Cryptogamie, Bryologie, 2015, 36 (1): 3-17

Modelling the distribution of the epiphytic moss *Orthotrichum rogeri* to assess target areas for protected status

Rémy PONCET, Vincent HUGONNOT & Thierry VERGNE*

Conservatoire botanique national du Massif central, le Bourg, 43230 Chavaniac-Lafayette, France

Abstract – The conservation of rare and endangered species like *Orthotrichum rogeri* Brid. requires a precise knowledge of their ecology and distribution. However, the scarcity of financial resources and the inadequacy of chorological data difficult the design of efficient conservation policies. In this context, species distribution models (SDM) can provide useful information to apply conservation measures over large areas like Auvergne region, France (26,000 km^2). Unfortunately, the use of SDM to assist the introduction of conservation measures is uncommon in bryology. *O. rogeri* is a rare and poorly known moss at the national scale which is well represented in Auvergne. The European Union through the "Habitats and Species Directive" made its protection compulsory. The aim of this work is to use SDM to improve our current knowledge on *O. rogeri* distribution in order to provide guidance for designing conservation measures. To do so, we first designed a survey to gather presence/absence data and then fit logistic regression model. Model accuracy was assessed using previous knowledge on species occurrences (which have not been used in SDM). The output of the SDM leads us to an improved understanding of the chorology of *O. rogeri*. Our results showed that this species is clearly too scarcely represented in the Natura 2000 regional network and pointed to the need of targeted surveys. Natura 2000 sites are either too severely fragmented and/or too small to allow efficient conservation of *O. rogeri* and the suite of related remarkable epiphytes. We suggest that slight modifications of current outline of Natura 2000 sites to allow the integration of several known populations. *O. rogeri* shows some paradoxical habitat requirements, in some areas it is strongly linked to anthropogenic habitats while in others it is linked to ancient woodlands without anthropogenic activities. Disturbance regime is identified as of prime relevance for the conservation of appropriate habitats. Due to the contrasted requirements of the species diverging conservation strategies could be adopted. Besides, taking into account the various scenarios offers the possibility to anticipate environmental changes caused by global warming and its likely effect for the successful implementation of conservation measures.

Bryophytes / predictive mapping / geographic information system / logistic regression / disturbance regime / conservation strategy / Natura 2000 network / biodiversity

Résumé – La conservation des espèces rares et en danger telles qu'*Orthotrichum rogeri* Brid. requiert une connaissance précise de leur écologie et de leur distribution. Cependant, l'insuffisance des données chorologiques et la rareté des ressources financières disponibles pour pallier à ce manque s'avèrent être des inconvénients majeurs pour mettre en place des politiques efficaces de conservation. Dans ce contexte, la modélisation peut s'avérer être un outil utile d'aide à l'application de mesures de conservation sur de vastes territoires comme la région Auvergne, France (26,000 km^2). Toutefois, l'usage de la modélisation comme outil

* Corresponding author: remy.poncet@cbnmc.fr

doi/10.7872/cryb.v36.iss1.2015.3

d'aide à la décision pour les mesures de conservation n'est pas courant en bryologie. *O. rogeri* est une mousse rare et méconnue à l'échelle nationale, qui pousse en Auvergne et dont l'Union Européenne a rendu la protection obligatoire au travers de la « Directive Habitats et Espèces ». L'objectif de ce travail est d'utiliser la modélisation pour améliorer les connaissances actuelles sur la répartition d'*O. rogeri* afin de proposer une aide à la décision dans le cadre de l'application d'une politique de conservation. Pour cela, nous avons défini une stratégie d'échantillonnage visant à recueillir les informations d'absence/présence *d'O. rogeri* qui ont servi au calage du model. Sa précision a ensuite été testée par comparaison avec les données préexistantes (non utilisées pour la modélisation). La modélisation nous a permis d'améliorer la connaissance concernant la chorologie d'*O. rogeri*. Nos résultats montrent que cette espèce est trop peu représentée dans le réseau Natura 2000 régional et que des inventaires ciblés sont nécessaires. Les sites Natura 2000 sont à la fois trop fragmentaires et/ou trop petits pour permettre une conservation efficace d'*O. rogeri* et de son cortège d'espèces remarquables associées. Nous suggérons que de légères modifications des contours des sites Natura 2000 devraient permettre d'y intégrer plusieurs populations connues. *O. rogeri* montre des exigences paradoxales en matière d'habitat, d'une part en étant fortement liée à des habitats anthropiques et d'autre part en étant fortement menacée par les activités anthropiques dans les forêts anciennes. Les régimes de perturbations sont identifiés comme des facteurs de première importance pour la conservation d'habitats appropriés à la conservation de cette espèce. Des stratégies de conservations contrastées sont dès lors concevables. L'application de divers scénarios permet d'anticiper les changements environnementaux causés par le réchauffement climatique et de le prendre en compte dans la mise en œuvre des mesures de conservation.

Bryophytes / cartographie prédictive / système d'information géographique / régression logistique / régime de perturbation / stratégie de conservation / réseau Natura 2000 / biodiversité

INTRODUCTION

In the past 20 years, bryophytes have steadily gained credibility among conservationists (Söderström *et al*., 1992; Hallingbäck, 1995; Hallingbäck & Hodgetts, 2000). In view of the major environmental changes that bryophytes are facing, the conservation of rare and threatened bryophyte species has progressively become of international importance (Schumacker & Martiny, 1995). As a crisis discipline, Conservation Biology appeared in response to a rising public and political demand to mitigate the ongoing loss of biodiversity and the need to take steps to anticipate, prevent and reverse the trend (Heywood & Iriondo, 2003). The European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (the so-called "Habitats and Species Directive") seeks to ensure the conservation of important sites for priority species. The establishment of networks of protected areas for conservation is an obligation placed on all members of the European Union. In the present state of knowledge, 11 bryophytes species listed on Annex II of the Habitats and Species Directive are known to be present in France. From a regulatory perspective (Directive 92/43/CEE), these species require the designation of Special Areas of Conservation (SAC).

Orthotrichum rogeri Brid. is one of the 11 French species mentioned in Annex II of the Habitats and Species Directive. The European Union recently urged the administrative body of Auvergne region to designate more SAC specifically intended to protect populations of *O. rogeri*. In fact, this species was considered to be insufficiently taken into consideration. *O. rogeri* is a near

European endemic (Hugonnot, 2008), also recorded in Caucasus (Lara *et al*., 2010), which is considered as Vulnerable (following IUCN criteria) in the Red-List of European Bryophytes (Schumacker & Martiny, 1995). Garilleti *et al*. (2002a) proposed to move the species into the category Rare on account of the relatively high number of new localities observed in the recent years (Sotiaux & Sotiaux, 2002; Hugonnot, 2008; Lüth, 2010).

The identification of *O. rogeri* remained problematical until the revisionary work of Garilleti *et al*. (2002b) and its incorporation in the European key of the species of the genus *Orthotrichum* (Lara *et al*., 2009). The main morphological characters used to differentiate this species are the erect endostome teeth, provided with fine striae, the naked calyptra, the different male and female branches, with strong dimorphic phyllidia and the large spores (often more than 20 µm in diameter). The identification is made easier on the field because of the obtuse apex of the leaves and the very peculiar shrinking of the tuft (Lüth, 2010). Recent surveys (Boudier, 2004) and a recently published preliminary French map of *O. rogeri* shows that the Pyrenees, Alps and Massif Central are the main centers of national occurrence (Hugonnot, 2008), yet the distribution of this species still remains poorly known at the regional scale. *O. rogeri* is an epiphytic moss that most often grows on the bark of *Salix* species and a wide array of other trees and shrubs, known at altitudes ranging from 350 to 1,950 m (Garilleti *et al*., 2002b; Hugonnot, 2008; Lara et *al*., 2010; Lüth, 2010). Taking into account its ecological requirements, this species is potentially present in more than 1/2 of the 26,000 km^2 that reaches the Auvergne region. In Auvergne, less than 100 localities have been recently found which seems relatively few compared with the virtually endless suite of potential sites (Hugonnot, 2008).

Maps of species distributions or habitat suitability are required to prioritize or target areas for protected status, to assess threats to those areas, and to design reserves (Richard & Evans, 2006; Callaghan & Ashton, 2008; Franklin, 2009). Due to the scarcity of financial resources, it was nevertheless impossible to lead a comprehensive survey of such an immense territory like Auvergne. Existing conservation networks have proved inadequate in many instances (see review in Rodrigues *et al*., 1999). In this context, Species Distribution Modelling (SDM) is a useful tool to overcome this problem. Although the species-by-species approach to conservation has partially proved inefficient (Hutto *et al*., 1987), the back-performance of the existing network in representing low public-appeal groups of plants (epiphytic bryophytes) deserves additionally to be tested. The aim of this study is to draw a predictive map of *O. rogeri* in order to assess whether the species can easily be integrated into extent SAC or if the designation of new SAC is required. In terms of conservation, lessons are taken from this predictive mapping.

MATERIAL AND METHODS

Physiographic and climatological description of the territory

Auvergne region is settled in the centre of France (Fig. 1A) and is known for its mountain ranges and dormant volcanoes. Together the Monts Dore and the Chaîne des Puys include 80 volcanoes. The Puy de Dôme is the tallest volcano in the region with an altitude of 1,465 m. The Sancy Massif in the Monts Dore is the highest point in Auvergne (1,886 m).

A large portion of the region is part of the hercynian massive, dating back from the end of the primary era, strongly modified during the tertiary ages a consequence of the upthrust of the Alps. Vast plateaux alternate with deep gorges, rift bassins and numerous volcanic edifices.

Auvergne's climate is clearly complex. The south-western part is marked by an oceanic influence. The summit of Cantal receives 2,500 mm of rainfall annually, with a significant snow cover. The southern slope from Monts Dore to Monts d'Aubrac stands as a climatic limit, with a pronounced Foehn effect and decreasing atlantic influence. Farther east and north of this border, the continental trend is strengthening, with dropping of annual precipitation (max: 1,400 mm) and colder winters. More than 1/2 of the territory is marked by a clear mountainous climate. The mediterranean influence is noticeable in the south of Haute-Loire and Cantal and along large alluvial corridors (Loire and Allier). These are the two major rivers in Auvergne. The Loire, which runs through the southeast and borders the northeast, and the Allier which runs from north to south down the center of Auvergne with branches going east and west. Over many years the Allier river has created what are known as the Allier gorges.

Species data modelling

The predictive mapping was made following a 3 steps procedure: a) the definition of the survey design, b) the selection of variables which will characterize the species' location and c) the choice of a statistical model.

a) Survey design

Two pieces of data were used separately in the SDM. First, new data obtained following the survey of a sample were used to modelling. Secondly, the previously known and reliable data of *O. rogeri* in Auvergne were used to validate the SDM.

In response to the necessity to improve knowledge of distribution of *O. rogeri* in the four departments of Auvergne region (Allier, Puy de Dôme, Cantal & Haute-Loire), a random sampling of the whole territory was done. To this end, Auvergne region was divided into 1,044 UTM (Universal Transversal Mercator) 5 × 5 km grid cells. A random manual selection of 96 territorial units (UTM 5 × 5 km) was made (see Fig. 1B). Each of these 96 cells corresponds to one territorial unit in which *O. rogeri* will be sought in order to note if the species is present or absent into its limits. This dataset will be the only source used in modelling.

Owing to the financial constraints, it was decided to limit the prospecting time to two hours per grid cells. A total of 24 days were necessary to obtain presence/absence data in the sample.

b) Variables selected

The choice of selected variables principally depends on the existence and availability of land data and is closely dependant upon the scale of analysis. Although ecological conditions needed for most mosses are likely to be micro-

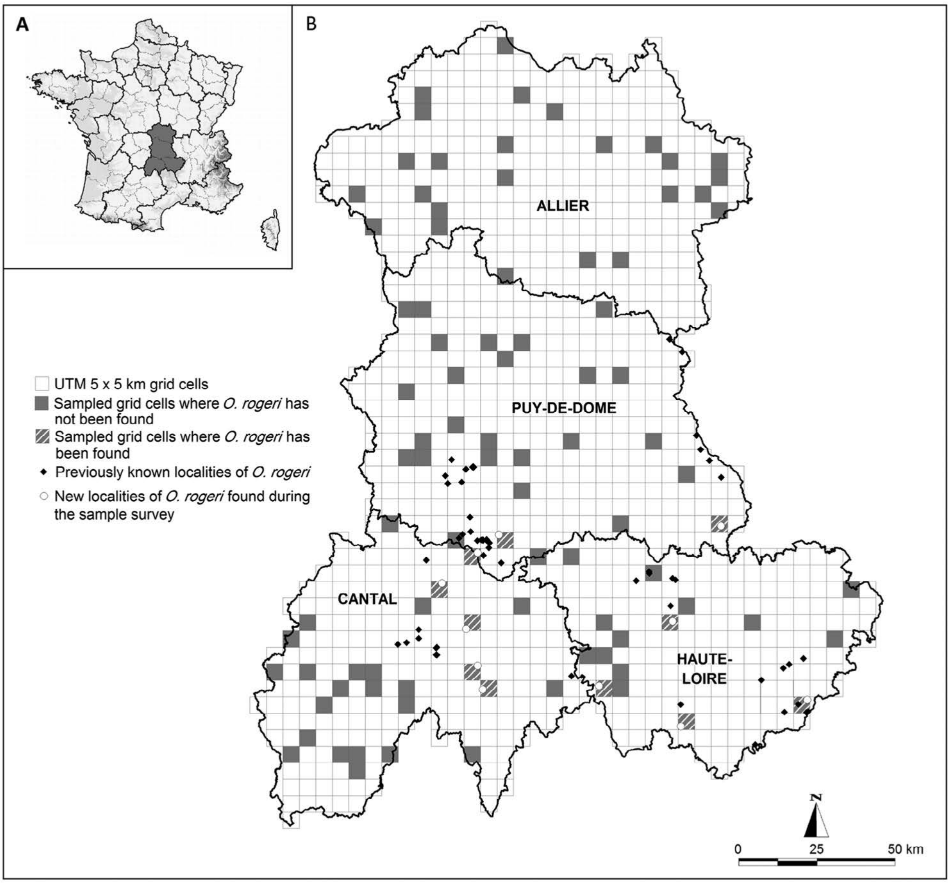

Fig. 1. Map of the study area. A: Location of Auvergne region in France. B: Location of the 96 sampled grid cells (5 × 5 km) in which *Orthotrichum rogeri* was sought (data used for the SDM) and of the 11 grid cells where *O. rogeri* was found and location of previously known and new localities of *O. rogeri* in Auvergne region.

environmental (Glime, 2007), mapping at the regional scale does not allow the use of very fine data (non-existent at this scale). The set of environmental variables used and their origin were the following:

– Altitude: Institut National de l'Information Géographique et Forestière (IGN) (2014a).

– Mean annual rainfall: Estienne (1956).

– Geology: Bureau de Recherches Géologiques et Minières (BRGM) (2014).

– Land use: Ministère de l'écologie, du développement durable et de l'énergie (MEDDE) (2014).

– Soil: map of the CBN Massif central, from Antonetti *et al.* (2006).

– Forest types: Institut National de l'Information Géographique et Forestière (IGN) (2014b).

Only a few point data of temperature were available for the whole territory and consequently this variable has not been included in the SDM. So, no indexes like Emberger nor Dantin-Revenga were possible to calculate.

c) Modelling tool selected

The mathematic tool selected to treat informative data of *O. rogeri*'s presence/absence was multiple logistic regression. It can be used for quantitative and qualitative variables and allows prediction of the effects of one or several variables on a binary type response: 1 = presence of the species in the spatial unit; 0 = absence of the species.

All the analyses were performed using Excel 2003 & XLSTAT. The logistic regression was applied to the significant variables ($P < 0.05$):

$$y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n$$

y is the occurrence of *O. rogeri,*
a_0 is the intercept value,
$a_1 \ldots, a_n$ are the regression coefficient,
$x_1 \ldots, x_n$ are the independent variables.

Then, the probability of occurrence of *O. rogeri* in each grid cells has been calculated with this formula (Hill & Domínguez Lozano, 1994):

$$P = exp^y / (exp^y + 1)$$

The result obtained for each spatial unit is between 0 and 1, with the higher presence probability when it is close to 1.

RESULTS

Out of the 96 grid cells (5 × 5 km) surveyed, 11 were found to host at least one individual of *O. rogeri* (grey and white striped quadrants in Fig. 1B). This presence/absence dataset was used to perform the logistic regression.

The new localities (white circles in Fig 1B) combined with the 69 records that were previously known (black diamonds in Fig. 1B), allowed to update the distribution map of *O. rogeri* in Auvergne.

The linear logistic regression obtained with the significant variables for *O. rogeri* in the Auvergne region was:

O. rogeri = 1.45096 + 0.04156 *mean annual rainfall* + 0.07562 *altitude*

With adjusted $R^2 = 0.84012$; with $P < 0.0001$.

The factors which appear to control the distribution of *O. rogeri* at the region scale are "altitude" and "mean annual rainfall" both with a positive relation. The four other variables have not been integrated in the SDM because of high P value ($P > 0.05$) that mean low significance level.

According to these results, among the 1,044 grid cells, a set of 85 ones have a higher probability than 90% of species presence, 74 of them are between 85 and 50%, and 64 between 40 and 10% (Fig. 2). When taking into account the previously known localities of *O. rogeri* (white diamonds in Fig. 2) that have not been used in the SDM, it appears that 51 (63.75%) of them fall into grid cells with a probability of presence higher than 90%, 18 (22.5%) in ones between 85 and 50%, and 11 (13.75%) in cells which had not been identified as potential. Hence, the predictive performance of the distribution of *O. rogeri* of the model is considered satisfying.

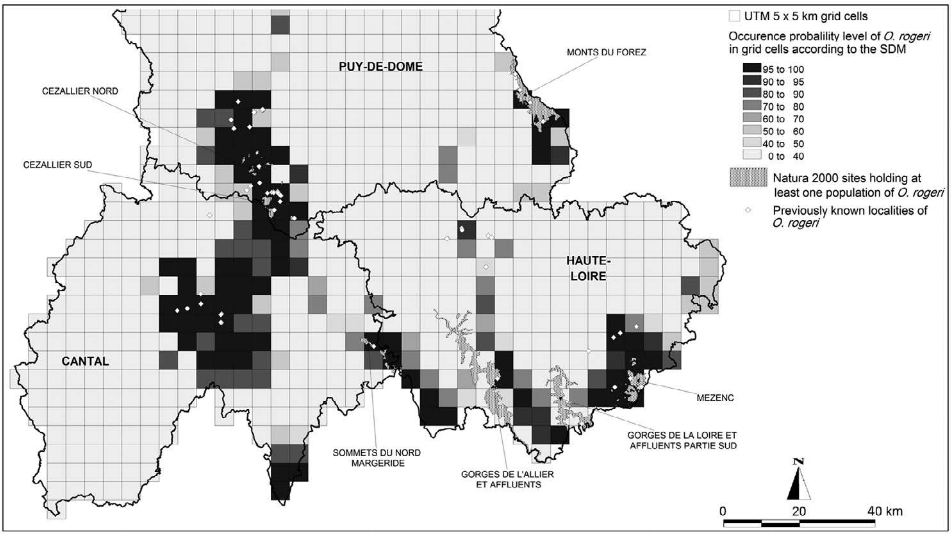

Fig. 2. Map of occurrence probability level of *Orthotrichum rogeri* in Auvergne (Allier missing). Previously known localities of *O. rogeri* and Natura 2000 sites holding at least one population of *O. rogeri* are indicated.

Only 17 (21.25%) of previously known localities of *O. rogeri* are currently integrated in the Natura 2000 regional network. A significant number: 63 (78.75%) of previously known localities of *O. rogeri* populations are currently located outside the Natura 2000 network sites but at a very short distance from their borders. 56 (70%) *O. rogeri* populations are located at a distance not exceeding one km from the border of an extant Natura 2000 site. For example, in the case of the "Massif cantalien partie est et ouest FR8301055" site (Fig. 3), 9 populations are located oustside the site and in wooded stands. This site has only 7.8% of wooded surfaces.

All grid cells with a high probability of occurrence are located in the southern part of the region. The departments of Puy-de-Dôme and Cantal house the highest number of cells with a high probability of occurrence. Large areas of south-western Cantal or northern Puy-de-Dôme appear to lack potential. The department of Allier is almost without any cells with a high probability of occurrence.

Out of 81 Natura 2000 sites which were designated in Auvergne, only 7 of them ("Monts du Forez", "Cézallier Nord", "Cézallier Sud", "Affluents partie Sud", "Mézenc", "Nord Margeride" and "Gorges de la Loire") currently hold at least one *O. rogeri* population (Fig. 2).

DISCUSSION

In Auvergne, the species was logically encountered in grid cells of altitudes ranging from 1,000 to 1,400 m and with a mean annual rainfall of more than 1,000 mm/year which conforms well to the superior mountain belt (Estienne,

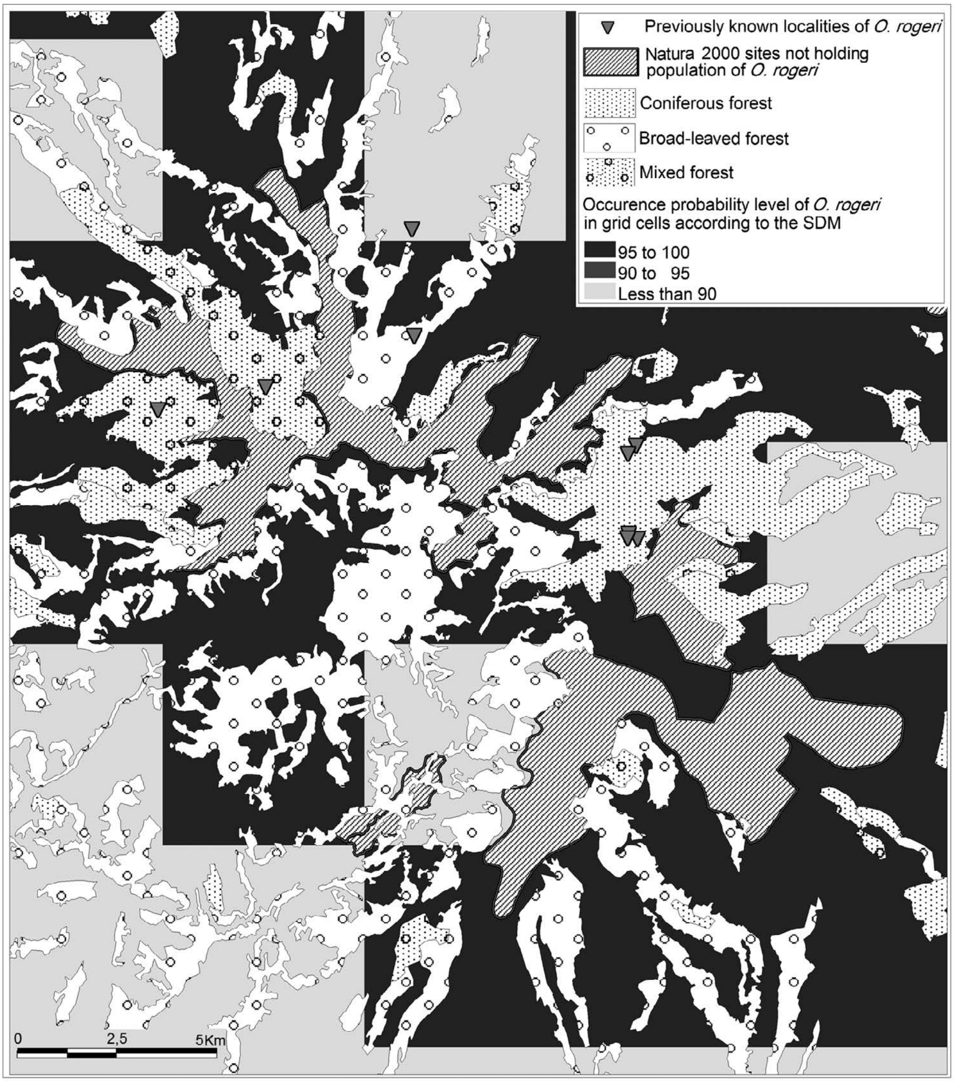

Fig. 3. Outline of "Monts du Cantal" Natura 2000 site. Position of known *Orthotrichum rogeri* populations, probability of occurrence of *O. rogeri* and forest cover (coniferous forest, broad-leaved forest and mixed forest) are indicated.

1956). Overall humidity, which is assessed in different ways, is likely to be one of the most important predictor for humidity sensitive plants like bryophytes as it was shown that the number of rain days each year was the most significant driver of bryophyte-richness in north-west England (Callaghan & Ashton, 2008). Yet, altitude and mean annual rainfall are not necessarily the main factors dictating the species occurrence. Other ecological parameters not taken into account in our model may have a significant influence onto the regional distribution of *O. rogeri*. Geology and pedology did not account for the distribution pattern of *O. rogeri*.

A significant correlation between bark chemistry and soil chemistry could be demonstrated on *Populus tremula* L. through a probable transportation of nutrients from roots to bark (Gustafsson & Eriksson, 1995) suggesting that soil properties could affect the bryophytic vegetation. The absence of such a relation in the case of *O. rogeri* could be an indication of its relative indifference in chemical components of the bark. In Auvergne, *O. rogeri* was found growing on barks with contrasting pH properties, such as *Abies alba* Mill., with a bark pH of 4, and *Sambucus racemosa* L., with a bark pH of 7 (unpublished observations). This should be investigated further.

The predictive map supplemented with the data of effective occurrence of *O. rogeri* allows estimation of the current conservation level of the moss and the potential for improvement. With only 8.6% of the Natura 2000 sites holding just 21% of its currently known populations, *O. rogeri* is actually insufficiently represented in the Natura 2000 regional network. Where known populations are located at a short distance of the border of a Natura 2000 site (for instance "Monts du Cantal" site, Fig. 3), a slight modification of the current outline to include them is definitely recommended. Natura 2000 sites located within the grid cells of maximum probability of occurrence of that species are certainly the best candidates if a choice is to be done. Several extent Natura 2000 sites are settled in high probability of occurrence cells but without currently known populations of this species being included in the site. In this case, a targeted systematic survey within the borders of the site should be carried out. Additionally, a systematic grid-recording of the 56 cells with a very high probability of occurrence (representing an area of 1,400 km^2) should be undertaken. New Natura 2000 sites, specifically intended to protect *O. rogeri*, could be designated on that basis. These procedures compel with limited conservation funding because only 5% of the territory should be surveyed in this case.

Despite the overall fitness of our model, several discrepancies arose nevertheless at the local scale. For instance, in the "Monts Dore" site a non negligible proportion of the previously known *O. rogeri* populations falls outside the higher occurrence probability grid cells. Arguably, distribution probability was modelled on 25 km^2 average climate data. In reality the climate experienced by an individual bryophyte will strongly depend on microclimatic parameters that are not transposed at a wider scale. But more importantly, "Monts Dore" site was initially designated on flagship subalpine heavily grazed habitats which are evidently not favourable to epiphytic communities. The traditional agricultural practices, such as pastoralism and dairy farming, account for the high man-made landscape biodiversity but strongly lowered the possibility for epiphytic mosses to survive. Inadequacy of sites designated on vascular plant assemblages in preserving bryophyte diversity has been documented elsewhere (Vellak *et al.*, 2010). In Auvergne, *O. rogeri* is often linked to anthropogenic habitats like hedgerows, isolated trees in quarries, *Salix caprea* L. scrubs in pastures, *S. pentandra* L. of wooded mires (Sotiaux & Sotiaux, 2002; Hugonnot, 2008; Lüth, 2010). It favours young phorophytes whose maintenance is dependent upon a disturbance regime. At the bark scale, this moss is linked to the first stages of bryophyte colonization and is very sensitive to competition so that it disappears as soon as other more robust and vigorous species come to invade the tree (*Orthotrichum affine* Schrad. *ex* Brid., *O. striatum* Hedw.) (Hugonnot *et al.*, 2011). Barkman (1958) and van der Pluijm (2001) observed that the early epiphytic assemblages of the bark of a *Salix* individual shift towards dominant species within several tenth of years so that permanent recreation of new habitat should be ensured. Mesic pioneer tree stands in open landscapes are certainly not considered as key habitats for bryophytes (Hallingbäck & Hodgetts, 2000). But such taxa, like *O. rogeri*, appear well adapted to such dull habitats with prominent edge conditions (enhanced wind velocity, amount of light and aggravated rate of evaporation...) (Vanderpoorten *et al.*, 2004) and rely on cyclic regeneration of phorophytes. This could be easily achieved here outside or even inside protected areas by reconsidering the biodiversity value of mesic-mesohygric *Salix-Sambucus* spp. woodland with various proportions of these trees.

A common practice in designating Natura 2000 sites in Auvergne has been to select severely fragmented areas to only incorporate extreme altitude summits thus excluding large forested areas surrounding them (Fig. 3). Such sites surely do not form functional ecocomplexes and this type of designation consequently excludes the complete suite of epiphytic bryophytes.

Another set of SAC have been specifically designated for mire conservation (poor fens, wet heaths, bogs and springs). Summer grazing and mowing are the two regimes that allowed vegetation to remain open for centuries (Berger *et al.*, 1990; Bordessoule, 2001). Spontaneous scrubs and trees encroachment in mires and bogs is generally perceived as a serious threat to the ecosystem functioning (Dupieux, 1998). Colonization of mires by *Salix* (mostly *S. atrocinerea* Brot., *S. aurita* L., *S. caprea*, *S. pentandra*) is considered harmful to their biodiversity so that wood eradication is most often considered as the appropriate management (Hindryckx *et al.*, 1989; Barnaud & Fustec, 2007). Derelict portions of mires would nevertheless lead to large areas of potential habitats for epiphytes like *O. rogeri* without the need of any expensive interventionism. Then the recreation of a complex mosaic made of irregular alternation of open, semi-open and wooded mires/bogs should be considered as an innovative alternative to the conservation of *O. rogeri*.

At the other extreme, *O. rogeri* is also found in pristine, old-growth and ancient forests with a natural dynamic of disturbance (wind throw, senescent fallen tree, etc.) (Hugonnot, 2008) where it colonizes young shrublets (*Sambucus racemosa*, *Salix caprea,* etc.) or young or upper branches of trees, or very small branchlets at the base of the trunk. Disturbance as a natural (tree mortality caused by wind) or anthropogenic events appears of prime importance in both habitats. The conservation of stands where processes continue at a rate not directly influenced by anthropic management is necessary. Protection of forests from intensive harvesting then appears as a long-term alternative for conservation of *O. rogeri*. But in front of the unpredictability of the disturbance regime needed, the designation of suitable area is only conceivable at a large spatial scale, that of landscape. SAC encompassing very wide forested areas, identified in our model as potential for *O. rogeri*, would be necessary for this species linked to some regime of random disturbance. Existing Natura 2000 sites are always of relatively small surfaces, which are considered inconsistent with dynamics requirements of epiphytes. The appropriate area should be far greater than current Natura 2000 sites but this issue requires further inquiry to determine with accuracy the optimum surface.

The somehow contradictory ecological requirements of *O. rogeri* raise the question of bryophyte conservation in anthropogenic habitats *vs*. natural and high conservation value ancient ones. Is conservation of *O. rogeri* in habitats resulting from anthropic activities an efficient way to preserve permanently this epiphytic species? It was shown that the conservation of epiphytic *Orthotricha* is possible, though very expensive, at the local scale, through rejuvenation of a particular stand, by cutting old individuals and allowing young ones to take their places (Hugonnot *et al.*, 2011). This requires constant attention and careful monitoring of populations. Unfortunately local firewood gatherers who might help with annual cutting are not interested in such soft-wooded trees. Conservation of *O. rogeri* is equally possible, outside protected network, through a reconsideration of the value of anthropogenic mesic and mesohygric woodlands. At the other extreme, putting emphasis on natural dynamics in large forested functional ecosystems instead of maintaining a species in some designated areas would be an innovative conservation device that simply requires the designation of large enough SAC. This was also advocated by Porley *et al.* (2008) which showed that the conservation of a dynamic species cannot be achieved by small designated sites but requires a landscape scale strategy. This kind of policy would be more efficient in the long run as no more expensive anthropic action (refreshment of the pioneer vegetation) would be needed.

Attempting to predict the occurrence of *O. rogeri* resulted in a map where this species is expected in a high number of grid-cells but where it has still not been observed. Is the species really able to fill all the available locations? *O. rogeri* is a rather transient species that keeps on moving from one locality to the other by means of sexual spores. During (1979) described such a life strategy as long-lived shuttle. *O. rogeri* is also an autoicous moss frequently producing sporophytes. We assume that the potential life span of this moss does not exceed a few years because preliminary unpublished observations suggest than a maximum of three successive fertile modules can occur (corresponding to three generations of sporophytes). Vegetative propagation is unknown in this species. The spores are mostly more than 20 μm in diameter, a size considered compatible with long-distance dispersal (van Zanten, 1977, 1983; van Zanten & Pócs, 1981; van Zanten & Gradstein, 1988) but which is almost twice as wide as most other accompanying *Orthotricha*. Compared with most other *Orthotricha*, *O. rogeri* has a smaller capsule and relatively bigger spores and hence seems to not possess the best attributes for long wind-dispersal. Additionally, for some unknown reasons, perhaps relating to competitive inability, *O. rogeri* numbers fewer individuals compared with other *Orthotricha* (*O. affine*, *O. lyellii* Hook. & Taylor, *O. speciosum* Nees, *O. striatum*) at almost all regional locations (Hugonnot, 2008). A reduced ability for colonization (spore germination, protonemal survival) after spore landing could be an alternative explanation. Therefore, it seems likely that, compared with other epiphytic species, some dispersal limitations prevent a perfect fit to the model.

Orthotrichum rogeri is known to grow in bryophytic communities rich in species with high conservation value, at the region scale (Hugonnot, 2008) as well at the European scale (van der Pluijm, 1990; Ignatov & Lewinsky-Haapasaari, 1994; Schäfer-Verwimp, 1995; Lüth, 2010). *Orthotrichum columbicum* Mitt., *O. patens* Bruch *ex* Brid., *O. pulchellum* Brunt., *O. scanicum* Grönvall, *O. shawii* Wilson, *Ulota coarctata* (P. Beauv.) Hammar, *Zygodon dentatus* (Limpr.) Kartt. are high conservation value and special concern bryophytes that are known to grow together with *O. rogeri* in a significant number of localities (unpublished personal observation). *O. rogeri* is a good example of an “umbrella” species (Ozaki *et al.*, 2006), whose conservation ensures at the same time the conservation of a rich suite of associated bark-dwelling bryophytes (Hallingbäck & Hodgetts, 2000; Vanderpoorten *et al.*, 2006). A fairly good correlation exists between areas of high probability of occurrence of *O. rogeri* and of other taxonomically related epiphytes (unpublished data). Important assemblages of corticolous taxa could then be protected by focusing on a single flagship species. Dealing with dramatically distinct habitats, *Hamatocaulis vernicosus* (Mitt.) Hedenäs has been used with success as flagship listed on Annex II of the Habitats and Species

Directive for neutral flushes in eastern Europe (Štechová & Kučera, 2007; Štechová *et al.*, 2008, 2010, 2012).

Climate change is likely to substantially affect the spatial distribution of bryophytes, mostly through changes in humidity-related parameters (Gignac, 2001). Frahm & Klaus (2001) and Frahm (2005) documented climate-induced western intrusion of oceanic or subtropical species into central Europe. A dramatic northern and western range drift of *Sematophyllum substrumulosum* (Hampe) E. Britton distribution area was predicted using SDM (Sérgio *et al.*, 2011) and monitoring surveys are particularly worrying since it has been found to fill predicted localities in north Wales and northern Ireland with anticipation (Bosanquet, 2013). Although projections carry a large amount of uncertainty, given that global warming is predicted to overturn precipitation regime and increase the mean annual temperature in Europe, a reasonable assumption is that *O. rogeri* will endure an altitude shift towards wetter and cooler conditions. The maximum height of Auvergne is reached at the Puy de Sancy and is 1,885 m a.s.l. Today *O. rogeri* is mostly encountered at altitudes ranging from 1,000 to 1,400 m and out of 1,044 5 × 5 km regional grid cells, only 2.3% have a centroid reaching at least 1,400 m high. Clearly, the limited altitude here does not allow unlimited transposition of potential habitats and this is a special issue of protected area-selection methods (Dockerty *et al.*, 2003; Araújo *et al.*, 2004). The possibility that *O. rogeri* and comparable mountain species are today in an altitudinal bottleneck because of unsuitability of areas under protective legislation should be seriously considered. Then, adjusting current outline of Natura 2000 sites appears of utmost relevance. Paradoxically, the only suitable areas for *O. rogeri* are predicted to be precisely those that are today bare of potential phorophytes because of unfavourable current management practices (see above). The capacity of protected areas in Auvergne to provide suitable habitats for *O. rogeri* is essentially dependant upon at least the lowering of human impacts on ecosystems to allow medium-term succession to partially close some areas.

SDM of *O. rogeri* could be a useful tool to evaluate the impact of global warming on bryophyte spatial occurrence. A medium-term monitoring using SDM techniques as those used in the present study would be an easy way to measure the evolution of potential habitats surfaces where this species can survive.

Aknowledgments. David Happe (DREAL Auvergne) is thanked for providing fund and help in many ways during the completion of this work. Sam Bosanquet offered many valuable suggestions and helped us to improve significantly our text.

REFERENCES

ANTONETTI P., BRUGEL E., KESSLER F., BARBE J.P. & TORT M., 2006 — Aperçu sur les sols de l'Auvergne. *In :* Antonetti P., Brugel E. & Kessler F. (eds), *Atlas de la Flore d'Auvergne*. Chavaniac-Lafayette, Conservatoire Botanique National du Massif Central, pp. 43-51.

ARAÚJO M.B., CABEZA M., THUILLER W., HANNAH L. & WILLIAMS P.H., 2004 — Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. *Global change biology* 10: 1618-1626.

BARKMAN J.J., 1958 — *Phytosociology and ecology of cryptogamic epiphytes*. Assen, Netherlands, Van Gorcum and Comp., 628 p.

BARNAUD G. & FUSTEC É., 2007 — *Conserver les zones humides : pourquoi ? comment ?* Dijon/Versailles, co-édition Educagri and Quae éditions, 296 p.

BERGER G., BERGERON R., BOURGIER J.P., COMMERE R., COUHERT J.-P., CRETIN C., DEGORCE J.-N., ETLICHER B., GEREST H., JALLAT H., JANSSEN C.R.,

STARON G., SUCHEL J.-B. & THEBAUD G., 1990 — *Les monts du Forez : le milieu et les hommes*. Saint-Étienne, Université Jean Monnet, Centre d'Études Foreziennes, 227 p.
BORDESSOULE E., 2001 — *Les « montagnes » du Massif central. Espaces pastoraux et transformation du milieu rural dans les monts d'Auvergne*. Clermont-Ferrand, Presse Universitaire Blaise Pascal, 372 p.
BOSANQUET S., 2013 — *Sematophyllum substrumulosum*: a rapidly changing picture. *Field bryology* 109: 3-5.
BOUDIER P., 2004 — Observations en Auvergne de quelques bryophytes épiphytes. *Bulletin de la société botanique du Centre-Ouest, N.S.* 35: 347-352.
BUREAU DE RECHERCHES GÉOLOGIQUES ET MINIÈRES (BRGM), 2014 — Carte géologique 1/50 000 vecteur harmonisée®. Web site : http://infoterre.brgm.fr/. Accessed 21 January 2014.
CALLAGHAN D.A. & ASHTON P.A., 2008 — Knowledge gaps in bryophyte distribution and prediction of species-richness. *Journal of bryology* 30: 147-158.
DOCKERTY T., LOVETT A. & WATKINSON A., 2003 — Climate change and nature reserves: examining the potential impacts, with examples from Great Britain. *Global environmental change* 13: 2125-135.
DUPIEUX N., 1998 — *La gestion conservatoire des tourbières de France.* Premiers éléments scientifiques et techniques – 1998 –. Programme Life-Nature « Tourbières de France ». Espaces Naturels de France, 244 p.
DURING H.J., 1979 — Life strategies of Bryophytes: a preliminary review. *Lindbergia* 5: 2-18.
ESTIENNE P., 1956 — Recherches sur le climat du Massif central français. *Mémorial de la météorologie nationale* 43 in-4º: 1-242.
FRAHM J.-P. & KLAUS D., 2001 — Bryophytes as indicators of recent climatic fluctuations in Central Europe. *Lindbergia* 26: 97-104.
FRAHM J.-P., 2005 — Bryophytes and global change. *Bryological times* 115: 8-10.
FRANKLIN J., 2009 — *Mapping species distribution. Spatial inferences and prediction.* Cambridge, Cambridge University Press, 320 p.
GARILLETI R., LARA F., ALBERTOS B. & MAZIMPAKA V., 2002a — Datos preliminares para una Lista Roja de las especies europeas del género *Orthotrichum* Hedw. (Musci). *Conservación vegetal* 7: 3-5.
GARILLETI R., LARA F. & MAZIMPAKA V., 2002b — New differential characters for *Orthotrichum rogeri* Brid. (Orthotrichaceae, Bryopsida). *Nova Hedwigia* 75: 207-216.
GIGNAC L.D., 2001 — Bryophytes as indicators of climate change. *The bryologist* 104: 410-420.
GLIME J., 2007 — *Bryophyte Ecology. Volume 1. Physiological Ecology.* Ebook sponsored by Michigan Technological University and the International Association of Bryologist. Accesed 15 February 2014 at http://www.bryoecol.mtu.edu/.
GUSTAFSSON L. & ERIKSSON I., 1995 — Factors of importance for the epiphytic vegetation of aspen Populus tremula with special emphasis on bark chemistry and soil chemistry. *Journal of applied ecology* 32: 412-424.
HALLINGBÄCK T., 1995 — The practice of bryophyte conservation. *Cryptogamica Helvetica* 18: 119-129.
HALLINGBÄCK T. & HODGETTS N. (compilers), 2000 — *Mosses, Liverworts, and Hornworts. Status Survey and Conservation. Action Plan for Bryophytes.* IUCN/SSC Bryophyte Specialist Group. Gland, Switzerland and Cambridge, UK, IUCN, 106 p.
HEYWOOD V.H. & IRIONDO J.M., 2003 — Plant conservation: old problems, new perspectives. *Biological conservation* 113: 321-335.
HILL M.O. & DOMÍNGUEZ LOZANO F., 1994 — A numerical analysis of the distribution of Liverworts in Great Britain. *In*: Hill M.O., Preston C.D. & Smith A.J.E. (eds), *Atlas of the Bryophytes of Britain and Ireland, Volume 3. Mosses (Diplolepideae),* Colchester, Harley Books, pp. 11-20.
HINDRYCKX M.-N., DAMBLON F. & SCHUMACKER R., 1989 — Nécessité des études paléoécologiques pour une gestion raisonnée des tourbières hautes. L'exemple des Hautes-Fagnes. *Travaux de Conservation de la Nature 15/2, Actes du Colloque « Gérer la Nature »* : 443-458.
HUGONNOT V., 2008 — Chorologie et écologie d'*Orthotrichum rogeri* Brid. en France. *Cryptogamie, Bryologie* 29: 275-297.
HUGONNOT V., BENARD D., DUMAS C., VERGNE T. & MULOT P.-E., 2011 — La conservation des bryophytes épiphytes à l'échelle locale – l'exemple d'*Orthotrichum rogeri* Brid. dans le marais de Moissac-Bas (Haute-Loire, France). *Actes des premières rencontres végétales du Massif Central:* 157-162.
HUTTO R.L., REEL S. & LANDRES P.B., 1987 — A critical evaluation of the species approach to biological conservation. *Endangered species update* 4: 1-4.

IGNATOV M.S. & LEWINSKY-HAAPASAARI J., 1994 — Bryophytes of Altai Mountains. II. The genera *Amphidium* Schimp., *Orthotrichum* Hedw. and *Zygodon* Hook. & Tayl. (Orthotrichaceae, Musci). *Arctoa* 3: 29-57.

INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE (IGN), 2014a — La BD ALTI®. Web site: http://professionnels.ign.fr/bdalti. Accessed 21 January 2014.

INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE (IGN), 2014b — L'inventaire Forestier®. Web site : http://inventaire-forestier.ign.fr. Accessed 21 January 2014.

LARA F., GARILLETI R., MEDINA R. & MAZIMPAKA V., 2009 — A new key to the genus *Orthotrichum* Hedw. in Europe and the Mediterranean region. *Cryptogamie*, *Bryologie* 30: 129-142.

LARA F., MAZIMPAKA V., MEDINA R., CAPARRÓS R. & GARILLETI R., 2010 — Northeastern Turkey, an unnoticed but very important area for the *Orthotrichaceae* (Bryophyta). *Beihefte zur Nova Hedwigia* 138: 165-180.

LÜTH M., 2010 — Ökologie und Vergesellschaftung von *Orthotrichum rogeri. Herzogia* 23: 121-149.

MINISTÈRE DE L'ÉCOLOGIE, DU DÉVELOPPEMENT DURABLE ET DE L'ÉNERGIE (MEDDE), 2014 — CORINE Land Cover 2006®. Web site : http://clc.developpement-durable.gouv.fr/. Accessed 21 January 2014.

OZAKI K., MASAHIRO I., TAKAYUKI K., SHIGEO I., TAKUMA K. & FUKUYAMA K., 2006 — A mechanistic approach to evaluation of umbrella species as conservation surrogates. *Conservation biology* 20: 1507-1515.

PLUIJM VAN DER A., 1990 — Enkele voor Nederland nieuwe blad- en levermossen in de Biesbosch. *Lindbergia* 16: 28-34.

PLUIJM VAN DER A., 2001 — *Orthotrichum acuminatum* H. Philib. a Mediterranean moss new to the Netherlands. *Lindbergia* 26: 111-114.

PORLEY R., PAPP B., SÖDERSTRÖM L. & HALLINGBÄCK T., 2008 — European bryophyte conservation in the new Millennium. *In:* Mohamed H., Bakar B, Boyce A & Lee P (eds), *Bryology in Asia in the New Millennium*. Proceedings of the World Conference of Bryology, 23-27 July 2007, Crystal Crown Hotel, Petaling Jaya, Malaysia. University of Malaya, International Association of Bryologists and Malaysian Ministry of Natural Resources, pp. 459-485.

RICHARD D. & EVANS D., 2006 — The need for plant taxonomy in setting priorities for designated areas and conservation management plans: a European perspective. *In:* Leadlay E. & Jury S. (eds), *Taxonomy and Plant Conservation*. Cambridge, Cambridge University Press, pp. 162-176.

RODRIGUES A.S.L., TRATT R., WHEELER B.D. & GASTON K.J., 1999 — The performance of existing networks of conservation areas in representing biodiversity. *Proceedings of the royal society of London B 266*: 1453-1460.

SCHÄFER-VERWIMP A., 1995 — Erstnachweis von *Orthotrichum rogeri* für Südwestdeutschland. *Herzogia* 11: 81-92.

SCHUMACKER R. & MARTINY P., 1995 — Threatened bryophytes in Europe including Macaronesia. *In:* European Committee for Conservation of Bryophytes (ed.), *Red DataBook of European Bryophytes*. Trondheim, University of Trondheim, pp. 29-193.

SÉRGIO C., FIGUEIRA R. & MENEZES R., 2011 — Modelling the distribution of *Sematophyllum substrumulosum* (Hampe) E. Britton as a signal of climatic changes in Europe. *In:* Tuba Z., Slack N.G. & Stark L.R. (eds), *Bryophyte ecology and climate change*. Cambridge, Cambridge University Press, pp. 427-439.

SÖDERSTRÖM L., HALLINGBÄCK T., GUSTAFFSON L., CRONBERG N. & HEDENÄS L., 1992 — Bryophyte conservation for the future. *Biological conservation* 59: 265-270.

SOTIAUX A. & SOTIAUX O., 2002 — *Orthotrichum rogeri* (Orthotrichaceae, Musci), mousse épiphyte nouvelle pour la bryoflore belge, dans le district ardennais. Clé d'identification des Orthotrichaceae de Belgique. *Belgian journal of botany* 135: 27-31.

ŠTECHOVÁ T. & KUČERA J., 2007 — The requirements of the rare moss, *Hamatocaulis vernicosus* (Calliergonaceae, Musci), in the Czech Republic in relation to vegetation, water chemistry and management. *Biological conservation* 135: 443-449.

ŠTECHOVÁ T., HÁJEK M., HÁJKOVÁ P. & NAVRÁTILOVÁ J., 2008 — Comparison of habitat requirements of the mosses *Hamatocaulis vernicosus, Scorpidium cossonii* and *Warnstorfia exannulata* in different parts of temperate Europe. *Preslia* 80: 399-410.

ŠTECHOVÁ T., HOLÁ E., MANUKJANOVÁ A. & MIKULÁŠKOVÁ E., 2010 — Distribution and habitat requirements of the moss *Hamatocaulis vernicosus* (Mitt.) Hedenäs in the Bohemian Forest. *Silva Gabreta* 16: 1-11.

ŠTECHOVÁ T., STECH M. & KUČERA J., 2012 — The distribution of *Hamatocaulis vernicosus* (Mitt.) Hedenäs (Calliergonaceae, Bryophyta) in the Czech Republic. *Bryonora* 49: 5-16.

VANDERPOORTEN A., ENGELS P. & SOTIAUX A., 2004 — Trends in diversity and abundance of obligate epiphytic bryophytes in a highly managed landscape. *Ecography* 27: 567-576.
VANDERPOORTEN A., SOTIAUX A. & ENGELS P., 2006 — A GIS-Based model of the distribution of the rare liverwort *Aneura maxima* at the landscape scale for an improved assessment of its conservation status. *Biodiversity and conservation* 15: 829-838.
VELLAK K., INGERPUU N., VELLAK A. & MEELIS P., 2010 — Vascular plant and bryophytes species representation in the protected areas network on the national scale. *Biodiversity and conservation* 19: 1353-1364.
ZANTEN VAN B.O., 1977 — Experimental studies on trans-oceanic long-range dispersal of moss spores in the Southern Hemisphere. *Bryophytorum bibliotheca* 13: 715-733.
ZANTEN VAN B.O. & PÓCS T., 1981 — Distribution and dispersal of bryophytes. *Advances in bryology* 1: 479-562.
ZANTEN VAN B.O., 1983 — Possibilities of long-range dispersal in bryophytes with special reference to the Southern Hemisphere. *Sonderband Naturwissenschaftlicher Verein Hamburg* 7: 49-64.
ZANTEN VAN B.O. & GRADSTEIN S.R., 1988 — Experimental dispersal geography of neotropical liverworts. *Beihefte zur Nova Hedwigia* 90: 41-94.