

# The concept of lichen refugia classification. A proposal based on the case study of Krajeńskie Lakeland, Poland

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**Abstract.** The article presents a proposal for the classification of lichen refuges based on the research conducted in the Krajeńskie Lakeland in 2009–2014. Four types of refuges have been distinguished during the research: 1 – primeval (natural) – associated with the least transformed areas, 2 – regenerative (semi-natural) – with species of high conservation value, spread by natural forces despite a small anthropogenic impact, 3 – colonized (anthropogenic) – solely formed by human activity and extraneously inhabited by adventive lichens, 4 – incidental (spontaneous) – formed instantaneously as a result of a favourable situation or an event. The last type was not found in the course of the study. The publication presents the characteristics of all types of refuges along with a key for their identification.

**Key words:** lichens, refuge, endangered species, Krajeńskie Lakeland.

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## 1. Introduction

Refuge (lat. refuge from *refugere* – escape, avoid, escape alive) (Kopaliński, 2007), according to IPA (Important Plants Areas) (including also bryophytes, macrophytic algae, macromycetes fungi, lichens and mycetozoa) is defined as: “a natural or semi-natural area, distinguished by exceptional botanical richness and/or constituting the habitat for the distinctive set of rare, threatened and/or endemic plant species and/or plant communities of high botanical value” (Mirek et al., 2005).

Refuges play an increasingly important role in preserving and sustaining biodiversity in the landscape transformed by man. It is particularly important for endangered, rare or relict species, which are a remnant of the previous ecological systems. Selecting and protecting areas with refuge characteristics may increase the chances of regional survival of the most valuable species.

However, in the lichenological literature, the issue of lichen refuges is a main research subject in only few publications (Cieśliński, 1999, 2000, 2006; Kossowska, 2002; Kościelniak, 2005, 2009; Wójciak & Urban, 2012; Kapek, 2014). In most of them, the issue of refuges appears in study summaries and/or has only additional aspect (Cieśliński, 2003; Kukwa & Jabłońska, 2006; Kolanko, 2009; Gruszka, 2010, 2011; Kubiak, 2011; Bielczyk, 2012; Czarnota, 2012; Hachułka, 2012; Kubiak & Sucharzewska, 2012; Golubkov et al., 2012; Kościelniak, 2012).

Given the scarcity of scientific publications on this topic, the intention of this study was to propose the author’s attempts to classify lichen refuges and initiate an evidence-based discussion.

## 2. Study area

The mesoregion of the Krajeńskie Lakeland is located in north-western Poland (Fig. 1). It belongs to the North European Plain Province, Southern Baltic Lakelands Subprovince and the region of Southern Pomerania Lakeland. It is located between the Gwda Valley, Brda Valley and Central Noteć Valley, surrounded by Charzykowska Plain and Tuchola Forest in the north. It occupies an area of approximately 4380 km<sup>2</sup> (Kondracki, 2001). Krajeńskie Lakeland is located between 53°05' and 53°50' north latitude and between 16°45' and 17°50' east longitude (Umiński, 1991).

Krajeńskie Lakeland is a typical agricultural land (more than 70% of the area) (Waldon & Ratyńska, 2008), its forest cover is 27.3% (Trampler et al., 1990). The dominant forest associations are pine forests and mixed forests, although there are also large associations of mixed deciduous forests. The stands mainly consist of *Pinus sylvestris* (over 85%), the undergrowth is dominated by *Juniperus communis*, *Frangula alnus* and *Corylus avellana* as well as *Quercus* spp., *Fagus sylvatica* and *Acer* spp. saplings (Umiński, 1991). Forests in the vast majority are very homogeneous. The vast majority of forest area is occupied by single-storied stands. The decisive factor in recent years was the promotion of single-species plantings (Proгноza oddziaływania..., 2005).

## 3. Methods

Field study of the mesoregion was conducted in the years 2009–2014. Studies involving marking areas as refuges require examining the terrain of reference, in order to select especially valuable species, which are indicators of the refuge. Therefore, the material collection sites were selected in such a way so to obtain a comprehensive information of the lichen biota in the entire area. The obtained results are a model for the analysis of distribution diversity of lichen biota, and thus a reference point indicating the most valuable areas.

The specimens of common species, easy to identify in the field, were not collected and only their presence was recorded. Lichen specimens were collected to identify them in the laboratory. Thin layer chromatography (TLC) was used in determining the types of secondary metabolites in sterile crustose lichens (for example genus *Lepraria* or *Chrysothrix flavovirens*) according to the guidelines of Orange et al. (2001) and Kubiak and Kukwa (2011). All the collected and marked specimens were placed in the herbarium of the Department of Biology, Morphological and Health Sciences, Faculty of Physical Culture in Gorzów Wielkopolski. The nomenclature follows Index Fungorum (date of exploration 26.09.2017)



Figure 1. Location of the Krajeńskie Lakeland in Poland (Gruszka, 2014)

## 4. Results

In total, 160 species of epiphytic lichens have been identified in the Krajeńskie Lakeland, as a result of the present research (Gruszka, 2014). Among the identified taxa 34 are new to the area, 69 are included in the Red list of species threatened with extinction in Poland by Cieślński et al. (2006). The largest group are the endangered species (23 species) and vulnerable (22 species), the smallest represented only by two least concern taxa. 11 species are under partial protection and 18 are under strict pro-

tection (Rozporządzenie, 2014). Of all identified species of lichens, the most valuable 43 species were identified as indicators of refuges (Table 1). Most of them belong to endangers of extinction in the country and they are rare (or very rare) on Krajeńskie Lakeland. 9 areas were marked as lichen refuge in Krajeńskie Lakeland. Among the identified six were located in the existing nature reserves.

### 4.1. Classification of refuges

On the basis of the comparative analysis of the characteristics of each refuge (including, the degree of naturalness,

Table 1. Species that distinguish forest areas as refuges of lichens in the Krajeńskie Lakeland

Species	Primeval refuge	Regenerative refuge
<i>Acrocordia gemmata</i> (Ach.) A. Massal.	+	
<i>Alyxoria varia</i> (Pers.) Ertz & Tehler	+	+
<i>Arthonia atra</i> (Pers.) A. Schneid.	+	+
<i>Arthonia spadicea</i> Leight.	+	
<i>Arthonia vinosa</i> Leight.	+	
<i>Arthothelium ruanum</i> (A. Massal.) Kőr.	+	
<i>Bacidia arceutina</i> (Ach.) Arnold	+	
<i>Bacidia circumspecta</i> (Norrl. & Nyl.) Malme	+	
<i>Bacidia rosella</i> (Pers.) De Not.	+	
<i>Bacidia rubella</i> (Hoffm.) A. Massal.	+	
<i>Bacidia subincompta</i> (Nyl.) Arnold		+
<i>Bacidina sulphurella</i> (Samp.) M. Hauck & V. Wirth	+	
<i>Biatora efflorescens</i> (Hedl.) Räsänen	+	+
<i>Biatora globulosa</i> (Flörke) Fr.	+	
<i>Bryoria implexa</i> (Hoffm.) Brodo & D. Hawksw.	+	+
<i>Bryoria sophiae</i> (Motyka) Bystrek		+
<i>Bryoria vrangiana</i> (Gyeln.) Brodo & D. Hawksw.		+
<i>Calicium adpersum</i> Pers.	+	+
<i>Calicium salicinum</i> Pers.	+	
<i>Calicium viride</i> Pers.	+	+
<i>Chaenotheca brachypoda</i> (Ach.) Tibell	+	+
<i>Chaenotheca brunneola</i> (Ach.) Müll. Arg.	+	
<i>Chaenotheca furfuracea</i> (L.) Tibell	+	+

Species	Primeval refuge	Regenerative refuge
<i>Chaenotheca trichialis</i> (Ach.) Hellb.		+
<i>Chrysothrix candelaris</i> (L.) J.R. Laundon	+	+
<i>Chrysothrix flavovirens</i> Tønsberg	+	
<i>Fellhanera bouteillei</i> (Desm.) Vězda		+
<i>Gyalecta flotovii</i> Körb.		+
<i>Hypogymnia farinacea</i> Zopf		+
<i>Lobaria pulmonaria</i> (L.) Hoffm.	+	
<i>Micarea elachista</i> (Körb.) Coppins & R. Sant.	+	
<i>Micarea melaena</i> (Nyl.) Hedl.	+	+
<i>Opegrapha vermicellifera</i> (J. Kunze) J.R. Laundon	+	
<i>Opegrapha vulgata</i> (Ach.) Ach.	+	
<i>Pertusaria flavida</i> (DC.) J.R. Laundon	+	
<i>Pertusaria leioplaca</i> DC.	+	+
<i>Pertusaria pertusa</i> (L.) Tuck.	+	+
<i>Pseudoschimatomma rufescens</i> (Pers.) Ertz & Tehler	+	+
<i>Pyrenula nitida</i> (Weigel) Ach.	+	+
<i>Pyrenula nitidella</i> (Flörke ex Schaer.) Müll. Arg.	+	
<i>Ramalina baltica</i> Lettau	+	
<i>Usnea fulvovirens</i> (Räsänen) Räsänen		+
<i>Varicellaria hemisphaerica</i> (Flörke) I. Schmitt & Lumbsch	+	+

type and scale of human intervention, distribution and resources of valuable species), a dichotomic key was created that was used to classify them:

1. Indicator lichen species distinguishing the area as a refuge
  - a. already existed in it as a permanent element of the environment .....**2**
  - b. colonized it in an extraneous manner “from the outside”.....**3**
2. The nature of the area and the distribution of species
  - a. typically small areas, fairly homogeneous, stable habitats, with little environmentally detrimental human pressure, species dispersed ± in the whole area (if aggregated, then on short distances), a high number of potential habitats in all or majority of the area – **primeval (natural)** refuge

- b. usually large-surface areas, very heterogeneous, subject to human activity, species arranged clearly disjunctively throughout the area in aggregates (or as single localities), a limited number of potential habitats (often very distant), a noticeable spread of species around the centers of occurrence – **regenerative (semi-natural)** refuge

3. Etiology of refuge formation

- a. Direct or indirect human pressure – **colonized (anthropogenic)** refuge
- b. Absence or cessation of anthropogenic pressure – **incidental (spontaneous)** refuge.

In view of the results of research carried out in the Krajeńskie Lakeland, three types of refuges were distinguished in this region: primeval, regenerative and colonized refuges. A possibility of existence of another type of refuge was indicated, which was defined as incidental.

#### 4.2. Characteristics of refuges

**Primeval (natural)** – in which significant species of lichens are present, lasting with the remains of ecosystems existing in the environmental space for a long time. The occurrence of endangered, rare species in them is a result of persistence of the remaining (often fragmentary) population, which was present in the area in the past. This is an area which “survived” the common changes introduced by man and “survived” among degraded and transformed ecosystems (Fig. 2). They represent fairly compact areas with a greater or lesser degree of naturalness with a minimal human activity – mostly aimed at sustaining them. This is undoubtedly the most valuable group of refuges. Areas with well-preserved biota (or at least its remnants) are a valuable reservoir of propagules, from where species can spread. Among the determined refuges in the Krajeńskie Lakeland, areas of nature reserves: Osiedle Kormoranów, Sosny, Buczyna, Dęby Krajeńskie, Borek, Zielona Góra were included in this category (Fig. 3). The status of nature reserve protects them from the negative effects of forest management leading to the destruction of trees, where valuable lichens are present. Such areas require mainly maintenance works, protecting the stability of lichen biota habitats.

**Regenerative (semi-natural)** – these are areas with the remnants of naturalness, where there is human intervention, but it is smaller, i.e., not as frequent and/or not as intensive, as in other areas. Biodiversity of such areas is a result of previous changes in the environment caused by, e.g., forest management (logging, thinning, removing fallen trees etc.), the consequence of which is the low diversity of habitats. Examples of such refuges are fragments of stands, in which impoverished (and usually fairly dispersed) biota of valuable lichens still persists (Fig. 4). Their occurrence in the particular area indicates the persistence of favorable combination of environmental factors. In such areas, the process of recolonization is visible, which with appropriate management will still occur there. Due to the possible potential and deficiency of other areas of a refuge nature, they must also be treated as a priority. Lichens associated with this type of refuges are highly endangered, because habitat restoration with an appropriate species composition of biota is very difficult and extended in time. In addition, rare species localities are often involuntarily damaged. As regards the Krajeńskie Lakeland, part of the “Torfowisko Messy” Landscape-Nature Protected Complex, “Uroczyska Złotowskie” Natura 2000 area and the “Struga Białośliwka” Natura 2000 were included into this type of refuges (Fig. 3).

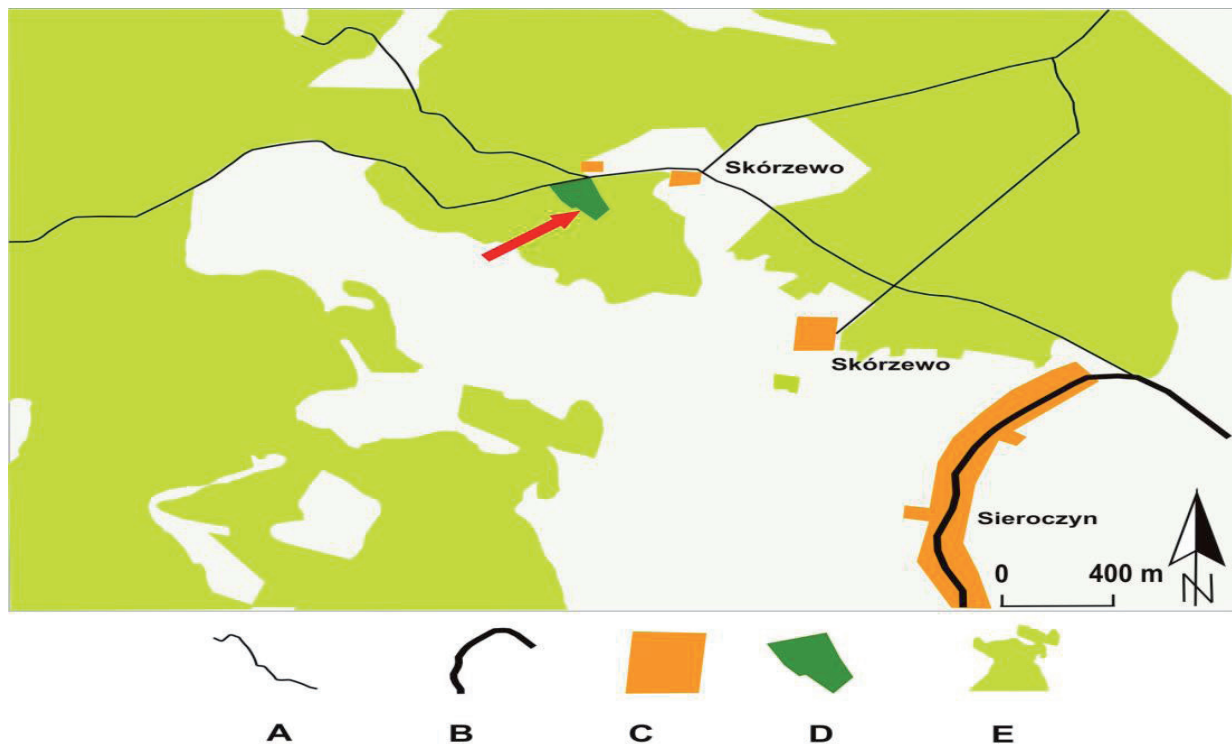


Figure 2. Location of the “Sosny” reserve, as an example of primeval refuge A – unpaved roads, B – roads, C – built-up areas, D – reserve, E – commercial forests (Gruszka, 2014)

**Colonized (anthropogenic)** – formed solely by human activities and entirely subject to his intervention (which is often a condition of their persistence). They are colonized by lichens extraneously from outside the refuge area. Examples of such refuges in the Krajeńskie Lakeland are some roadside tree alleys and valuable taxa associated

with them that include: *Anaptychia ciliaris*, *Ramalina* spp., *Pleurosticta acetabulum*, *Physconia perisidiosa*, *Melanelixia* spp. *Melanohalea* spp.

In view of frequent logging of roadside trees, the role of alleys that have been preserved begins to significantly increase. Most valuable lichenologically sections of the al-



Figure 3. Distribution of primeval and regenerative lichen refuges in the Krajeńskie Lakeland (Gruszka, 2014). Explanations: A – Krajeńskie Lakeland border, B – water bodies, C – forest areas, D – lichen refuge: 1 – “Osiedle Kormoranów” nature reserve; 2 – “Sosny” nature reserve; 3 – “Buczyna” nature reserve; 4 – “Dęby Krajeńskie” nature reserve; 5 – “Uroczyska Złotowskie” Nature 2000 area; 6 – “Torfowisko Messy” Landscape-Nature Protected Complex; 7 – “Struga Białośliwka” Nature 2000 area; 8 – “Zielona Góra” nature reserve ; 9 – “Borek” nature reserve

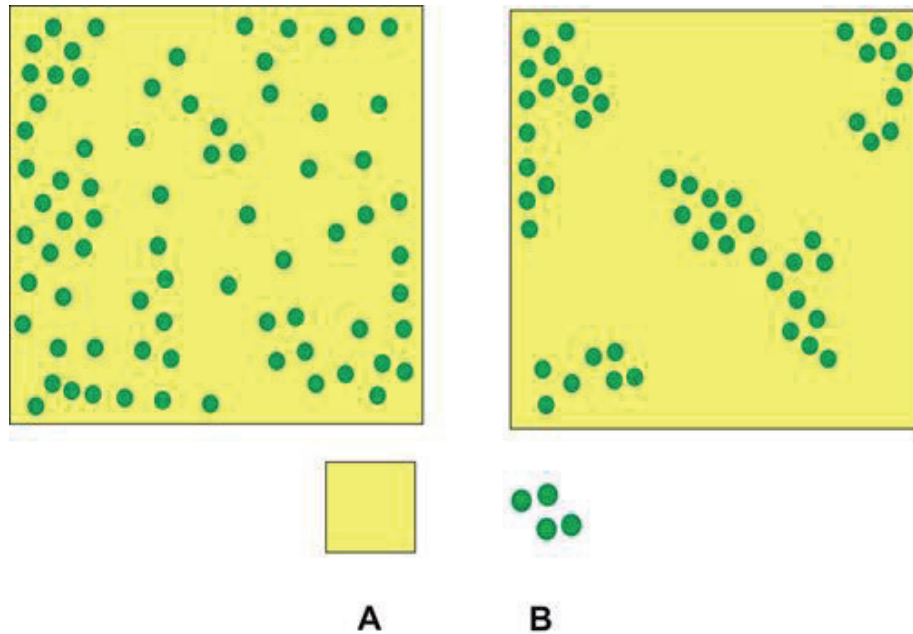


Figure 4. Schematic distribution of lichen indicators localities in the primeval (left) and regenerative (right) refuge A – refuge area, B – lichen indicators localities

leys are located, among others, between Prusionowo and Rozwory (near Debrzno), between Głubczyn and Krajenka, between Dąbrówka and Drożdżenica (near Sępólno Krajeńskie), between Więcbork and Jastrzębiec, between the villages of Szczytno and Lisewo (near Przechlewo). The only lichen refuge of this type subject to legal protection, as a natural monument is almost a two-kilometer-long alley (Fig. 5) between Powalki and Jarcewo in Tuchola Forest (Lipnicki, 2012). Previous attempts to protect other, most valuable lichenologically alleys or fragments thereof in the region of the Krajeńskie Lakeland were unfortunately not approved by the representatives of local authorities and failed, despite the submission of relevant applications and proposals (Gruszka, 2012).

**Incidental (spontaneous)** – as opposed to anthropogenic, the impetus to the formation of incidental refuge is not direct human activity, but its absence or cessation, which created suitable conditions for the colonization of the area by lichens. This group includes an area originally devoid of lichens, in which changes have occurred enabling their emergence *de novo*. It was assumed that spontaneously appearing wooded lands could be an example of such refuge.

However, lichenological studies in the Krajeńskie Lakeland did not demonstrate that mid-field patches of trees constitute lichen biota refuges. In fact, the whole core of biota was represented by a widespread, ubiquitous species resistant to human pressure (including *Lecanora conizaeoides*, *Hypocenomyce scalaris*, *Hypogymnia physodes*,

*Parmelia sulcata*). Therefore, no outstanding and distinctive lichenological qualities were found. In addition to poor species representation, lichens were observed only in marginal, better lit parts, where the light access was greater. High canopy shading and a very strong development of the understory layer prevented the development of epiphytic lichens in the internal parts of trees. Hence this type of refuge has not been found during the study.

## 5. Discussion

The reference to the results of other studies related to this issue is difficult, because the lichenological literature is scarce in terms of detailed studies on lichen refuges, as a stand-alone subject. The results of research carried out in the Krajeńskie Lakeland confirm that this is currently a matter of particular importance. For in the process of broadly understood anthropogenic changes and lichen protection proposals submitted for a long time (including Motyka, 1934; Szwejkowski & Tobolewski, 1959; Lipnicki, 1988, 1991; Fałtynowicz, 1992), refuges have played and will play an increasingly important role in preserving biodiversity (Cieśliński & Czyżewska, 2002; Cieśliński, 2009), or as a source of propagules, from which lichens will be able to spread (Doering & Coxson, 2010). Białowieża Forest (Cieśliński & Czyżewska, 2002; Kościelniak, 2008; Golubkov et al., 2012), Bieszczady (Kościelniak, 2009,



Figure 5. Roadside tree alley between the villages Powalki and Jarcewo as an example of anthropogenic refuge (Photo by Wojciech Gruszka)

and literature cited therein) and Tuchola Forest (Lipnicki, 2012) are among the most important national centers of lichen species diversity. Examples of centers at the regional level include the following reserves: Budzisk, Starożyn, Borki, Warmia Forest, Krutynia, Zagożdżon (Czyżewska et al., 2002; Czyżewska & Cieśliński, 2003).

In contrast to the provided definition (Mirek et al., 2005), it was assumed that lichen refuge does not necessarily have to be the area with semi-natural characteristics (at least), but even the object completely shaped by man, on which valuable taxa remain. The most important for the area is the protection of populations of rare species. Therefore, with respect to lichens, lower naturalness of such an object should not be a disqualifying factor.

However, the naturalness of ecosystems is a particularly important factor (Cieśliński & Tobolewski, 1988; Cieśliński et al., 1996; Dettki & Esseen, 1998; Lesica et al., 1991; Czyżewska & Cieśliński, 2003; Kubiak & Sucharzewska, 2012 after Kubiak, 2013), and should be taken into account as a parameter at the beginning of searching for lichen refuges. This is due to the fact that the process of renaturalization of isolated forest fragments on the post-

agral land occurs only with the inflow of diaspores from the outside. First, the available habitats are occupied by species with wide tolerance. This regularity was observed in the case of vascular plants (Woziwoda, 2006), but it is also related to the spread of lichens, as none of the examined wooded lands contained typical forest species or species belonging to the relics of primeval forests. On the other hand, in the area of the Krajeńskie Lakeland, roadside tree alleys and their associated threatened taxa (*Anaptychia ciliaris*, *Ramalina* spp., *Pleurosticta acetabulum*, *Physconia perisidiosa*) are undoubtedly examples of refuges, which are not of natural origin (in this case, they are not the forests remnants). Some of these species are still relatively common, but due to numerous loggings and air pollution (Fałtynowicz, 1992), their degree of extinction danger increases. It should be noted that each species has a number threshold, below which a population is facing the threat of extinction from year to year (Wilson, 1999).

Considering the fact that the most important and most effective method is protection in situ (Cieśliński & Czyżewska, 2002), and the fact that the refuge problem is discussed to a small extent in the lichenological litera-



ture, there is a need for further research. These investigations should identify new refuges of lichens and include stability analysis and transformation of lichen biota in areas already designated as refuges.

The author realizes that theses and proposals contained in this publication are novel and not exhaustive. The author counts for their constructive assessment and verification, and hopes for a substantial discussion, which will result in the formulation of new proposals complementing the subject.

## 6. Conclusions

The following conclusions can be drawn from the results of lichen biota analysis and the discussion presented in this paper:

1. In the area of refuge, it is necessary to examine the indicated area in order to identify the most valuable species, which are indicators of the refuges.
2. The most suitable areas for refuge typing are forest areas that are distinguished by the presence of natural-like fragments with old trees.
3. Each refuge should be examined individually as it relates to its size, character, human influence, the degree of isolation, regeneration capacity.
4. Due to the fact that the problem of the refuge is to a lesser extent taken into account in lichenological literature, further research seems to be justified in this regard.

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