes in rainfall patterns (could alter plant performance)	X	X	X	X	X	X	X	X	X	X	X	X
PJ05 Saline intrusion & PJ06 Changes in wave exposure (extreme weather events & coastal erosion could lead to intrusion of sea, causing population decrease)	X	X	X	X	X	X	X	X	X	X	X	X
PJ12 Desynchronization of biological/ecological processes (altered seasonal patterns could desynchronize germination & flowering)	X	X	X	X	X	X	X	X	X	X	X	X
PJ13 Species distribution change (arrival of other species could reduce effective niche)	X	X	X	X	X	X	X	X	X	X	X	X

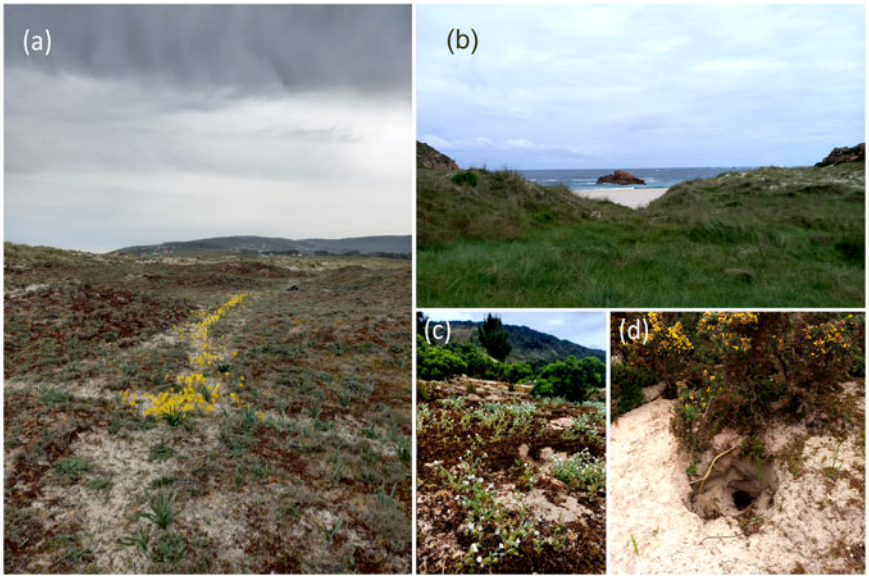

PLATE 1 (a) An example of the preference of *Iberodes littoralis* subsp. *gallaecica* for footpaths; each yellow tag indicates the position of an individual (Baldaio). (b) Tall vegetation covering a grey dune area that was previously occupied by *I. littoralis* subsp. *gallaecica* (Pedrosa). Typical aspect of (c) a sparse perennial grassland of small plants and (d) disturbed soil where the plant occurs (Ínsua-Cagallóns). Photos: Nerea Alvite.

between populations. However, although weather stations were situated relatively close to the dune systems, they may not reflect the actual conditions experienced by the subspecies. Monitoring of microscale data on temperature and water availability in the plant's habitat is warranted to investigate this further.

Variations in human presence at different localities could contribute to demographic variability. Our observations indicate that this plant benefits from moderate disturbance that reduces competition with other plants (Plate 1). Moreover, a significant part of this anthropogenic perturbation occurs after the plant has released its seeds, suggesting this perturbation may not affect seed production, although it might disturb seed dispersal at the local scale. This concords with the observation that some of the most easily accessible populations at the northern and southern ends of the subspecies' range are the largest. Anthropogenic pressures could, however, have detrimental effects on other components of the dune system. Data on visitor numbers and timings would be required to assess these impacts.

Our findings suggest that maintaining the level of protection provided by the EU Natura 2000 network will be crucial for the conservation of *I. littoralis* subsp. *gallaecica*. This includes avoidance of the construction of infrastructure and controlling human presence (measures MF01 and MF03; Table 3). The greater abundance and AOO recorded in 2023 compared to 2009 should not obscure the observation that most of the increases were in a few localities, whereas others show abundances and AOO that were similar to or lower than those recorded in 2009. The low genotypic diversity and high differentiation of the populations of this subspecies mean that losing a single local population could represent a considerable loss. Continuing the reintroduction of the plant to sites from which it has recently disappeared could be a beneficial strategy for areas that, in some cases, may require restoration of the target habitat (MF02; Table 3). As protecting these areas from local pressures could also contribute to improving resilience against climate change (Jackson, 2008), local-scale conservation measures could also help mitigate the potential effects of climate change (MJ01; Table 3).

Our results do not support the notion that the subspecies is in continuing decline, as reported in the 2006 IUCN Red List assessment. However, in addition to our findings, previous reports have suggested that it undergoes marked

TABLE 3 Potential conservation measures that could be implemented for *I. littoralis* subsp. *gallaecica* in Galicia, according to the list of conservation measures of the EU Habitats Directive (EEA, 2023).

Conservation measure	Additional information
MF01 Managing impacts of construction & development of residential, commercial, industrial & recreational infrastructure	Construction of infrastructure (PF03) should be avoided so as not to produce negative impacts. Should such construction already have been carried out, affected habitat should be restored & the subspecies reintroduced.
MF02 Restoration of habitats affected by residential, commercial, industrial or recreational infrastructure	
MF03 Reducing the impact of sports & recreational activities	Although the subspecies benefits from a certain level of habitat disturbance, ensuring that these activities do not alter the habitat or negatively influence its life cycle is needed.
MJ01 Implementation of measures to mitigate climate change	Reducing pressures from local actors could increase resilience to climate change.

fluctuations in both AOO and number of mature individuals (Serrano & Carbajal, 2004). Further regular and systematic censuses will be required to determine the size and timing of these fluctuations. These ongoing assessments will not only improve our understanding of the subspecies' population dynamics but also facilitate the formulation and implementation of conservation measures to ensure the long-term protection of this threatened plant. Meanwhile, we will recommend to the appropriate IUCN Red List Authority that *I. littoralis* subsp. *gallaecica* should be recategorized as Critically Endangered under criteria B2ac(ii)(iv) as its AOO is < 0.8 km² (B2), it is severely fragmented (a) and there are extreme fluctuations (c) in AOO (ii) and number of mature individuals (iv).

Author contributions Study concept: EGM; study design: NA, RB; data generation: NA; data analysis: NA, RB; writing: all authors.

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Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

Data availability Because of the threatened status of *Iberodes littoralis* subsp. *gallaecica*, detailed distribution data are not publicly available, but coarse-resolution data are available from the corresponding author upon reasonable request.

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