CROSS-BORDER ECOLOGICAL NETWORK FOR THE SPECIES DEPENDENT ON BROAD-LEAVED ANCIENT AND VETERAN TREES

Daugavpils University
Nature Studies and Environmental Education Centre
Uldis Valainis, Maksims Balalaikins, Inese Gavarāne
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INTRODUCTION

Development of ecological networks is a part of European Union policy (Bern Convention, Habitats Directive, Natura 2000). The networks must ensure complete functionality of Natura 2000 sites and meet the requirements laid down by Article 17 of the Habitats Directive. Cross-border Ecological network for the species dependent on broad-leaved veteran trees will deliver a significant contribution to this aim and will help to ensure long term survival of the target species and habitats. The Lithuanian – Latvian ecological network plan was created by using hermit beetle *Osmoderma barnabita* as an umbrella species – areas in which it is necessary to ensure the continued functioning of ecological processes and the viability of species populations within a wider landscape of semi-natural and managed areas have been defined. In the last decade, studies of hermit beetles in Latvia and Lithuania have become more active, revealing many new localities of the species. As a result, the sustainability of the identified metapopulations has also become relevant, combining the problems of genetic diversity, isolation and the availability of suitable habitats for these metapopulations. (Bāra et al. 2015., Telnov et al. 2016., Telnov & Matrozis 2012, Šablevičius 2011). However, before planning the conservation of the species, it is important to see where the metapopulations are located and where the gaps in the gene flow between them occur. This document will serve as a basis for conservation planning of *O. barnabita* and other saproxylophagous species in future.

To take into account global-scale peculiarities of species distribution, while planning the development of Ecological network plan for Lithuania, data from LIFE+ project EREMITA MEADOWS, realized in Latvia, has also been used – data was obtained in the elaboration of Ecological Network Plan for Assurance of Conservation of Saproxylophagous Beetles. During the development of the Ecological network plan for Lithuania, potentially suitable territories for species occurrence were selected based on criteria elaborated within the LIFE+ EREMITA MEADOWS project. In the framework of cooperation the developed networks are connecting and forming one cross-border ecological network, thus ensuring the possibility to plan species conservation measures on the international scale.

Ecological network plan has been prepared based on known and potential habitats of *O. barnabita* by using results from:

1) analysis of existing biological data in national spatial databases;
2) inventory of the species in the field (project territories);
3) genetic analyses of the target species;
4) GIS modelling and interpolations.

Within the framework of the project, an interactive map has been created, which cartographically depicts all identified potentially suitable habitats of *O. barnabita*. Such an instrument will facilitate the planning of species protection and habitat management measures in specific areas.

IMPORTANCE OF BROAD-LEAVED VETERAN TREES IN NATURE CONSERVATION

Old broad-leaved trees – often referred to as ancient or veteran – have always attracted attention of interest in them from an ecological and conservation perspective. Ancient and veteran trees (see Figure 1) are defined as being of interest biologically, culturally or aesthetically because of their age, size or condition (Read 2000). The majority of their associated species (e.g. invertebrates) occur in the canopy and in or on the decaying parts of the wood and bark of branches, stem and roots. Also, the intact surface of living bark can support a rich assemblage of epiphytes, including lichens and bryophytes, together with a wide range of associated specialist invertebrates (Butler et al. 2001; Horak 2017; Ranius & Jansson 2000; Rose 1991; Zapponi 2017).

Hollows in standing living trees in forests and open landscapes are one of the most relevant microhabitats for saproxylic insects (Alexander 2008; Müller and Bütler 2010; Müller et al. 2014). They can occur in different parts of the tree and provide a stable abiotic environment and long-lasting resources to a complex assembly of species from different trophic guilds (Micó 2018; Ranius et al. 2009a) that are influenced to a fairly high extent by the history of management that has taken place in each woodland (Ranius et al. 2009a, b; Stoklandet et al. 2012; Sebek et al. 2013). Hollows in large trees could remain suitable for the specialised invertebrate fauna for hundreds of years (Dajoz 2000). Such hollow trees are therefore expected to have many well adapted species to this kind of stable habitat and therefore demonstrating low dispersal abilities (Nilsson and Baranowski 1997).

Figure 1. **Veteran trees provide nutrition and shelter to a whole ecosystem of species; the species richness a tree supports generally increases with age (Photo: U. Valainis)**

The loss of veteran trees in woodlands and open landscapes would lead to the loss of saproxylic organisms – an important part of biodiversity (Alexander 2008; Horak 2017). Forest reduction and fragmentation, climate change and the abandonment of cultural practices are causing a decrease in availability of trees with hollows in natural and semi-natural habitats, threatening the survival of the species that depend exclusively on them. Conservation and retention of hollowed trees has crucial importance for forest diversity maintenance worldwide; thus, actions should be urgently adopted (Micó 2018; Miklín and Čížek 2014).

OSMODERMA BARNABITA AS AN UMBRELLA SPECIES

Some organisms are recognized in conservation biology as umbrella species – habitat management for such species thus protects and shelters a range of other species that require similar conditions (Caro et al. 2010; Roberge and Angelstam 2004; Breckheimer et al. 2014). Species of the genus *Osmoderma* are defined as an umbrella species for the protection of tree hollow communities (Audisio et al. 2007; Carpaneto et al. 2015; Micó 2018; Ranius 2002a, 2002b), because measures taken to conserve these species will also favour many other inhabitants of hollows.

Represented by four species, the genus *Osmoderma* is one of the most endangered groups of saproxylic beetles in Europe (Audisio et al. 2009). Among the insect inhabitants of veteran trees, the beetle genus *Osmoderma* forms a flagship taxon of invertebrate conservation (Audisio et al. 2007; Landvik et al. 2016a; Nieto & Alexander 2010). In Lithuania and Latvia genus *Osmoderma* is represented by one species – *O. barnabita* (see Figure 2). This species is particularly vulnerable to the loss of veteran trees, as its larvae requires tree cavities (Ranius and Nilsson 1997; Landvik et al. 2016a) where it occurs in nutritious wood mould substrate (Landvik et al. 2016a*). Osmoderma* species are well adapted to this kind of stable habitat and therefore they are demonstrating low dispersal abilities (Ranius & Hedin 2001; Dubois & Vignon 2008; Hedin et al. 2008; Svenson et al. 2011; Oleksa et al. 2013; Valainis et al. 2015). Due to the low dispersal capacities, *Osmoderma* species are considered as ones of the most threatened invertebrates in Europe.

Figure 2. ***Osmoderma barnabita* (Photo: U. Valainis)**

The primary habitat of hermit beetles consisted of broadleaf old-growth forests with an abundance of hollow trees and dead wood (Maurizi et al. 2017; Oleska et al. 2007). Due to the alteration of natural forests by commercial management, the number of trees with hollows, necessary for larval development, reduced – the hermit beetles disappeared in many suitable broadleaf forests, therefore the species survival now depends on artificial habitats outside of forests, such as urban parks, wooded grasslands (see Figure 3), old orchards and tree rows along the roads (Vignon et al. 2004; Ranius et al. 2005; Oleksa 2007; Carpaneto et al. 2010). In many aspects hermit beetles are considered as an oak-dependent species (Ranius et al. 2005; Ranius et al. 2009a, 2009b, 2009c; Landvik et al. 2015), while limetrees (*Tilia* spp.) were mentioned as the second most important host tree (Oleksa 2007). In many regions, willows (*Salix* spp.), ashes (*Fraxinus* spp.), elms (*Ulmus* spp.), beech (*Fagus sylvatica*), aspen and poplars (*Populus* spp.), maples (*Acer* spp.), hornbeam (*Carpinus betulus*), common alder (*Alnus glutinosa*) and fruit trees (*Prunus* spp., *Pyrus* spp., *Malus* spp.) are also indicated as suitable host trees (Ranius et al. 2005; Tauzin 2005; Dubois et al. 2009; Chiari et al. 2012; Sebek at al. 2012; Kadej et al. 2016; Maurizei et al. 2017).

Figure 3. **Fennoscandian wooded meadows (6530*) is one of the most suitable habitats for *O. barnabita* (Photo: U. Valainis)**

ECOLOGICAL PLANNING AS AN INSTRUMENT IN PROVISION OF INTERESTS OF NATURE CONSERVATION

Habitat connectivity plays an important role in population viability because it ensures gene flow and facilitates migration, dispersal, and re-colonization (Théau et al. 2015). Ecologists and biologists recommend strengthening the connectivity between fragmented habitats to create a coherent large-scale ecosystem as a solution to enable threatened species to survive (Rayfield et al. 2011; Garcia-Feced et al. 2011). Thus, ecological networks, with the function of strengthening connectivity among habitat patches, are increasingly being used to meet the needs of biodiversity conservation (Ignatieva et al. 2011; Pryke and Samways 2012; Mossman et al. 2015). Establishing ecological networks is currently one of the main objectives of landscape ecology and nature and landscape protection (Miklós et al. 2019). Nowadays it is clear that ecological networks are essential to conserve biodiversity and to reverse the fragmentation process of landscapes and habitats. Ecological networks are also important for people and society because their concept appeals to the general public and policy-makers (Gonzalez et al. 2017). It also provides a framework for stakeholder involvement and supports the Ecosystem Approach, as endorsed under the Convention on Biological Diversity.

Nowadays development of high-quality planning documents is unimaginable without application of opportunities given by Geographic Information System (GIS). Use of GIS allows to plan species conservation not only in a frame of one specific territory, but on a bigger scale as well. By applying information from various geographic databases, it is possible to identify habitats appropriate for each species, to define potential risks and model various development scenarios, by taking as basis species ecological demands to surrounding environment and habitats.

PRINCIPLES AND SOURCES OF SELECTION OF HABITATS POTENTIALLY SUITABLE FOR *OSMODERMA BARNABITA*

All available databases were used while developing the Ecological network plan for the species-dependent on the broad-leaved ancient and veteran trees. The data selection included all available geospatial data that could indicate the occurrence of old broadleaf trees in both forests and opened landscapes. In order to specify the selection criteria *Osmoderma barnabita* was chosen as the main target species. This species has very high environmental requirements and reflects the general environmental quality requirements of other umbrella species.

The following databases were used:

- ✓ Latvian State Forest Service © State Register of Forests, database updated in 2017;
- ✓ Lithuanian State Forest Service © State forest cadastre;
- ✓ Vector data layer of umbrella species localities © prepared by The Nature Conservation Agency 2020 (Latvia);
- ✓ Vector data layer of umbrella species localities © prepared by Nature observation website *dabasdati.lv* 2020 (Latvia);
- ✓ Ministry of Environment of the Republic of Lithuania © The Informational System for Protected Species;
- ✓ Vector data layer of wooded meadows polygons © prepared by The Nature Conservation Agency 2020 (Latvia);
- ✓ State service for protected areas © The Republic of Lithuania protected areas state cadastral data;
- ✓ Vector data layer of ancient trees localities © prepared by The Nature Conservation Agency 2020 (Latvia);
- ✓ Vector data layer of the manor and parks localities © prepared by The Latvian Geospatial Information Agency 2020 (Latvia);
- ✓ Gintaras Rumšas © Lithuanian Manors 2018;
- ✓ Lithuanian State Forest Service © Woodland Key Habitat inventory of Lithuania 2009;
- ✓ Ministry of Environment of the Republic of Lithuania © Natural habitats of EU importance 2015;
- ✓ Lithuanian Fund for Nature © 2020.

The hexagonal tessellation has been used for habitats suitability identification for the species dependent on old broad-leaved trees. The dimensions of the hexagon were based on proved information on the flight distance of the hermit beetle, available in the literature. The maximum known *O. barnabita* relocation distance is 2.09 km, which was fixed by the re-capture method (Valainis et al. 2015). Thus, the distance of 2.09 km was taken as the length of one edge of the hexagon, which also corresponds to the distance from the center of this figure to each of its angles (see Figure 4). The hexagon, as the basis of the network, was taken because it has some advantages from being closer in shape to circles than squares are. Therefore a hexagon has a shorter perimeter than a square of equal area, which potentially reduces bias due to the edge effects (Krebs 1989). The value based on the developed criteria of habitat suitability for the hermit beetle occurrence was assigned to each hexagon.

Three main criteria were used to assess the probability of occurrence of the species in the territory of hexagons:

- Criteria 1 – broad-leaved tree species suitability for *O. barnabita*.
- Criteria 2 – age of broad-leaved tree species suitable for *O. barnabita*.
- Criteria 3 – localities of other umbrella species inhabiting old broad-leaved trees.

The effect of each criteria was evaluated separately in both open areas and forest lands. For assigning a value to a specific hexagon, the total value of habitats in forest areas and the full value of open area habitats were compared, which is higher. After comparing one, the most significant value was assigned to the hexagon. Thus, it was established for each hexagon, whether the most favourable conditions for *O. barnabita* were found in the forest or open landscape. According to this system, the maximum value that can be assigned to one hexagon are 12 points.

Figure 4. **The principle of hexagon formation**

Evaluation of forest areas

- **CRITERIA 1.** Evaluation of hermit beetle potential habitats in forest stands – based on dominant tree species in a forest stand, but in the case of oak – any representation in the emergent layer of forest stand. If the hexagon contains several suitable forest sites for the hermit beetle, the value of one most suitable forest site is taken into account. The principle of value assignment by Criteria 1 is shown in table 1.

Table 1. **The principle of value assignment by Criteria 1.**

Factor (tree species in forest stand)	**Numeric value (shows the possibility of *O. barnabita* correlation with a specific tree species**	**Notes**
Oak	4	Value is assigned **for the presence** of the species in the emergent layer.
Lime tree	3	Value is assigned **for the dominant tree** in the emergent layer.
Maple, ash, elm, beech, hornbeam	2	Value is assigned **for the dominant tree** in the emergent layer.
Willow	1	Value is assigned **for the dominant tree** in the emergent layer.

➢ **CRITERIA 2.** Evaluation of tree age correlation with the possibility of hermit beetle habitat in forest stands. The value of one of the oldest forest stand is taken into account when assigning value to the hexagon. The principle of value assignment by Criteria 2 is shown in table 2.

Table 2. **The principle of value assignment by Criteria 2.**

Factor (diameter of tree species in forest stand)	**Numeric value (shows the possibility of *O. barnabita* occurrence correlation with the age of the tree)**
Oak	
Any oak representation in an emergent layer (> 251 years)	4
Any oak representation in an emergent layer (201 – 250 years)	3
Any oak representation in an emergent layer (151 – 200 years)	2
Any oak representation in an emergent layer (121 – 150 years)	1
Other suitable trees	
Lime tree, maple, ash, elm, beech, hornbeam or willow dominant (> 166 years)	4
Lime tree, maple, ash, elm, beech, hornbeam or willow dominant (131 – 165 years)	3
Lime tree, maple, ash, elm, beech, hornbeam or willow dominant (101 – 130 years)	2
Lime tree, maple, ash, elm, beech, hornbeam or willow dominant (66 – 100 years)	1

➢ **CRITERIA 3.** Evaluation of localities of umbrella species inhabiting old broad-leaved trees in forest stands. Four factors are used to evaluate the umbrella species habitat suitability for hermit beetle:

- species has a low dispersal capacity;
- a relationship with oaks or lindens (the most suitable trees for the *O. barnabita*) have been established;
- species prefers open, “sunlit” habitats;
- species at one of the development stages is associated with cavities/hollows.

If there is more than one locality of umbrella species in a hexagon, only the value of the most valuable species is taken into account. Each umbrella species is assigned one point for compliance with each of the factors. The principle of umbrella species value assignment is shown in table 3.

Table 3. **The principle of umbrella species value assignment.**

Species	**1st factor**	**2nd factor**	**3rd factor**	**4th factor**	**The total value**
Mammalia					
Myotis nattererii	0	0	0	1	1
Myotis brandtii	0	0	0	1	1
Glis glis	0	0	0	1	1
Aves					
Strix aluco	0	0	0	1	1
Insecta					
Osmoderma barnabita	1	1	1	1	4
Protaetia lugubris	1	0	0	1	2
Gnorimus variabilis	1	1	1	1	4
Elater ferrugineus	1	1	1	1	4
Prionicus ater	1	1	0	1	3
Pseudoscorpiones					
Anthrenochernes stellae	1	1	1	1	4
Fungi					
Hapalopilus croceus	1	1	1	0	3
Grifola frondosa	0	1	0	0	1
Xylobolus frustulatus	1	1	1	0	3
Inonotus dryophilus	1	1	0	0	2
Perenniporia medulla–panis	1	1	0	1	3
Fistulina hepatica	1	1	0	0	2
Lichens					
Sclerophora coniophaea	1	1	1	0	3
Chaenotheca phaeocephala	1	1	1	0	3
Bactrospora dryina	1	1	0	0	2
Sclerophora farinacea	1	1	1	0	3
Chaenotheca cinerea	1	1	1	0	3
Chaenotheca hispidula	1	1	1	0	3
Pertusaria flavida	1	1	1	0	3
Calicium quercinum	1	1	1	0	3
Calicium adspersum	1	1	1	0	3
Ramalina baltica	1	1	1	0	3
Sclerophora farinacea	1	1	1	0	3

Evaluation of open areas

- **CRITERIA 1.** The presence of potentially suitable habitat for *O. barnabita* in the open area of the hexagon:
    - Parks and manor houses with surrounding parks;

- Fennoscandian wooded meadows (6530*).

For parks, wooded meadows, the same value (4 points) is assigned, which does not add up if both habitats are present in the hexagon.

- **CRITERIA 2.** The presence of potentially suitable ancient trees for *O. barnabita* in the open area of the hexagon. The value assigned to the hexagon does not depend on the number of trees found within its territory. The presence of a factor is assigned a value of 4 points.

- **CRITERIA 3.** Evaluation of localities of umbrella species, the species whose requirements associated with old broad-leaved trees. Four factors are used to evaluate the umbrella species habitat suitability for hermit beetle. The calculation is the same as for species in the forest habitats.

Steps of data selection and processing:

- Characteristic quantities of the selected habitats potential for hermit beetle occurence are expressed in ArcGIS Pro model builder (selected by atribute using SQL query expression).
- The hexagon network with a total area of 132347 km², consisting of hexagons (11,35 km² each), was developed for the entire territory of Latvia and Lithuania using the © ESRI software ArcGIS Pro geoprocessing tool (Generate Tessellations).
- Geoprocessing tools have been added to the model builder – layers selected by attributes for which SQL queries expressions have been created, allowing to select only the suitable objects, for example, by the dominant tree, age, umbrella species, wooded meadow and others.
- From a geoprocessing tool – the copy function was used: exporting data from the databases. Only data that corresponded to specific factors was exported.
- The function of selecting a layer by location was used to determine the location of certain polygons or points in a particular hexagon.
- For selected hexagons value assignation, field calculation tools were used.

OSMODERMA BARNABITA POTENTIAL DISTRIBUTION MODEL IN LITHUANIA AND LATVIA

Development of a map based on hexagons to identify habitats suitable for *O. barnabita*

The assessment of habitat suitability for species dependent on broad-leaved trees was based on the obtained values of the hexagon. The maximum possible value for a hexagon are 12 points, which is the sum of the maximum values in each of the three matching criteria (the presence of broad-leaved trees, age of broad-leaved trees and umbrella species associated with these trees). When creating a graphical display of hexagons on the map, according to their value, a certain colour intensity was assigned, increasing the colour intensity with an increase in the value assigned to the hexagon. An example of a map on a local scale with created hexagons is shown in Figure 5. For a cartographic representation of hexagon values at the scale of Lithuania and Latvia see Figure 6.

To get a general idea of the occurrence possibilities of *O. barnabita* in a particular hexagon, a simplified map was created where all hexagons were divided into three categories depending on suitability for the species (see Figure 7). The following categories were used:

- 0 to 3 points – low possibility of *O. barnabita* occurrence;
- 4 to 8 points – medium possibility of *O. barnabita* occurrence;
- 9 to 12 points – high possibility of *O. barnabita* occurrence.

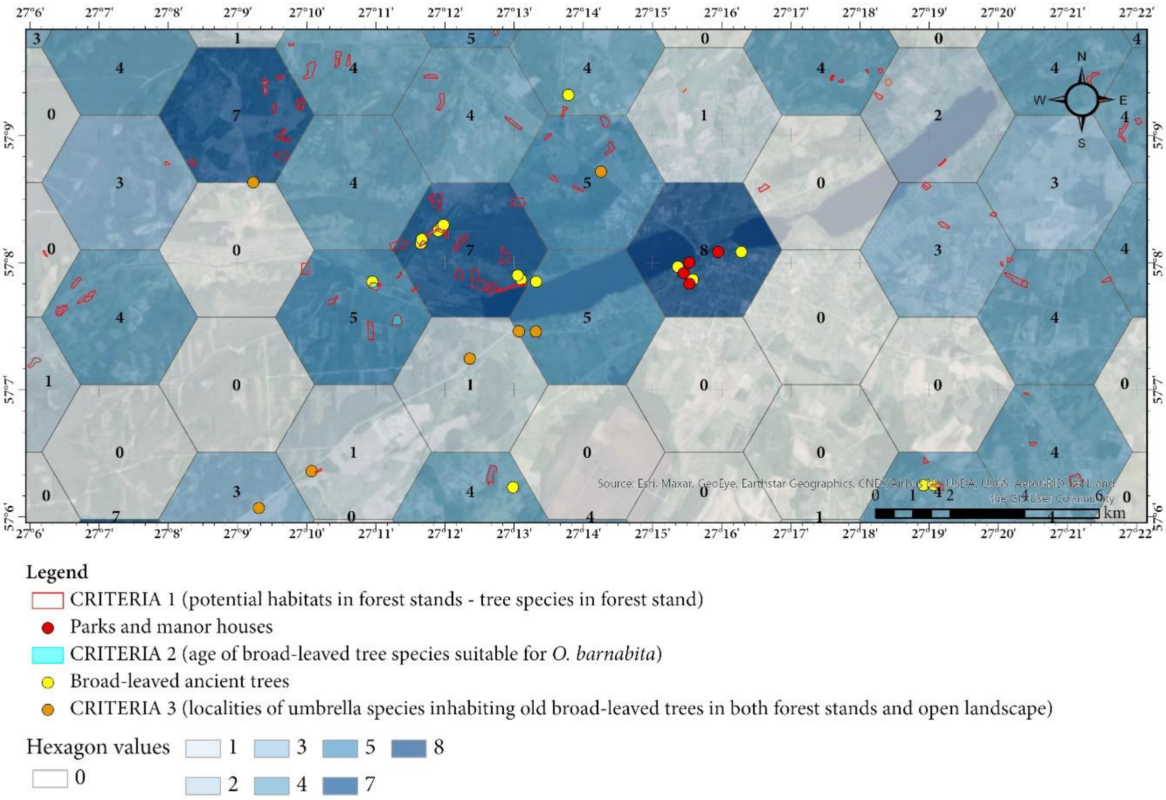

Figure 5. **Hexagon value formation example on a local scale**

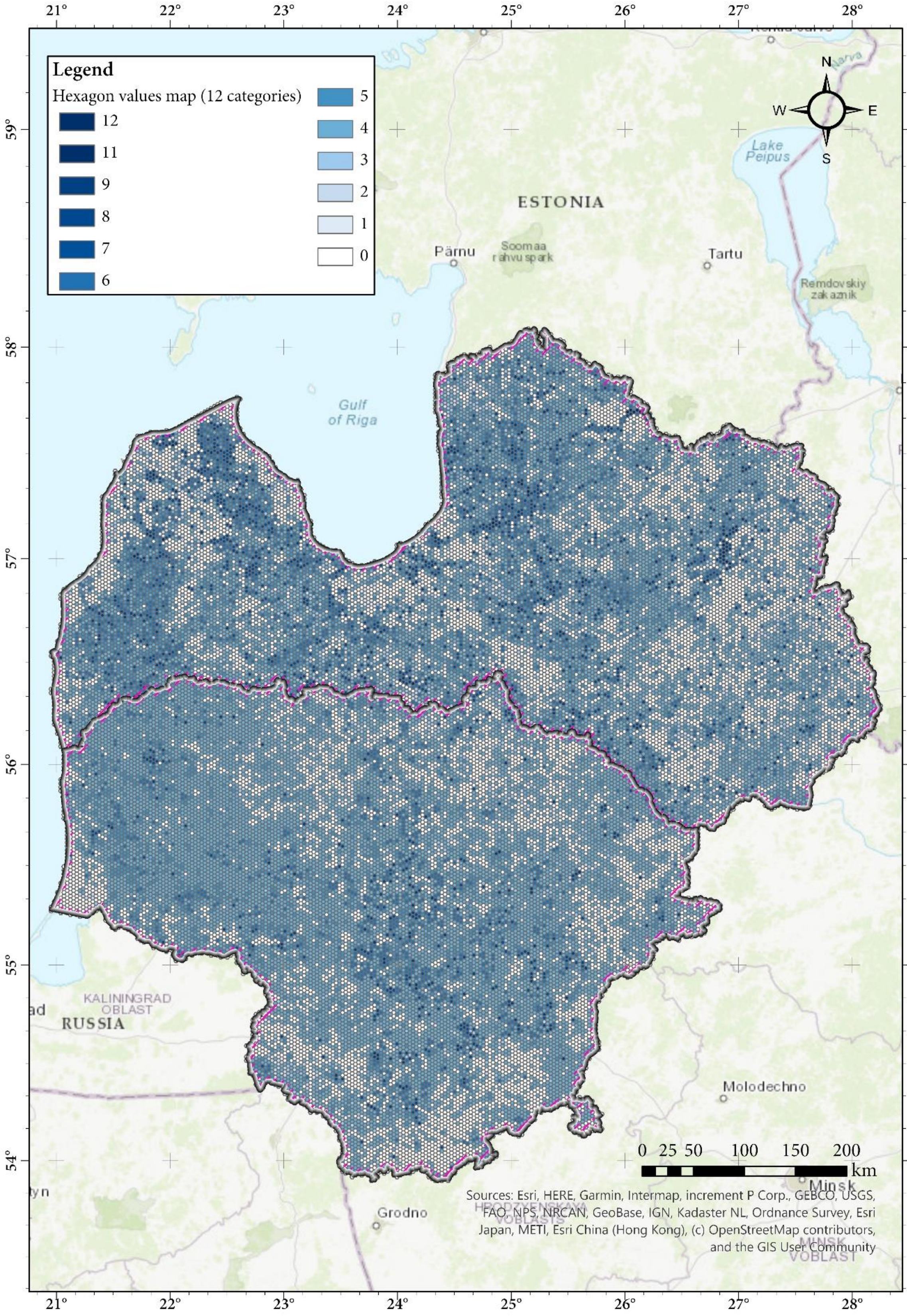

Figure 6. **Cartographic representation of hexagon values at the scale of Lithuania and Latvia**

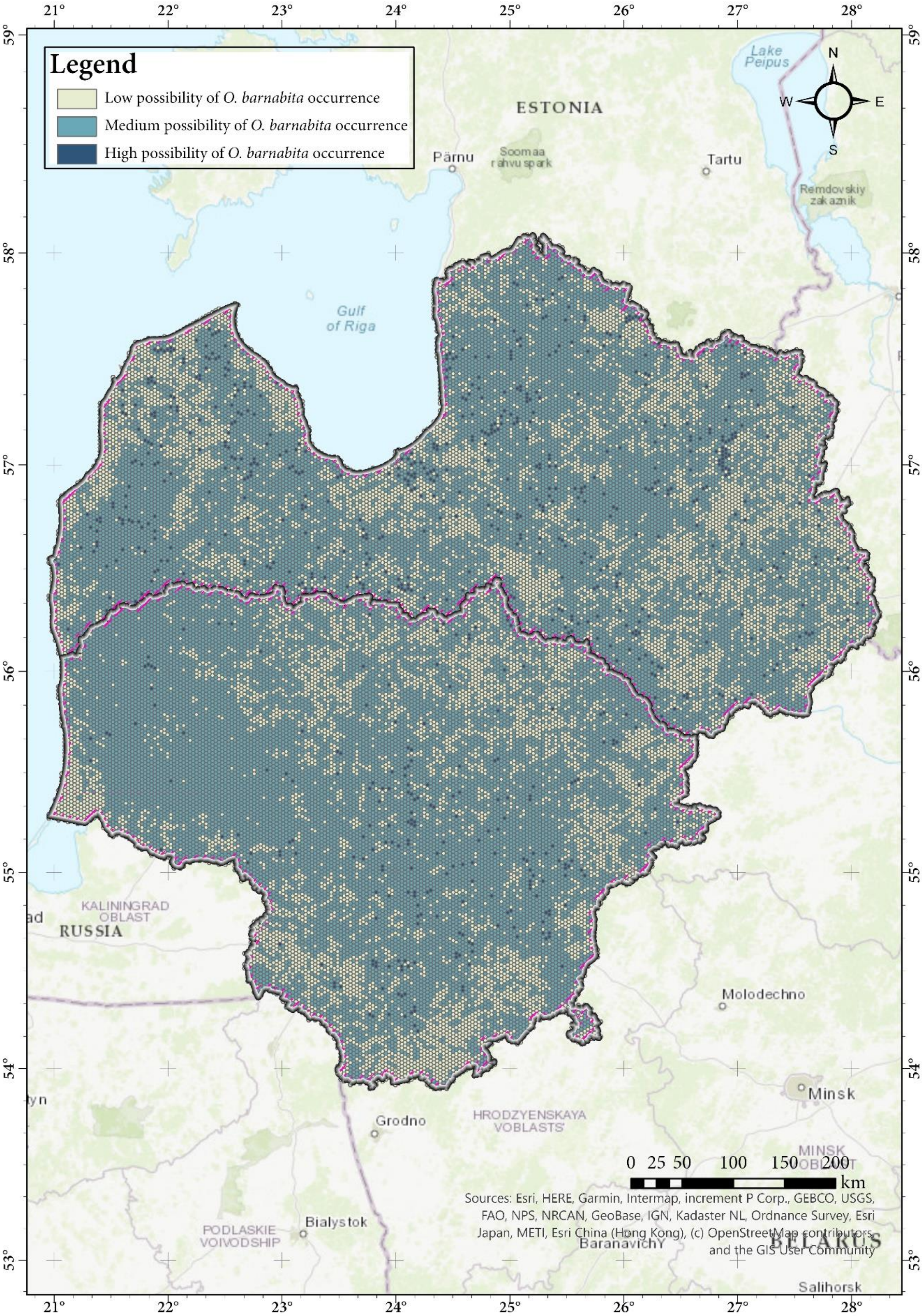

Figure 7. **Cartographic representation of hexagon values at the scale of Lithuania and Latvia (assessment of hexagons in 3 categories)**

Creation of an interactive map and the review of available GIS data layers

For a detailed survey of the territory of Latvia and Lithuania and planning of management measures, an interactive map has been created. To comply with data protection rules, two versions of an interactive map were created: the first one with in free access, where general information is published, and the second version, with access for specialists of nature conservation and environmental protection, which contains detailed information.

The public access version contains the following data:

- Hexagon values map (12 categories);
- Hexagon values map (3 categories);
- Ecological network data:
    - *O. barnabita* localities;
    - Core areas for *O. barnabita*;
    - Ecological corridors between the core areas;
    - Gaps between *O. barnabita* populations;
    - Results of *O. barnabita* populations genetic analysis.

Website address:
https://gis.biology.lv/portal/apps/webappviewer/index.html?id=f79a86a88c684596af52f48305932b1c

The version available to specialists of nature conservation and environmental protection contains the following data:

- Hexagon values map (12 categories);
- Hexagon values map (3 categories);
- The data selected for the identification of the first criteria: suitable broad-leaved trees for *O. barnabita* in forest stands;
- Parks and manors;
- EU protected habitat Fennoscandian wooded meadows (6530*);
- The data selected for the identification of the second criteria: age of suitable broad-leaved trees for *O. barnabita* in forest stands;
- Broad-leaved ancient trees in open areas;
- The data selected for the identification of the third criteria: localities of umbrella species inhabiting old broad-leaved trees in both forest stands and open landscape;
- Ecological network data:
    - *O. barnabita* localities;
    - Core areas for *O. barnabita*;
    - Ecological corridors between the core areas;
    - Gaps between *O. barnabita* populations;
    - Results of *O. barnabita* populations genetic analysis.
- Additional factors for planning species protection measures in ecological corridors:
    - Natura 2000 territories;
    - EU protected forest habitats 9180* (Tilio-Acerion forests of slopes, screes and ravines), 9020* (Fennoscandian hemiboreal natural old broad-leaved

deciduous forests) and 9160 (Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli);

- Woodland key habitats layer with large-dimensional broadleaf trees (available only for Lithuania);
- Protected alleys (available only for Latvia);
- Urban territories.

Website address:
https://gis.biology.lv/portal/apps/webappviewer/index.html?id=edc3bdd10921491895cabfc7ac9856cc

METHODOLOGY FOR IDENTIFYING THE BASIC ELEMENTS OF THE ECOLOGICAL NETWORK

For identification of Ecological network basic elements was used the Kernel Density Estimations (KDE) method. Kernel density estimators are widely applied to area-related problems in ecology, from estimating the home range of an individual to estimating the geographic range of a species (Fleming et al., 2016; Pengshan et at., 2016). Kernel Density tool calculates the density of point features around each output raster cell. Within this project the point has been assumed as the center of each hexagon. In modelling, the value of each hexagon (from 1 to 12) has been taken into account – the value has been allocated based on the probability of occurance of *O. barnabita* within specific hexagon. The KDE results were divided into 12 levels by the natural break classification method (see Figure 8).

Areas with the highest probability of species occurrrence according to the KDE method were defined in the Ecological Network as Core areas. The areas between the core sites with the highest probability of identifying potentially suitable habitats for the species were identified as ecological corridors (see Figure 9). Connecting the core areas with corridors, plots with a low probability of the hermit beetle occurrence were identified. These territories were defined as gaps within the ecological corridors on a global scale. These gaps disrupt gene flow between metapopulations, which leads to a reduction in the genetic diversity. The formation of such gaps should be prevented by the creation of artificial cavities or by veteranisation of trees potentially suitable for the species.

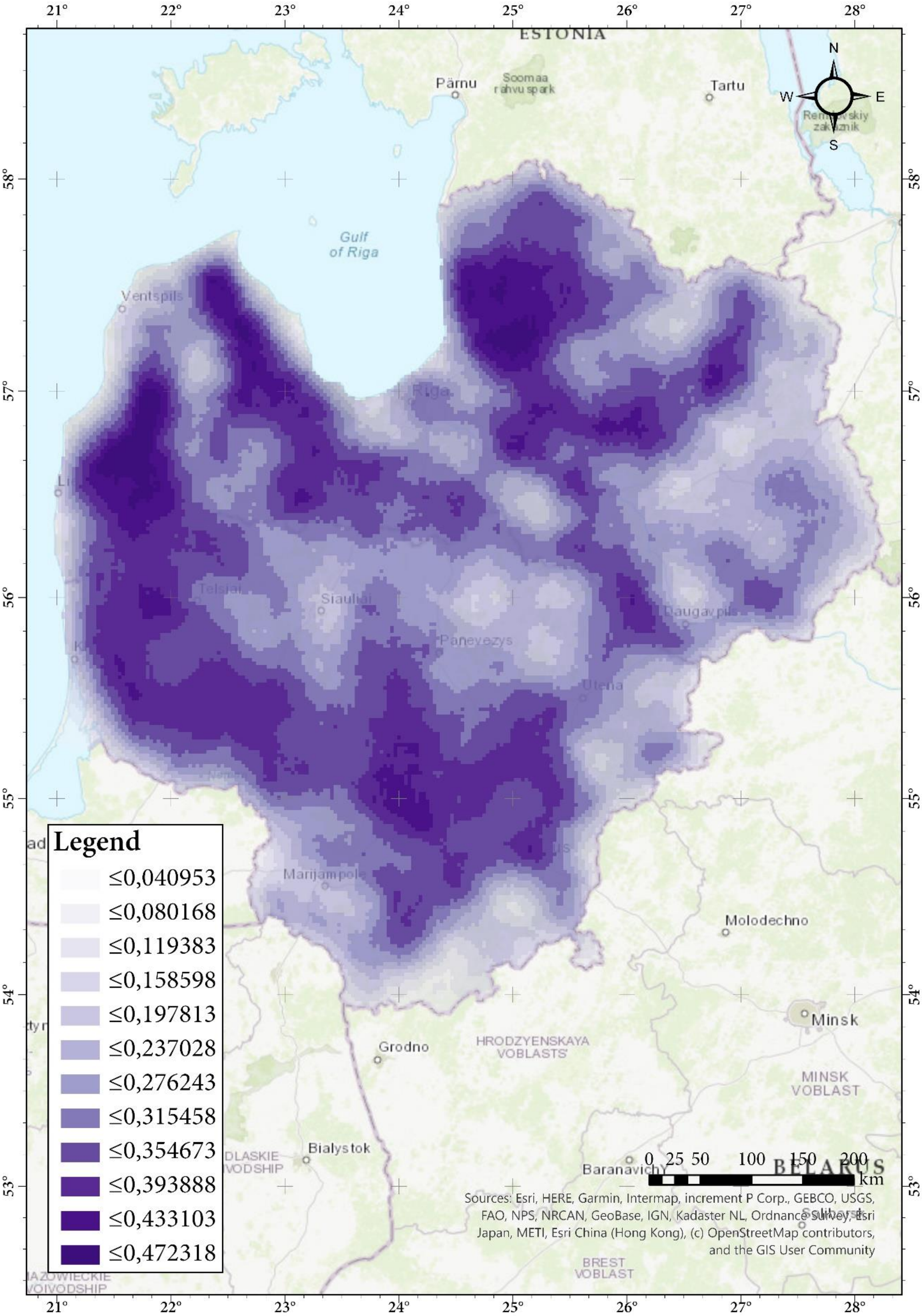

Figure 8. **Network Density Estimation computed over hexagons grid cells values in developed *O. barnabita* potential distribution model in Lithuania and Latvia (2090 m Bandwidth)**

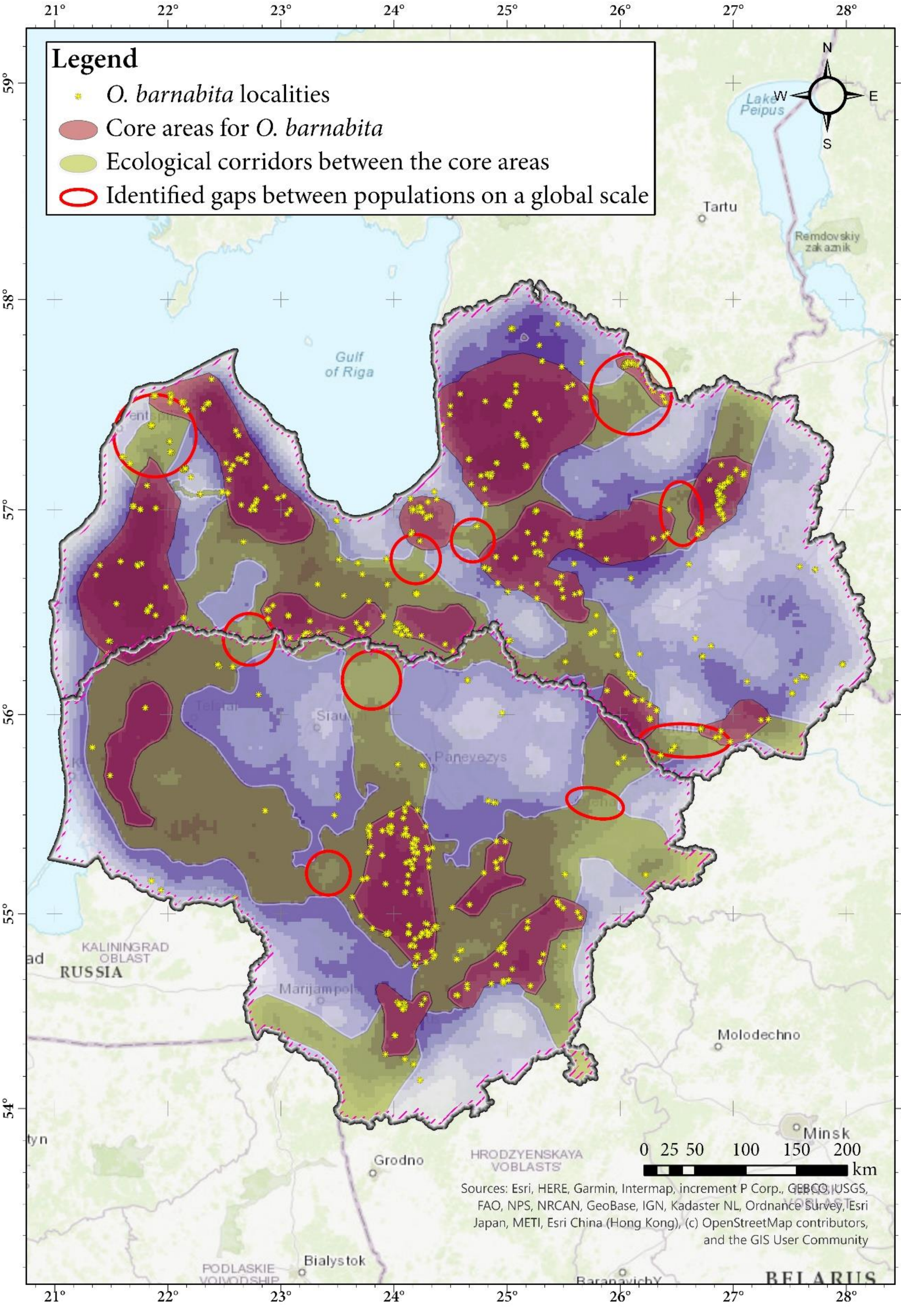

Figure 9. **Basic elements of developed Ecological network - core areas, corridors and gaps**

INTERPRETATION OF PERFORMED GENETIC ANALYSES DATA

The material required for genetic research was collected from 136 *Osmoderma* specimens in 28 sites in Lithuania. The samples of hind legs were used for DNA extractions. Overall, 136 DNA samples were isolated, however, only 134 DNA samples were suitable for analysis. 47 samples from 3 sites were collected in Latvia within the LIFE EREMITA MEADOWS project – they were analyzed to compare Lithuanian and Latvian metapopulations. Unfortunately, a sufficient number of sampled individuals were represented only by the metapopulations of eastern part of Latvia, therefore the genetic affiliation for the metapopulations located in northern and western parts of Latvia is still unclear.

Principal Coordinate Analysis (PCoA) was used to reconstruct the dissimilarities among metapopulations. Given that a part of the sampling places has been represented by a small number of specimens, samples were analyzed by combining the closest metapopulations to each other. PCoA was performed in total in 9 metapopulations in Lithuania and in 3 metapopulations in Latvia (see in Figure 11).

Obtained microsatellite data analysis represents historical data and is demonstrating that connection among metapopulations existed and is indicating that populations have a common ancestor. According to the obtained data (see in Figures 10 and 11) all analyzed metapopulations are divided into two groups. The first group includes Lithuanian metapopulations 4 and 9, as well as Latvian metapopulations 1, 2 and 3, while the second group includes metapopulations 5, 6, 7, 8, 9, 10, 11 and 14 in Lithuania. Although metapopulations 1 and 2 in Latvia are closer to the first group of metapopulations, they have a specific mixed genetic profile. These two metapopulations have a genetic profile which is sharing alleles with almost all populations. Additionally, the analysis of metapopulation 1 is indicating a probable connection with *O. barnabita* population in Estonia as the genetic profile of some samples differs from others.

The results are showing that metapopulations 4 and 9 in Lithuania have a strong connection and a similar genetic profile. Additionally, obtained results are also demonstrating the similar genetic profile of metapopulations from central part (7 and 14), eastern part (5) and southern part (8 and 10) of Lithuania – by this, it might be considered that these populations had a close connection.

Figure 12 represents a number of found alleles per locus, thus showing a variety among each locus and representing the variability of the population. In case, when more alleles are presented in one locus it is showing a greater variety and is indicating a higher viability of the populations in comparison with populations, which have a small number of alleles per locus. Variety of allele number per locus slightly differs among populations, which might indicate relatively recent isolation of populations. However overall genetic profile is showing connection among the populations.

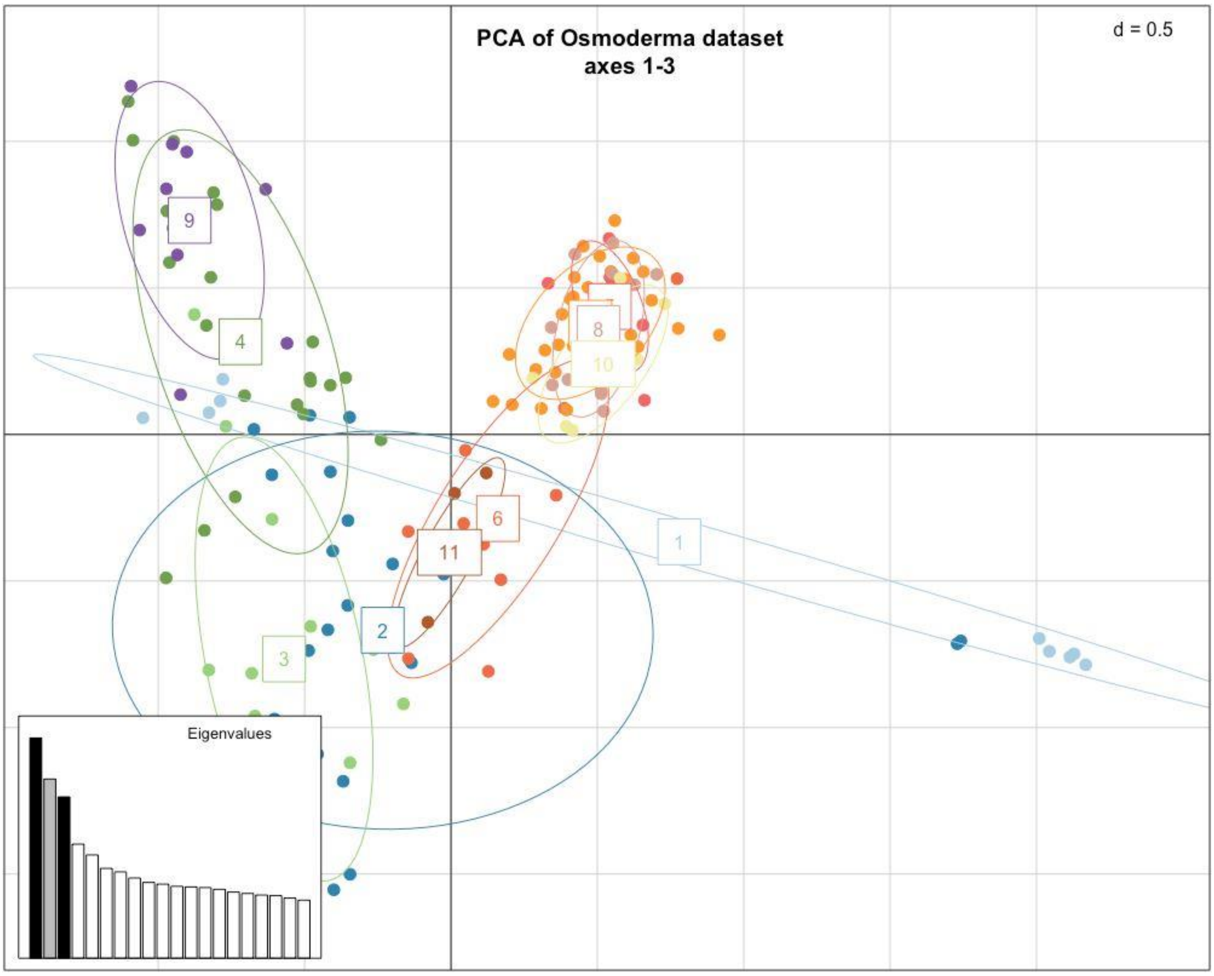

Figure 10. **Principal Coordinate Analysis (PCoA) data**

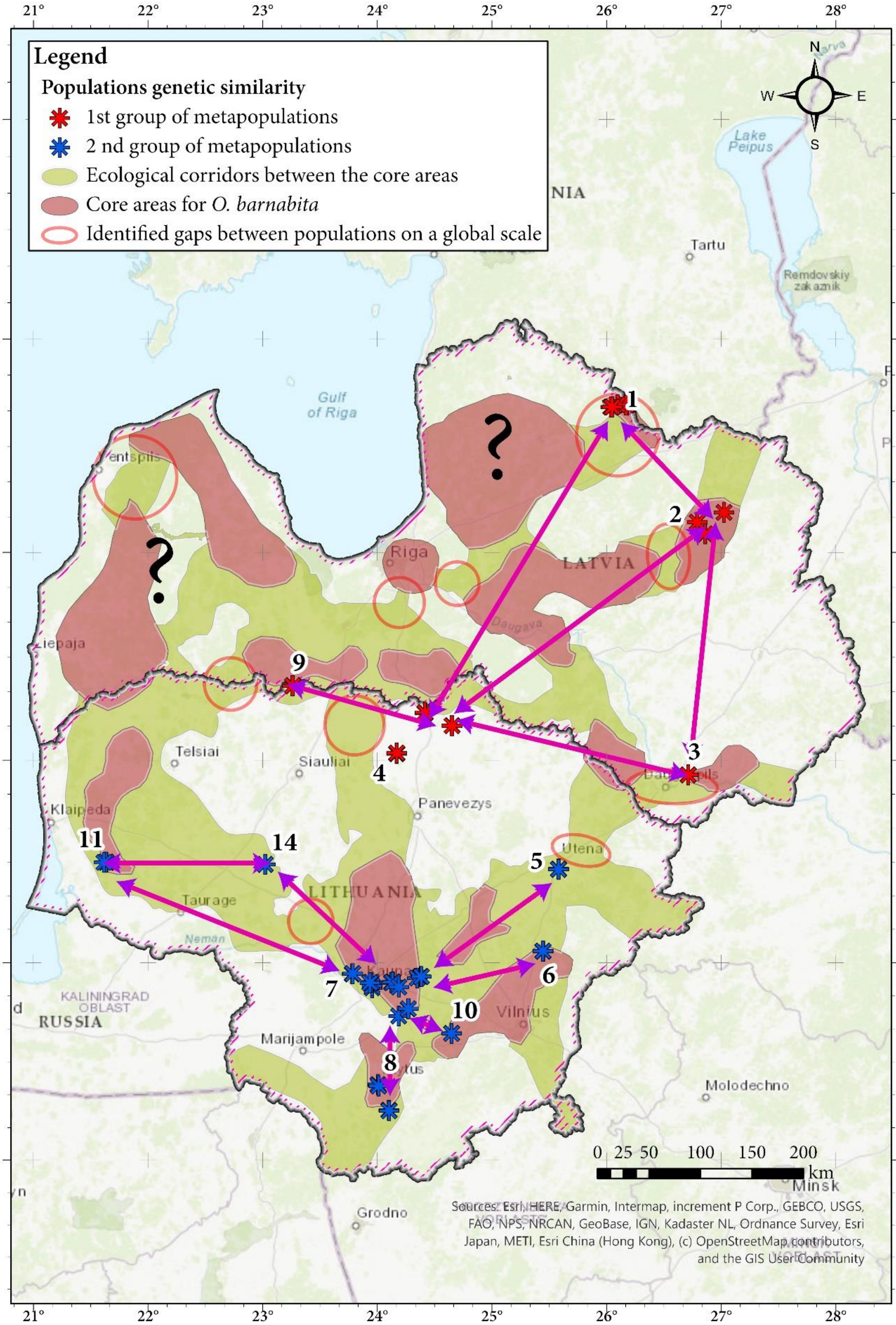

Figure 11. ***O. barnabita*** **metapopulation groups in the Ecological network**

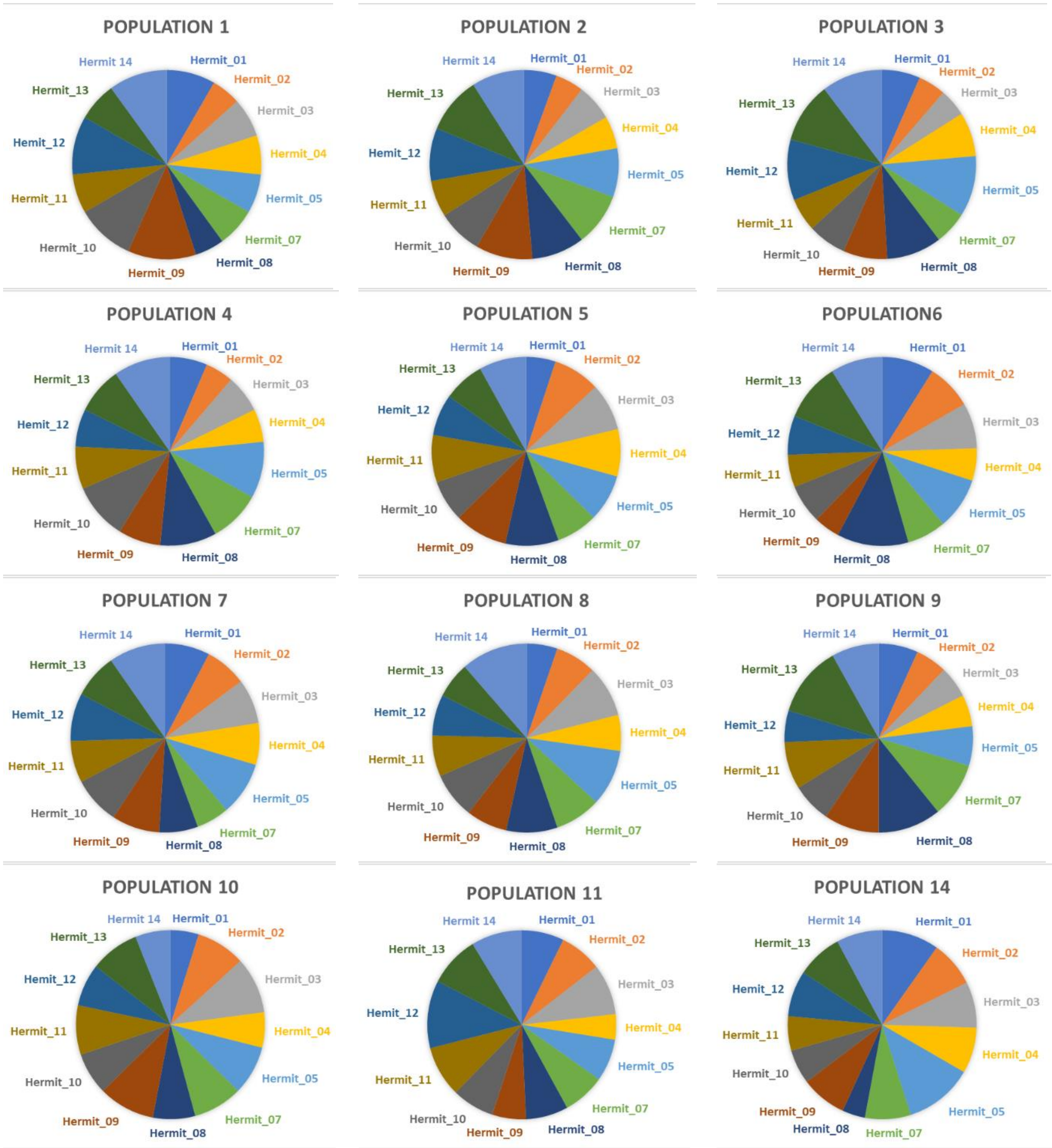

Figure 12. **Number of found alleles per locus in each of analyzed metapopulations**

RECOMMENDATIONS FOR *OSMODERMA BARNABITA* CONSERVATION MEASURES

The characteristics of the basic elements of the developed Ecological network and general suggestions for ensuring their functionality are summarized in the table 4.

Table 4. **Characteristics of the basic elements of the developed Ecological network and general suggestions for ensuring their functionality.**

Ecological network elements	Characteristics	Strategies
Core areas	Areas where the conservation of suitable habitats takes primary importance, even if the area is not legally protected. Regions where the species localities are concentrated, and the significant number of potentially suitable habitats for the species have been identified. Measures for the management of the hermit beetle habitat and species protection are often already applied in these areas.	• Inventorisation of core areas using both target species and structure-based indicators, such as the presence of old trees. • Identification of factors that could impact species negatively in existing and potential *O. barnabita* habitats. • Planning and implementation of the specific species protection measures (expansion of specially protected nature territories, creation of new ones, etc.) and habitat management measures.
Corridors	Corridors serve to maintain vital ecological connections by supporting physical linkages between the core areas. In principle, linking isolated patches of habitats can help increase the viability of local populations in several ways: • by allowing species individuals access to a larger area of habitat; • by allowing genetic exchange with other local populations; • by offering opportunities for individuals to move away from a habitat that is degrading or from an area that is under threat; • by securing the integrity of physical environmental processes that are vital to the requirements of certain species.	• Identification of potential gaps in *O. barnabita* distribution corridors and restoration habitats suitable for the hermit beetles. • Implementation of measures to protect the necessary structural elements for *O. barnabita*. Strict protection of corridors in fragmented landscapes (trees on the roadsides, ancient trees, etc.), including management to keep at least some areas open, e.g., by grazing or selective cutting. • Restoration of stepping stones between core areas, planting trees in places where the continuity of habitat has been disturbed, as well as other measures enhancing the microhabitat continuity in space and time e.g. promoting hollow creation by pollarding trees, veteranisation or fungal inoculation.
Gaps	Gaps are territories where the presence of habitats suitable for hermit beetle is unlikely, but which are essential for the functioning of species distribution corridors. During the development process of the Ecological network plan, gaps between several core areas were identified (see Figure 9). In these territories, species protection measures for the maintenance of existing habitats suitable for the species and	• Investigation of gaps in the field to find out if it is a gap or lack of data; • Placement of artificial microhabitats – surrogate tree cavities; • Veteranisation of oaks – managing trees to speed up habitat production; • Planting new broad-leaved trees.

	creation of new the ones should be implemented as a matter of priority. Gaps on a local scale can be identified using the developed interactive map. In the interactive map, gaps are hexagons where potentially suitable habitats for the species have not been identified.	

The main tasks in ensuring the functionality of the developed ecological network:

For the implementation of sustainable measures, including habitat management measures and creation of artificial habitats, for protection of the hermit beetle population, special attention should be paid on maintaining suitable habitats for species that depend on broad-leaved trees on a landscape, ecosystem and regional scale. In order to ensure the long-term conservation of the species, it is essential both to plan coordinated actions to ensure the conservation of the species on a global scale, as well as to implement local measures for the management of the species habitats.

Proposals for the implementation of measures necessary to ensure the conservation of the species:

- **Identification and integration of management measures necessary for the protection of species populations found in specially protected nature territories into nature conservation plans, ensuring the protection of *O. barnabita* populations.**

  An invertebrate expert should be involved in development of conservation plans for specially protected nature areas where the habitats of *O. barnabita* have been identified. A competent expert should provide advice on the protection of *O. barnabita* and site management measures necessary for the long-term survival of its population.

- **Inventorisation of *O. barnabita* habitats adjacent to specially protected nature territories (SPNT) and preparation of proposals for their inclusion in SPNT.**

  According to the currently known species localities data and information from Natura 2000 territories Standard Data Forms, 54,40 % in Lithuania and 61 % in Latvia of all *O. barnabita* registered localities are located in Natura 2000 sites. These sites are displayed in figure 13. This is a good indicator in the context of the protection of species population. Nevertheless, the intensity of research on protected species is much higher in protected areas, so in order to get a real situation, it is necessary to find out the occurrence of the species outside the protected areas. Consequently, the protection of the species populations cannot be considered sufficient at present, which is further strengthened by the factors negatively affecting the species and its habitat (habitat fragmentation, aging, felling of old trees, etc.) in the species localities, including Natura 2000 areas.

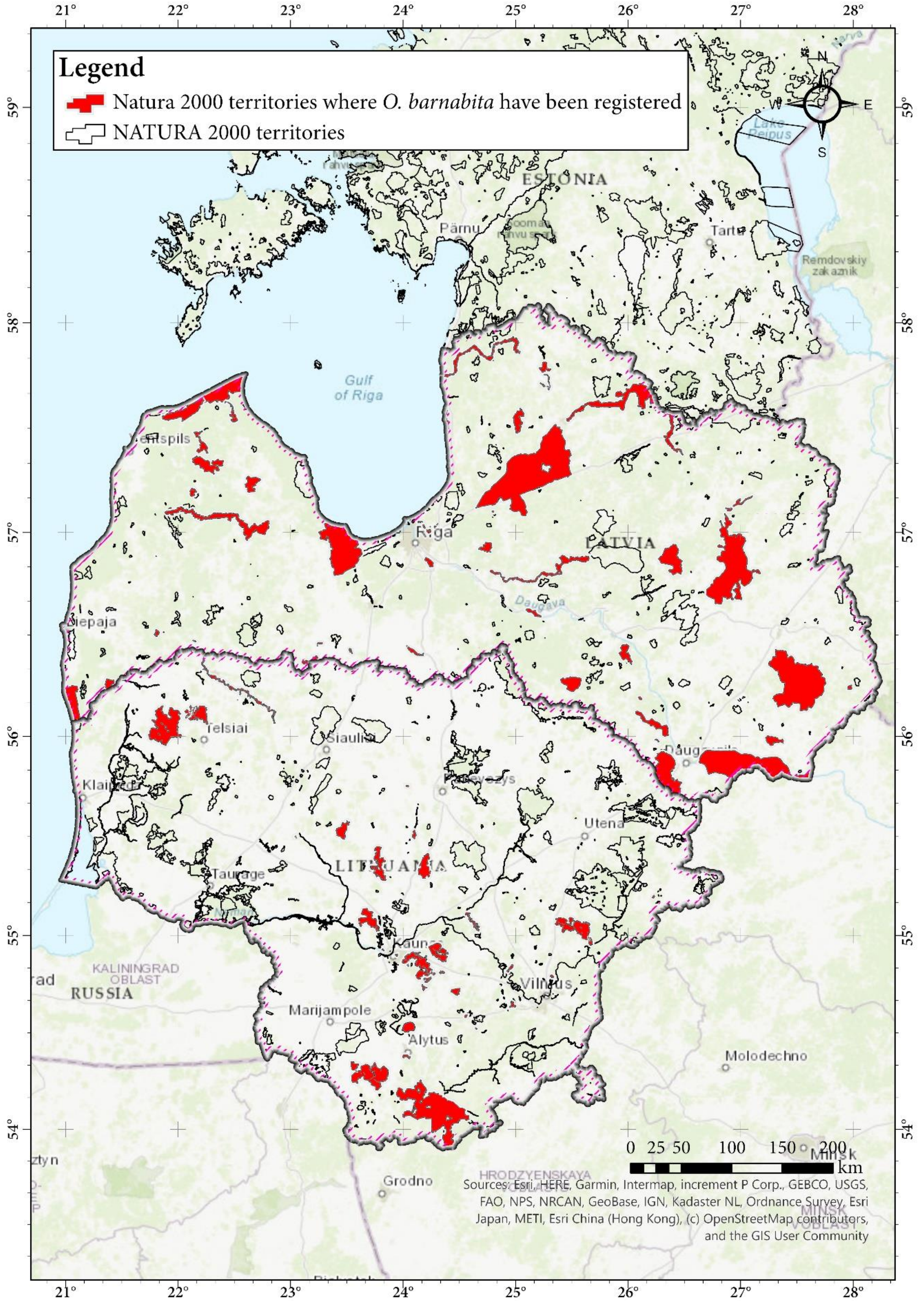

Figure 13. **Natura 2000 sites in Lithuania and Latvia where *O. barnabita* localities have been registred**

It is necessary to evaluate the possibilities of expanding Natura 2000 sites by including areas with registred localities and potentially suitable habitats of *O. barnabita* that are located in their immediate vicinity. Such a feasibility study has been carried out in Latvia (Kalniņš 2014), identifying 15 Natura 2000 sites, as well as 22 SPNT without Natura 2000 status, for which proposals for clarification of boundaries have been prepared. The inventory of *O. barnabita* habitats adjacent to SPNT and the development of such recommendations would also be useful for planning the protection of micropopulations of species occurring in other countries.

- **Establishment of micro-reserves to ensure the protection of the species outside specially protected nature territories.**

According to the legislation in force in Latvia, *O. barnabita* is one of the species for the protection of which micro-reserves may be established (Regulations of the Cabinet of Ministers (No. 940, 18.12.2012.) "Regulations Regarding Establishment, Protection and Management of Microreserves". Microreserves are territories that are designated for the protection of specially protected species and their habitats. In microreserves similarly to specially protected nature territories, actions that may threaten rare species or their habitats are restricted or prohibited.

Eight micro-reserves for *O. Barna bita* have been established in Latvia, and in two other micro-reserves, *O. barnabita* has been mentioned as another protected species. The maximum allowable micro-reserve area for this species is 30 ha. It could be used as a good example for other countries.

- **Maintenance of *O. barnabita* ex-situ population.**

The breeding is aimed at obtaining a series of specimens through ex-situ and in-situ reproduction, starting with individuals taken from natural populations. The breeding makes it possible to have beetles – larvae and adults – for reintroduction and repopulation activities. Based on the experience of experts from other countries, methodology of establishing a captive population of the hermit beetle in Lithuanian Zoological Garden (LZG) has been developed (in the framework of project LIFE OSMODERMA). The first zoo captive-bred specimens were returned to nature in the summer of 2020 (see Figure 14).

Breeding of *O. barnabita* in LZG will also be continued after the end of the LIFE OSMODERMA project to have a permanent captive population, which could be used for reintroduction of the species to its historic restored habitats.

Figure 14. **Restoration of *O. barnabita* population in the Verkiai Regional Park in the framework of LIFE OSMODERMA project (Photo: U. Valainis)**

- **Assessment of the necessary management actions in *O. barnabita* habitats implementing detailed broad-leaved trees mapping.**

Saproxylophagous beetle species are closely related to both the number of trees per unit area and the overall scale of the landscape (Bergman et al. 2012). The most important, as the longest-lived and most stable tree species, is oak, but other broad-leaved tree species also often serve as a habitat for these species. To assess more clearly the living conditions of hermit beetles and other ecologically similar species and their potential habitats in future, it is useful to identify the number of trees of different developmental stages, their growth conditions, and location in space.

During the detailed mapping, the information on a number of trees, their developmental stages (see Figure 15), and management needs should be collected.

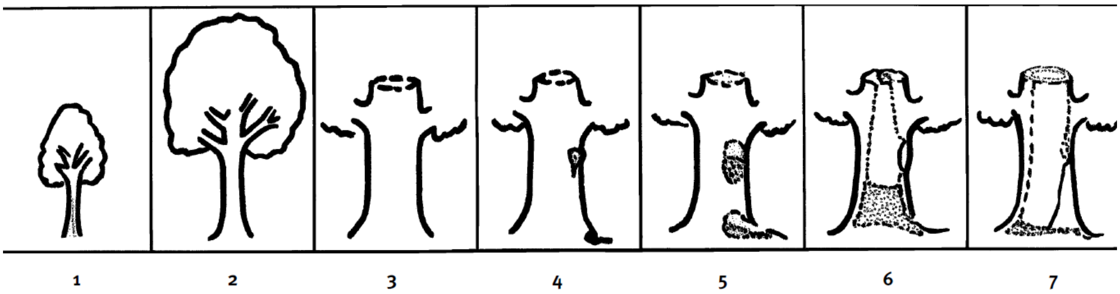

Figure 15. Development scheme for hollow trees, especially made for oaks but can also be used for other tree species, especially broad-leaved deciduous trees. The numbers used represent the development stage of the tree and also indicate the age. **1st stage:** Young tree without hollows; **2nd stage:** Middle aged tree without hollows; **3rd stage:** Older tree without hollows; **4th stage**: Old trees with small hollows and a small amount of wood moul; **5th stage:** Old tree with medium sizes hollows and a lot of wood mould; **6th stage:** Old tree with large holows and a lot of wood mould; **7th stage:** Old tree with large hollows and very little wood mould which is lying on the ground (Antonsson & Jansson 1997).

It will help to assess if the quantity of hollow trees in the planned management polygon is sufficient and whether various stages of tree development are represented homogeneously and in sufficient numbers (see Figure 16). The collected information should be useful to assess the borders of the managed area, to describe detailed management tasks (see Figure 17), and to estimate the probable costs. It is necessary to assess also the suitability of each broad-leaved tree for the occurrence of target species, as well as to note other information relevant to habitat management. It is also necessary to get the data on other specially protected and rare species identified in the mapping process (see Figure 16). Ecological requirements of other species distributed in the same habitats also must be taken into account when planning management measures.

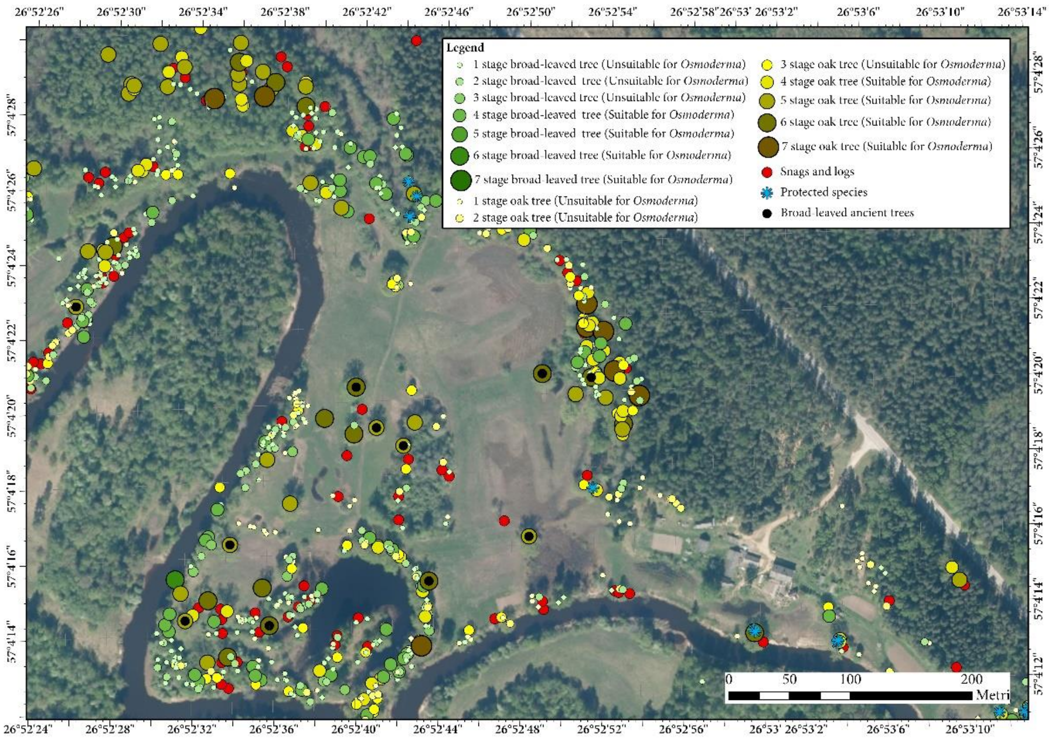

Figure 16. **Cartographic representation of developmental stages of mapped trees, protected species localities, ancient trees, snags and logs. Example from the mapping of *O. barnabita* habitats in the nature reserve "Lubāna mitrājs" (Natura 2000 code – LV0536600), Latvia (Latvian Environmental Protection Fund project No 1-08/294/2018 data)**

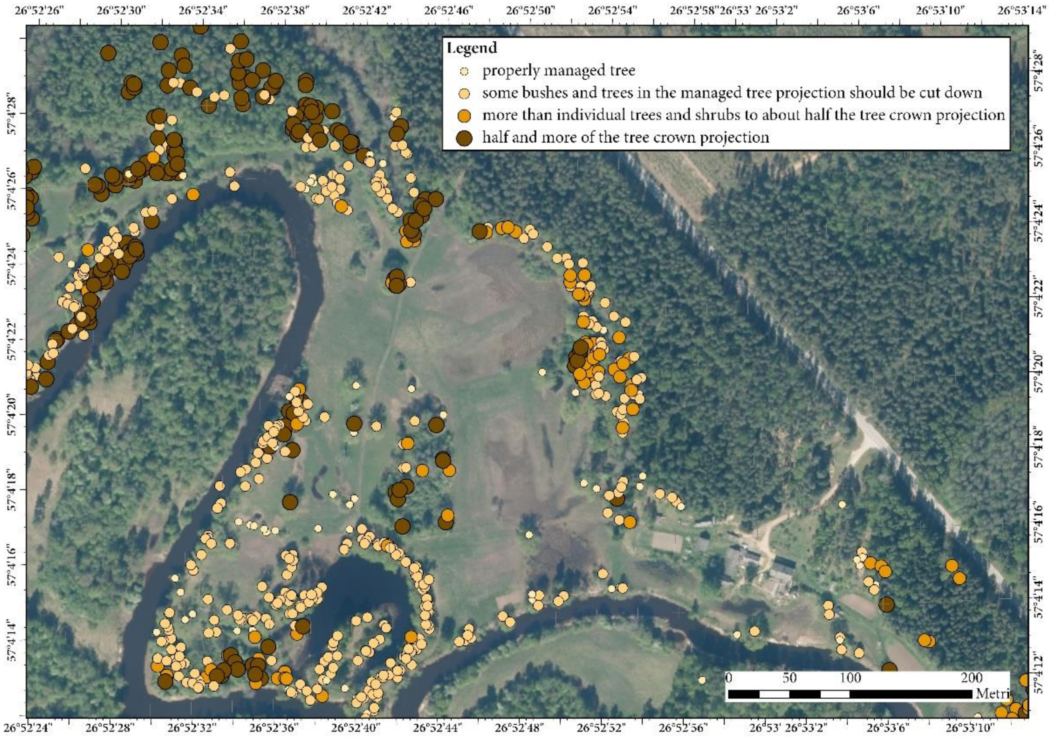

Figure 17. **Cartographic representation of the assessment of the management measures defined for each mapped tree. Example from the mapping of *O. barnabita* habitats in the nature reserve "Lubāna mitrājs" (Natura 2000 code – LV0536600) (Latvian Environmental Protection Fund project No 1-08/294/2018 data)**

In Latvia, detailed mapping of hermit beetles habitats and management planning has been already implemented in Gauja National Park (Natura 2000 site code – LV0200100) (LIFE+ FOR-REST project), protected landscape area "Ziemeļgauja" (Natura 2000 site code – LV0600700) as well as in nature reserves "Lubāna mitrājs" (Natura 2000 code – LV0536600), "Mugurves pļavas" (Natura 2000 site code – LV0528800) and "Sitas un Pededzes paliene" (Natura 2000 site code – LV0532000).

- **Informing public about *O. barnabita* and other rare species dependent on broad-leaved trees as well as the importance of old hollow trees in nature.**

Many species, including endangered saproxylic beetles, are threatened by anthropogenic factors, such as habitat loss, capture for the illegal wildlife trade, and climate change. People living in areas near endangered species and habitats are often unaware of their existence, how their actions negatively impact the species, or the laws protecting them. For this reason, systematic and attractive conservation education programs, public events, and other actions (Figures 18 and 19) need to be held not just for children and the youth, but for people belonging to all age groups. Such activities are meant to help people understand these issues and develop an ethic that will support a host of conservation behaviours. Specially protected nature territories have a unique role in public education in the field of nature conservation.

Figure 18. **In the framework of the project LIFE OSMODERMA organized educational programme "Save one – save a hundred" (Photo from the archives of Lithuanian Zoological Garden)**

Figure 19. **Exhibition "Life in tree" arranged within the project EREMITA MEADOWS in Slītere National Park (Photo: A. Soms)**

- **Training of nature conservation experts and specialists in the identification of species-dependent broad-leaved trees.**

An important measure in ensuring the protection of a species is the identification of habitats suitable for the species and the identification of the necessary management measures. For the successful implementation of the measure, it is necessary to provide training (see Figure 20) in the identification of species habitats and planning of the necessary management measures for specialists in the field of nature protection, who are engaged in daily survey and supervision of territories. Knowledge of the identification of habitats suitable for the species and the ecological requirements of the species will allow nature conservation specialists to independently identify the habitats of a previously unknown species, as well as to plan the management measures necessary for the sustainable existence of the species.

Figure 20. **Participants of a seminar for nature rangers and observers, organized within the project EREMITA MEADOWS, learning about habitats of saproxylic species (Photo: M. Nitcis)**

- **Consultations of landowners in implementation of *O. barnabita* habitat management activities.**

  In order to ensure proper management of the species habitats, it is essential to provide consultations to the landowners on whose land the species has been found.

- **Maintenance of "temporary habitats" in areas where the natural habitat of the species has been destroyed.**

  In places where a hollow tree inhabited by a hermit beetle was broken by wind or was cut down for some reason, it is essential to keep the fragments of hollow trunks (see Figure 21) in a state suitable for the species for as long as possible. One example of a successful implementation of temporary habitat was performed in Lithuania. 1,5 ha oak forest designated as Natura2000 territory for protection of two beetle species (*Osmoderma barnabita* and *Cucujus cinnaberinus)* was cut down at the beginning of 2019. The forest owner agreed to pass on 4 oak trunks with larvae and pupae of the hermit beetle to Verkiai Regional Park, which is a historical habitat of the hermit beetle. After more than one year, in July 2020 adult hermit beetles were observed on these tree trunks. It shows that such measures may reduce the negative impact of forest cuts for some protected species.

Figure 21. **“Temporary habitat” for *O. barnabita* created within the framework of the project LIFE OSMODERMA in Verkiai Regional Park (Photo: U. Valainis)**

- **Planting new broad-leaved trees and placing wooden boxes mimicking tree cavities in artificial habitats to establish ecological corridors in the areas with gaps between the metapopulations.**

One of the most significant problems of *O. barnabita* protection in Latvia and Lithuania is the lack of young broadleaf trees in the actual species localities. At the time when existing hollow trees became unsuitable for *O. barnabita*, often there are no other suitable trees in their vicinity. In such areas, it is necessary to plant broadleaf trees to ensure the formation of habitats suitable for *O. barnabita* in the future, as well as to place wood mould boxes in order to prevent the current breaks in the age structure of the trees.

Wood mould boxes for saproxylic insects, bats, and birds mimic conditions in a natural tree cavity. These boxes are built in areas with a lack of old hollow trees. Wood mould boxes may vary in size, dimensions of boxes built in Verkiai Regional Park (see Figure 22**)** are 250 x 50 x 50 cm, which gives a total volume of more than 400 L. Boxes are filled with a man-made wood mould: a mixture of broad-leaved trees sawdust and oak leaves, mixed with water. The substrate fills up three-quarters of the wooden box, giving approx. 300 L potential substrate for saproxylic organisms. There are holes in the roof of the box for rainwater as well as a plastic sheet on the bottom to retain moisture inside. A wire net attached to walls of the box is protecting the inhabitants from woodpeckers. There are separate entrances for birds and bats. The section for bats is composed of vertical wooden sections and serves as a daytime shelter for bats. Birds may be nesting in the upper part of the wooden box on wood mould. Saproxylic insects live in the lower part of the box, in the artificial wood mould (see Figure 23). All these organisms together form a small ecosystem inside the wood mould box, similar to a natural tree cavity. Research made in Sweden has shown that 70% of the beetle species that live in hollow oaks can live in boxes filled with man-made wood mould (Jansson et al. 2009). Information boards, explaining the value, threats, and conservation measures for saproxylic species are set up close to the boxes.

Figure 22. **Wooden box mimicking tree cavity created within the framework of the project LIFE OSMODERMA in Verkiai Regional Park (Photo: A. Banelienė)**

Figure 23. **Illustration of the organisms, living in the wood mould box.** Scale of the organisms is artistic and does not follow the real proportions **(Ilustration author: M. Jasnauskaitė)**

- **Ensuring long-term maintenance, and thus a favourable conservation status of *O. barnabita* micropopulations in extant species localities.**

In many places trees inhabited by *O. barnabita* are located in shade from nearby growing shrubs and younger trees. In these cases it is necessary to cut out the trees and shrubs that are forming the shade (see Fig. 24). If the overgrowth level of biologically valuable tree is low, then all unwanted trees and shrubs under the tree crown projection are cut out in one attempt. If the target tree has been growing in suppressed conditions and the trees nearby it reach its height, then attenuation of shade has to be gradual. That reduces the possibility of hollow trees dying from too rapid change of growth conditions. First of all, it is necessary to remove shrubs and younger trees, but during one of the upcoming years after that – trees of the emergent layer of a forest stand. As far as possible shrubs that are not forming negative shadow and while blooming serve as an important food source for insect pollinators, also protected species, have to be saved.

In order to preserve nestlings and birds while hatching eggs, management of biologically valuable trees has to be done during autumn or spring. Management measures have to be repeated after 5 to 7 years to cut out the newly grown shoots.

Figure 24. **Potential habitat of *Osmoderma barnabita* in the territory of nature reserve “Eglone” before the beginning of management (a) and after finishing the management works (b) (Photos: R. Cibuļskis)**

- **Increasing the viability of veteran trees by the professional arborists.**

  Veteran tree management clearly differs from standard arboricultural and forestry practice, being more complex, delicate and skill demanding. The management and understanding of veteran trees is a complex and sensitive field and as such it requires expert and specialist attention. When managing any veteran tree it is important to treat the tree as an individual and manage according to its specific needs. Assess any actual or potential threats to the tree, and then provide management to suit the requirements of this individual object, just because one veteran tree has been managed in one way doesn’t mean that they should all be managed in the same manner.

  Attracting professional arborists in management of veteran trees is especially important in cases when old hollow trees are located in urban territories and can pose risks for public safety. The involvement of specialists in such situations makes it possible to preserve important habitats for the species without endangering visitors of these areas.

- **Veteranisation of broad-leaved trees – managing trees to speed up habitat production.**

  Veteranisation is a method by which the ancient tree formation time i.e the time for trees to produce habitats and substrates only found on ancient trees can be reduced.The aim of veteranisation is thus to bridge the generation gap found in some old tree populations by trying to mimic natural damage caused by for example lightning strikes, branch failures and woodpecker holes by using tools. The treatments should be relatively mild in character so that the tree survives, but adequate to create decaying wood habitat in living trees. Veteranisation is generally suitable on sites, where there are plenty of younger trees, which may otherwise be removed to increase the level of light to favour other younger individuals or existing ancient trees and where there is a generation gap (Forbes and Clarke 2000; Read 2000). This means that you make use of the existing tree resource as an alternative to removal. This method is never appropriate to use on trees which may already be developing habitat or trees that already have important habitat, nor trees where safety may become an issue, such as in parks or towns (Bengtsson et al. 2012).

- **Involvement of nature experts in the risk management assessment of dangerous old trees in urban parks and along the rural roads to ensure both human safety and the conservation of biodiversity.**

  Urban parks can harbour small populations of saproxylic insects of high conservation concern, such as hermit beetles and other rare species. These areas often host old trees, which have become very uncommon in rural areas where they are threatened by commercial forestry management procedures based on frequent tree cutting. Nevertheless, old trees in urban parks may represent a hazard for public safety and are sometimes cut by management authorities.

  The following recommendations are given to promote the conservation of saproxylic insects in urban green areas, in agreement with actions for public safety (Carpaneto et al. 2010):
  (1) reducing cuts of secondary tree branches to conserve a canopy cover and optimal microclimate conditions within the holes;
  (2) leaving the largest branches and trunks on the ground after cutting, in order to increase development sites for larvae of saproxylic insects;
  (3) using steel ropes and other shores to hold collapsing trees;
  (4) applying Natural Fracture Techniques such as pruning methods used to mimic fractured ends which naturally occur on trunks and branches;
  (5) removing inadequate reinforcement materials used in the past to strengthen old trees or to occlude hollows;
  (6) removing trash and other objects left in hollows by people, in order to recover habitat conditions.
  (7) Smoke detectors in the cavities to prevent burning are suggested by LIFE Osmoderma.

  However, if a tree is found to be dangerous and needs to be cut down, it is recommended that an invertebrate expert participates in this process so that individuals of protected invertebrates that occur in the trunk of the tree can be moved to another suitable place.

- **Measures for trees protection from damages of beavers.**

  A significant part of the trees inhabited by hermit beetles are located near watercourses and waterbodies, where beavers can damage them. In such areas, it is necessary to implement measures to protect trees from beavers damages.


Figure 25. **Beaver gnawed *O. barnabita* inhabited lindens near Raķupe river in the nature reserve “Raķupes ieleja” (Photo: U. Valainis)**

Fortunately, there are ways to protect selected trees without destroying the beavers and their wetland ecosystem. Most of the following tree protection techniques are inexpensive, reliable, and relatively easy for nearly any person to do in a short period of time. Individual trees can be spared from beaver gnawing by placing wire cylinders around the base of their trunks (fig. 25). Afterwards trees should be regularly inspected if the tree trunk did not grow too wide for the cylinder.

Fencing can also help protect trees from beaver damage. This works especially well for smaller areas. To deal with uneven terrain or for a more aesthetic look, some people have reported good results using an electrified fences. The electric fence is less noticeable than a large fence enclosure, which is suitable aesthetically for areas with high visual value. However, an electric fence needs to be inspected periodically to ensure that a tree branch does not fall on it and short it out.

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