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Proposal for new method to evaluate lichen refuges

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Abstract. The paper presents a novel proposal for the evaluation of lichen refuges based on observations conducted in mesoregions Krajeńskie Lakeland, Tucholskie Forest and Charzykowska Plain in the last 20 years. Four basic parameters should be taken into account when evaluating the natural significance of refuges. These are: the stability of the area, biodiversity (species abundance), the number of sites where valuable species occur and the possibility of their dispersal. The characteristics and point scales of these parameters, as well as examples of calculations, are presented.

Keywords: lichens, refuges, endangered species, ecosystem fragmentation.

1. Introduction

According to Collins English Dictionary (2014), a refuge is a geographical region which has not been changed and now constitutes a safe haven for relict fauna and flora. Many researchers (e.g. Szweykowscy A. & J, 1993; Falińska, 1997; Dyduch-Falniowska et al., 1999; Symonides, 2007) consider the presence of valuable species as the sole (or the most important) distinguishing feature of refuge.

This definition also applies to refuges of lichens where they form a cluster of valuable species. For example, Cieśliński et al. (1996), Czyżewska and Cieśliński (2003), Kubiak (2013), Matwiejuk (2015) and Perhans et al. (2009) consider forest complexes rich in lichen species to be refuges. Similarly, Kościelniak (2004, 2008) reports that the primary and natural forests of the Bieszczady Mountains serve as refuges and Kapek (2014) – in the same region – regards abandoned villages as refuges. Many authors (e.g. Cieśliński, 2000, 2006; Kossowska, 2002) emphasize the role of protected objects in preserving valuable lichen species. Only a few studies consider the issue of refuges at the same time as the analysis of habitat condition and change, e.g. in British Columbia (Doering & Coxon, 2010) or in Australia (Kantvilas, 2018). Berryman and McCune (2006), in a study based in the western part of Oregon State, evaluate the possibility of preserving valuable epiphytic lichen species depending on the age of trees. A few researchers, e.g. Himelbrant et al. (2018), also take into account the historical aspect of changes in the lichen biota when considering the role of lichen assemblies in the analysed area (in the Leningrad Region, Russia).

The aim of this paper is to point out that when designating a site as a refuge for lichens, it is not only the presence of endangered, rare or protected relict species, etc., that should be taken into account. It is also very important to determine the chances of their persistence and dispersion within the site boundaries. Moreover, the value of sites as refuges, even if they are rich in quantity and quality in terms of valuable taxa, cannot always be compared; they may differ in terms of habitat condition (mainly

the presence and diversity of the substrate available for settlement), local microclimatic features, isolation from the source of dispersal, etc. These difficulties in assessing and comparing the natural value of sites, even within the same region, were pointed out by Cieśliński (2009).

The possibilities for determining and designating lichen refuges differently than has been performed heretofor were initially signalled in a publications by Gruszka (2017) and Gruszka and Lipnicki (2019). The proposal presented here is much more complete and should become the subject of substantive discussion.

2. Study area

The study covered the eastern part of the South Pomeranian Lakeland macroregion in the central part of northern Poland, comprising three adjacent mesoregions: Krajeńskie Lakeland (area 4380 km^2), Tuchola Forest (area 2400 km^2) and Charzykowska Plain (area 2100 km^2) (Kondracki, 2001) (Fig. 1).

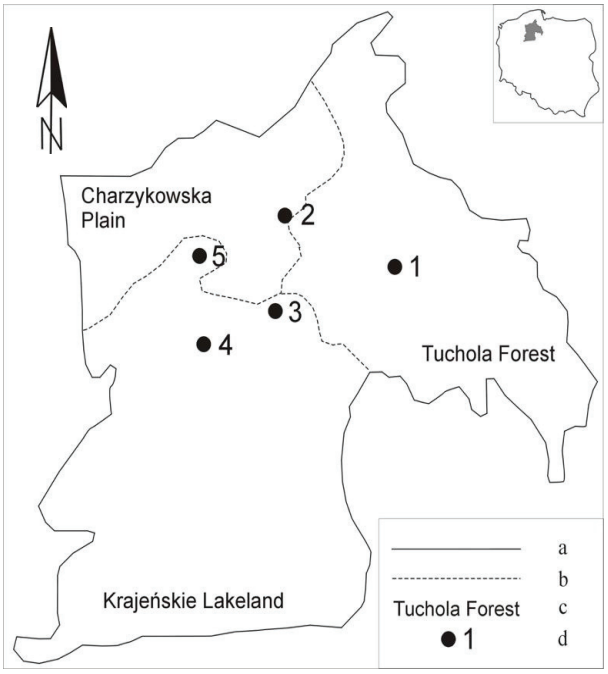

Figure 1. Study area; a – boundaries of the study area, b – boundaries of mesoregions, c – names of mesoregions, d – refuges described: 1 – Kręgi Kamienne Reserve, 2 – Bór Chrobotkowy Nature Reserve, 3 – Nature monument – roadside alley, 4 – Sosny Nature Reserve, 5 – Osiedle Kormoranów Nature Reserve

Krajeńskie Lakeland is mainly agricultural (more than 70% of the area) but forest (the vast majority very homogeneous) cover is 27.3% (Waldon & Ratyńska, 2008; Trampler et al., 1990). The dominant forest associations are pine and mixed forest, although there are also large associations of mixed deciduous forests (Umiński, 1991). Mesoregions Tucholskie Forest and Charzykowska Plain are located in a vast sandur and on a large area occupied by one of the largest forest complexes in the lowland part of Poland – Bory Tucholskie. These are almost entirely pine forests and only small areas, mainly in river valleys, are occupied by deciduous or mixed forests.

Examples using the described method are presented on the basis of analysis of the following areas, which function as lichen refuges in the research locality.

Kręgi Kamienne Reserve
This reserve, with an area of 16.91 ha, was established in 1958 in order to protect 12 stone circles (about 300 stones) and approximately 30 burial mounds. In the order of 90 species of lichen grow on the boulders' surfaces, forming one of the largest concentrations of mountain species in the Polish Lowland; in many cases these are postglacial relics. This represents the only concentration of valuable rock lichens in the study area.

Bór Chrobotkowy Nature Reserve
This is a forest reserve with an area of 41.5 ha. In relation to the whole study area (Fig. 1), the area is distinguished by containing the full species composition of terrestrial lichens, characteristic of *Cladonio-Pinetum*. There are also species of ground lichens, which are very rare in the country and region, including *Cladonia stellaris*, *Stereocaulon taeniarum* and *Flavocetraria nivalis*, and which can only be found in two lowland sites in Poland.

Nature monument – roadside alley
The alley is about 1.5 km long, stretching along both sides of the road between Powałki and Jarcewo. Very rare taxa grow on the trunks of trees here, known from only a few sites in the whole analysed area (including *Parmelina tiliacea* and *Anaptychia ciliaris*), as well as other protected and endangered species (e.g. *Bryoria* sp. div., *Ramalina* sp. div.).

Sosny Nature Reserve
This reserve was established in 1984 and covers an area of 1.49 ha. A fragment of Pomeranian fertile beech forest *Galio odorati-Fagetum* and numerous monumental pine trees are protected.

Osiedle Kormoranów Nature Reserve
This reserve was established in 1956. Under protection are the biocenosis of Pomeranian fertile beech forest *Galio odorati-Fagetum*, monumental specimens of beech and the landscape of the edge of moraine upland. The reserve

contains a number of rare and endangered lichen species (Gruszka, 2010; Gruszka & Janczar, 2010).

3. Methods

Studies that involve designating areas as refuges require careful examination of the terrain of reference, in order to distinguish those especially valuable species that are indicators of the refuge.

The main field study in the Krajeńskie Lakeland mesoregion was conducted in 2009-2014 for a doctoral dissertation (Gruszka, 2014) and this was continued up to 2017 (Gruszka 2017; Gruszka & Lipnicki, 2019).

Lichenological studies covering the whole forest complex of Bory Tucholskie were mainly conducted during the last quarter of the 20th century (i.e. Lipnicki, 1990). They enabled habitat fragments which form refuges for lichens to be identified. The results of these studies were used in the project documentation for a national park, landscape parks and numerous nature reserves (Lipnicki, 1992, 2006, 2012).

The presented attempt to evaluate selected refuges was conducted on the basis of their comprehensive evaluation in terms of analysed parameters. The following factors were taken into account: species diversity of lichens, the number of the most valuable species and their habitat requirements, size of the area, natural characteristics, immediate surroundings, anthropopressure and other threats. The nature, direction and pace of changes in the lichen biota were also evaluated in the refuges with the longest history of research (Kręgi Kamiennie Reserve, Bór Chrobotkowy).

The final evaluation of the quality of refuges was determined on the basis of a five-stage scale (Table 1) after summing up the points assigned to each parameter.

Table 1. Lichen refuge quality scale

Total sum of points	Value of refuge
4	negligible
5-8	small
9-12	moderate
13-16	large
16-20	very large

In order to evaluate lichen refuges, it is proposed that four parameters are analysed. These are: abundance, prevalence and – most strongly related – perspective and permanence. Below is a justification for their inclusion, descriptive characteristics and the criteria for estimating values.

3.1.Abundance

The expressed percentage of a given species refuge among all those distinguished as the most valuable in the region.

This parameter can only be determined after collecting data from the whole (larger) area and indicating valuable species. It is necessary to determine to which refuge area it refers (e.g. mesoregion, city, part of the country) and to characterize the local biodiversity as precisely as possible. In this way, a "reference point" will be defined (background), i.e. a model for analysing the local diversity of the lichen biota (Table 2).

Table 2. Lichen abundance levels

Lichen abundance	Quality characteristics of refuges	Number of points
negligible	A small number of regionally valuable species (< 10%); local taxa are clearly dominant	1
small	A still small number but clearly visible addition of regionally valuable species (10-20%) to the overall biota of lichens	2
average	Number of regionally valuable species is slightly higher (21-30%) than in other parts of the analysed area; however, locally frequent and widespread species still predominate	3
large	Clearly distinguishable share of valuable taxa, with a significant or number of regionally valuable species (31-40%), much larger than in other parts of the analysed area, rare and common taxa coexist	4
exceptional	High or very high number of regionally valuable species (>40%), undoubtedly a distinguishing area on the scale of analysed area	5

3.2. Prevalence

The percentage expressed represents the proportion of sites where the valuable species occurs in relation to all sites studied in a particular refuge area.

Prevalence is a quantitative parameter that determines the abundance of a population of valuable species or a group of such taxa in the refuge. In the case of a large number of valuable species it is possible to select a taxon that is representative and (according to the researcher) the

most valuable for a given region. To indicate the numerical value of the prevalence parameter, a modified frequency scale, after Czachorowski (2004), was adopted (Table 3).

Table 3. Prevalence levels of valuable species

Prevalence (%)	Descriptive frequency	Number of points
< 5	very rare	1
5-19,9	rare	2
20-49,9	frequent	3
50-79,9	pervasive	4
80% ≥	common	5

3.3. Perspective

Determines the extent to which the number of sites of valuable species in the refuge area can be preserved (or increased) in the future.

The perspective parameter is determined by analysing the long-term viability of a species existence and its spread (Table 4). The species' biology and habitat requirements should be taken into account; a lack of such knowledge may result in an incorrect classification of the area. If the site has been previously subject to an inventory study, historical data may be useful in analysing this parameter. This parameter allows trends in population change to be deduced.

Table 4. Refuge perspective scale

Refuge perspective	Descriptive characteristics	Number of points
critical	Lack of possibility of taxa spread, high risk to population sustainability	1
stagnant	Minor or very limited spread potential; population sustainability may be at risk	2
average	Slight but visible potential for spreading and increasing the number of sites; there is no clear threat to the sustainability of the population	3
substantial	High potential for spreading and increasing the number of sites; undisturbed population	4
colonization	Extremely large and supportive opportunities to spread and increase the number of sites	5

3.4. Permanence

Determines the long-term ability of the area to preserve the refuge function and the existence of valuable species within its boundaries.

The permanence parameter should be analysed in terms of the resilience of the entire area in the face of adverse external factors. It is important to assess whether the area has stable system features or is temporary with low homeostatic capacity. Stability is a complex parameter; its acceptance and the determination of its extent depend on the observer's experience in predicting long-term possible changes in the area. The final assessment presented in Table 5 may be based on an analysis of one species or a group of taxa.

Table 5. Refuge resilience scale

Permanence	Descriptive characteristics	Number of points
ephemeral	An area with minimal self-regulation. Completely susceptible to disturbing factors. Refuge fading or degrading. Lack of possibility to preserve the species within a foreseeable time frame	1
threatened	An area with low self-regulation. Partially resistant to moderate disturbance; low buffering properties. Low preservation potential for species, high likelihood of extinction	2
relatively stable	An area with significant self-regulation. Completely resistant to moderate disturbance; buffering capacity ensures habitat stability. Average preservation potential for species, but low extinction potential	3
secure	An area with full self-regulatory capacity. Resistant to higher disturbance factors; low risk of changes in habitat conditions. Very high preservation potential for species and no threat of extinction	4
supportive	Lack of disturbance factors or buffering capacity of the site ensures full habitat permanence and promotes the spread of taxa	5

4. Examples applying the methodology

4.1. Kręgi Kamienne Reserve

a) Abundance: most taxa are regionally extremely valuable and rare, **5 points**
b) Prevalence: most of the valuable species are common (90% of sites) within the larger area, **5 points**
c) Perspective: colonization present (evidenced by the settlement of lichens on boulders exposed as a result of archaeological work in the last several decades), **5 points**
d) Permanence: supportive, **5 points**.

Sum of points: 20; **value of refuge**: very large; **notes**: outstanding refuge with sustainable resources; it requires that the behaviour of tourists be supervised.

4.2. Bór Chrobotkowy Nature Reserve

a) Abundance: regionally exceptional, **5 points**
b) Prevalence: calculation of this parameter was based on analysis of the four most valuable elements of the site: the general set of species typical for *Cladonio-Pinetum* habitat and the populations of *Cladonia stellaris*, *Flavocetraria nivalis* and *Stereocaulon taeniarum* (Table 6)**.**
c) Perspective and permanence: the evaluation of perspective and permanence considered the same elements of the site as in the prevalence evaluation (Table 7).

Sum of points: 16; **value of refuge**: large; **notes**: requires active protection to slow down processes of natural succession.

Table 6. Assessment of lichen refuges: values of the prevalence parameter for the most valuable elements of the Bór Chrobotkowy Reserve

Analysed element	Evaluation		
	Percentage	Descriptive	Score
Set of species typical for *Cladonio-Pinetum*	95%	common	5
Cladonia stellaris	85%	common	5
Flavocetraria nivalis	15%	rare	2
Stereocaulon taeniarum	12%	rare	2
Total	≅ 52%	pervasive	**4**

Table 7. Assessment of lichen refuges: results of the analysis of perspective and permanence parameters for the Bór Chrobotkowy Reserve

	Perspective		Permanence	
Analysed element	**Descriptive evaluation**	**Score**	**Descriptive evaluation**	**Score**
Set of species typical for *Cladonio-Pinetum*	substantial	4	supportive	5
Cladonia stellaris	colonization	5	supportive	5
Flavocetraria nivalis	stagnant	2	relatively stable	3
Stereocaulon taeniarum	stagnant	2	relatively stable	3
Total	average	< 3	secure	4

4.3. Nature monument – roadside alley between Powałki and Jarcewo

a) Abundance: most taxa are regionally valuable **5 points**
b) Prevalence: based on *Parmelina tiliacea* as a representative species – 30%, **3 points**
c) Perspective: stable populations colonizing other trees only at a low and uneven rate (based on multiannual observations) – average, **3 points**
d) Permanence: the population of target species and other valuable taxa are not at risk unless local conditions change (ageing and removal of trees, increased motor vehicle traffic) – relatively stable, **3 points**.

Sum of points: 14; **value of refuge**: large; **notes**: requires supervision in order to prevent increased motor vehicle traffic

4.4. Sosny Nature Reserve

a) Abundance: 11 taxa of 43 are regionally valuable (25%), **3 points**
b) Prevalence: valuable species identified at individual sites, **1 point**
c) Perspective: very few potential sites, **2 points**
d) Permanence: this reserve experiences intensive shrub growth, high probability of extinction of lichens due to changes in habitat conditions, **2 points.**

Sum of points: 8; **value of refuge**: small; **notes**: surveillance zone as a result of natural succession.

4.5. Osiedle Kormoranów Nature Reserve

a) Abundance: 13 taxa of 43 regionally valuable (30%), **3 points**
b) Prevalence: based on *Ramalina balica* as a representative species, **1 point**

c) Perspective: many potential places to be occupied by the species, **4 points**
d) Permanence: lack of major disturbance factors, the ecosystem of this area retains high buffering potential, **5 points.**

Sum of points: 13; **value of refuge**: large; **notes**: this area with population of valuable species requires constant monitoring.

5. Discussion

Refuges have an increasing role in preserving and maintaining biodiversity, particularly in a landscape modified by people. The identification and protection of such areas can increase the chances of survival of the most valuable species in the region. In the process of broadly-understood anthropogenic transformations and long-standing demands for the protection of lichens (e.g. Motyka, 1934; Szwejkowski & Tobolewski, 1959; Lipnicki, 1988, 1991) refuges have, and will have, an increasingly important role in the preservation of biodiversity (Cieśliński & Czyżewska, 2002).

The authors of this paper, based on many years of field research and activities for the protection of valuable and endangered lichen sites, present four basic parameters for the evaluation of refuges. These parameters are: abundance, prevalence, perspective and permanence. They are sufficient to evaluate the value of potential lichen refuges.

In the case of **abundance**, the designation of a refuge area is due to the fact that the regional distribution of taxa is an unstable feature. The same species can be assigned to different categories of threats – cf. Regional Red Lists (e.g. Czyżewska, 2003). However, the Red List itself defines only the risk of extinction of species, while other aspects (e.g. phylogenetic, historical, cultural) may jointly significantly recommend a particular species for protection (Kędra, 2013). The parameter patronize large-area refuges due to the presence of more valuable species within their borders – (often even as single site). At the same time, it may underestimate the values of those within which valuable but few (or even single) species were found. The percentage ranges assigned to each degree (although quite wide) may turn out to be too rigid and perhaps descriptive characteristics should be introduced to allow more freedom in choosing the grade.

The need to calculate the **prevalence** level results from the fact that each species has its own population threshold (sites, number of individuals in the site, etc.), below which the population is threatened with extinction from year to year (Wilson, 1999). According to Markowski and Skrok (1999), the probability of population disappearance of a small number of sites in the remaining parts of a larger area is much higher than the probability of increasing their numbers. Even a common species, but for which a significant reduction in the number (or deterioration state) of habitats has been identified, may be considered to be at high risk of extinction (Kędra, 2013). From the authors' observations, the parameter quite well describes the prevalence in the refugium of a given species (or species). However, these observations focused on relatively small areas with clearly defined positions. The problem with its determination may appear in larger areas – which will require counting all surveyed stands during field work.

Perspective expresses the potential for the dispersion of valuable species Lichens are characterized by a limited range of spreading through diasporas. These distances usually do not exceed 100 m (i.e. Öckinger et al., 2005; Scheidegger & Werth, 2009; Jüriado et. al., 2011). According to, e.g., Selva (1994), Gu et al. (2001) and Kubiak (2013), the possibility of overcoming environmental barriers and the occupation of new habitats by many taxa is decreasing as a result of, among other factors, the dispersion of their sites. As a result, migration and opportunities for re-colonization are limited or even non-existent, and the risk of their extinction in a given area increases. This is because we are dealing with very small populations which tend to lose genetic diversity and, therefore, the ability to adapt to a changing environment (Pullin, 2004). Occupation of a larger area of the ecosystem means more stable conditions, favourable to colonization of the habitat, and thus potentially more and larger populations (Wilson, 1999). The parameter is very difficult to determine. We try to estimate the theoretical situations that may (but do not have to) occur in the future. This determination enables the development of practical actions that will lead to an increase in lichen sites and thus increasing the quality of the refuge.

While the previous parameter (perspective) was analysed from the point of view of the species, **permanence** considers the area as a whole. Changes in habitat conditions may initiate processes of dynamic change in the composition and structure of the ecosystem. In the case of lichens (especially those with a very narrow range of ecological requirements) such changes are particularly dangerous. This is mainly due to their slow growth rate, high sensitivity to anthropogenic factors and specific habitat selectivity. Regeneration of their population (despite the richness of potential sites) in changed conditions is difficult or even impossible. Factors which have a negative impact on lichens have a complex effect and, in many cases, it is difficult to identify the one responsible for the impoverishment of the lichen biota (Fałtynowicz, 2003). One of the threats to species is, e.g., a reduction in the area where potentially favourable conditions for the growth of of lichens has existed thus far. The supportive properties of natural ecological systems, characterized by stable ecosystems, e.g. forest ecosystems, weaken with their fragmentation (Cieśliński et al., 1996). In the case of areas subject to

strong anthropogenic pressure, the possibility and probability of the effectiveness of limiting the negative effects of these processes should be considered (active protection). In the authors' opinion, this is the most important parameter. All areas presented in the publication are protected by law, and that's why permanence parameters reached (usually) high values. But negative (from the point of view of lichen ecology) are also natural processes (plants succession, extinction of stands). That mostly was lowers the values (not anthropogenic factors).

6. Conclusions

The methodology presented above for the evaluation of the quality of lichen refuges may seem simplistic, but it is relatively quick and does not require support from statistical analysis. However, the method requires a very good knowledge of the research area, and the results must be well-argued. Therefore, the methodology is directed at more experienced lichenologists. The evaluation method presented may be helpful (and in some cases even crucial) in the identification of risk to the stability and continuity of refuges and subsequent development of their protection. Since the problem of refuges is largely unaddressed in the lichenological literature, it seems advisable to continue researching this problem in other areas. Using this method to check the quality of refugia for other groups of organisms (for example bryophytes or vascular plants) seems to be possible but requires verification.

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