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DETERMINING SPATIAL PARAMETERS OF THE ECOLOGICAL NICHE OF *PARUS MAJOR* (PASSERIFORMES, PARIDAE) ON THE BASE OF REMOTE SENSING DATA

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Determining Spatial Parameters of the Ecological Niche of *Parus major* (Passeriformes, Paridae) on the Base of Remote Sensing Data. Zimaroeva, A. A., Zhukov, O. V., Ponomarenko, O. L. — Using factor analysis of ecological niches, we found that *Parus major* has high marginality to such ecogeographical variables (EGVs), as normalized difference vegetation index, the altitude above sea level, the diffuse insolation, activity of chlorophyll, normalized difference water index. This species is highly specialized in relation to various vegetation indices. Based on the type of habitat preference map, we found that *Parus major* doesn't implement all its potential pro-spatial niche. Considering the ecological niche of great tit on different levels of scale, we noticed certain features: first, a list of factors that influence the distribution of great tit significantly altered by changing the scale, secondly, the factors that play a significant role in spreading *Parus major* on level of total consideration losing their weight and relevance on closer inspection (when the scale down); third, although specialization of great tits changes with the scale of consideration but *Parus major* mostly specialized by vegetation index.

Key words: *Parus major*, Ecological-Niche Factor Analysis, ecogeographical variables, marginality, specialization.

Introduction

Studies of species–habitat relationships basically rely on two approaches. Thus, retrospective research is aimed at determining within a great number of ecological variables those that have the most significant impact on an individual species. On the other hand, predictive modelling is used to predict a species' habitats suitability, especially for those areas that are new for the species or have different ecological conditions. With recently increased number of research concerned with predictions of global climatic changes, the significance of predictive studies regarding species behaviour in response to various climatic scenarios has been on the rise. Additionally, predictive models are essential for managing endangered species populations, assessment of populations' viability, understanding human–animal species interactions, decision-making with respect to restoration and conservation of ecosystems. All this proves that at present a social and research demand for predictive models is rather high (Calenge & Basille, 2008).

Ecological–Niche Factor Analysis (ENFA) is one of the predictive models, based on a comparative analysis of a species ecological niche (part of the study area inhabited by a species) with the ecological features of the reference area (preserved as layers of Geographical Information Systems — GIS), called eco-geographical variables (EGV) (Hirzel & Guisan, 2002). ENFA is based on the concept of the ecological niche, proposed by G. E. Hutchinson, who defines a niche as a hyper-volume in the multidimensional space of eco-geographical variables within which a species can maintain a viable population. Examples of Hutchinson's coordinate axes do not expose behavioral features, thus a niche, in his opinion, is foremost a location in the space similar to a microlocation(microhabitat) or a "biotop" niche (Hutchinson, 1965).

ENFA helps to evaluate a species' habitat suitability on a set of ecological variables and to construct a model of its potential ecological niche (Lachat & Butler, 2009). One of the major outcomes of this model application is a preference habitat map which can be used to show a species spatial distribution; to predict a potential range of a species or disease distribution; to outline the areas to be protected for endangered species; to map the biodiversity trouble spots (Calenge & Basille, 2008, Elham et al., 2014).

The given research is focused on the Great tit (*Parus major* Linnaeus, 1758) — a small bird of the genus *Parus*. This species is rather widely spread all over Ukraine. *P. major* is well adapted to man-created landscapes (Fesenko & Bokotej, 2002, Zimaroeva, 2013). It can be found in all types of forests as well as in urban areas.

This paper is concerned with evaluation of the *P. major* ecological niche in terms of ENFA and eco-geographical variables (EGVs), determined on the basis of the Earth's remote sensing data. Moreover, the paper considers the species ecological niche at various scale levels.

Methods

The data were obtained by seasonal observations in 2011–2014 on an ecological profile Dnipropetrovsk national university ecological station (Ukraine). The area of the referent polygon, which includes all the basic biogeocenosis types of the study site, constitutes 38.35 km^2. The area of the curved polygon, where birds were recorded, is 5.23 km^2. The area covering the cells of pseudo-absence varies depending on their proximity to the presence cells; with this distance being not less than 100 meters, the area is 6.44 km^2, with a distance of 200 meters, the area is 8.39 km^2, 500 meters — 11.96 km^2, 1000 meters — 20.25 km^2.

To study the birds-habitat relationships time-keeping (Dol'nik, 1982) was employed. This tool was extensively used and described by O. L. Ponomarenko (Ponomarenko, 2004), who studied birds' activity in a tree stand. Employing the above tool we used visual observation to keep time of the birds' activity for each sample in a tree stand. Bits of activity registered were not less than 30 meters apart, which correlates with 1 pixel in satellite imagery.

To employ this technique of bird observation one should obtain the following data:

1) the bird species;
2) the tree species, whose crown the bird occupied;
3) the determinant tree characteristics (age, height, crown size);
4) the bird's position:
   a) within the vertical and horizontal systems of a tree structure;
   b) within the substratum gradation system;
   c) within the Biallovich biogeohorizon system;
5) functional interaction with a certain tree sample with respect to the consortive relationships:
   a) trophic;
   b) topic; c) productive;
   d) phoric;
6) duration of the interaction (sec);
7) coordinates (in this research GPS Garmin eTrex was used after the activity was successfully recorded and the bird flew away) (Ponomarenko, 2004).

Multichannel space survey and three-dimensional relief models open new possibilities for a species-habitat interaction research and evaluation of growing conditions (Demidov et al., 2013). This paper is based on the data obtained by Operational Land Imager (OLI), installed on Landsat 8 (Scene ID: LC81780262014136LGN00). The survey was done on May 16, 2014.

Through the digital relief model the basic derivative geo-morphological parameters were computed (Demidov et al., 2013).

ENFA rests on the assumption that a species is not randomly distributed with regard to the eco-geographical variables. The focal species may be characterized by some marginality (expressed by the fact that the eco-geographical variable of the species mean differs from the global mean) and some specialization (expressed by the fact that the species variance is lower than the global variance) (Hirzel & Guisan, 2002).

Formally, marginality (M) may be defined as the absolute difference between global mean (mg) species mean (ms), divided by 1.96 standard deviations of the global distribution (σ_g):

$$M = |m_g - m_s| / 1.96 \cdot \sigma_g.$$

A large value of the marginality factor (close to one) means that the species lives in a very particular habitat relative to the reference set (Hirzel & Guisan, 2002). Negative marginality coefficients indicate that the focal species prefers values that are lower than the mean with respect to the study area, while positive coefficients indicate the species preference for values higher than the mean.

Specialization (S) may be defined as the ratio of the standard deviation of the global distribution (σ_g) to that of the focal species:

$$S = \sigma_g / \sigma_s .$$

The higher the absolute values of the specialization coefficients, the more restricted is the range of the focal species on the corresponding variable (Hirzel & Guisan; 2002, Demidov et al., 2013).

The digital relief model (Aster GDEM: https://lpdaac.usgs.gov/data_access/data_pool) allowed to compute the following derived geomorphological parameters within area studied: Topographical Wetness Index according to SAGA algorithm (TWI-Saga); Topographical Ruggedness Index (Ruggedness); Profile curvature (Prof. curv.), Planar curvature (Plan. curv.); Mass-balance Index; Slope length factor (LS, ls_factor) of the Universal Loss Soil Equation (USLE).

Other abbreviations used in the paper are: NDVI — Normalized Difference Vegetation Index — net production, transpiration; VI — Vegetation Index (biomass and vegetation types); Green NDVI — extremely sensitive to chlorophyll concentration; NDWI — Normalized Difference Water Index (water content in biomass); NDB4 — chlorophyll activity; GR — green; Dem — elevation; TWI — Topographical Wetness Index; Slope — angle the relief slope; W — wetness; direct_ insol — direct insolation; Diffuse_ insol — diffuse insolation; mrrtf — multiresolution index of the ridge top flatness; mrvbf — Multiresolution Index of Valley Bottom Flatness; wind — Livard wind influence index; altitude — altitude above the canal network (Friedrich, 1998).

The originality of the present approach lies in the fact that an ecological niche is described at different scale levels. ENFA provides quantitative estimates of an ecological niche comparing the EGVs in the species presence cells to those of the reference area, within which pseudo-absence cells are artificially distributed (Hirzel & Zimmermann, 2000). Generally, the size and configuration of the reference area are chosen at random. In this respect, features of the surveyed ecological niche were obtained at different ranges of proximity between the pseudo-absence cells and the curved polygon, where the species was recorded.

For this purpose, the pseudo-absence cells were distributed at distances which do not exceed 1000 meters, 500 meters, 250 meters, 100 meters from the *P. major* presence cells.

Statistical computation was implemented in the software Project R "R: A Language and Environment for Statistical Computing" (http://www.R-project.org/), library adehabitat (Calenge, 2006). For graphical data Surfer 11 was used.

Results and discussion

In the context of ENFA an ecological niche is defined as a subset of cells in the ecological space within which the focal species is expected to occur with reasonable probability. The spatial distribution of *P. major* in the study area is given in fig. 1.

ENFA provides quantified estimates of the ecological niche on any of its axes by an index of marginality and specialization (fig. 2).

EGVs which are mostly associated to the *P. major* presence, in relation to the marginality index are: NDVI (normalized difference vegetation index), Green NDVI (green normalized difference vegetation index), Dem (altitude above the sea level), Diffuse_insol (diffuse insolation), NDB4 (chlorophyll activity), NDWI (normalized difference water index, i. e. water content in green biomass), etc.

ENFA has proved that *P. major* gives preference to the sites with higher vegetation index (NDVI), chlorophyll activity (NDB4) and wetness (W), than the study area mean; on the other hand, its optimal biomass and vegetation type index (VI), Diffuse insolation

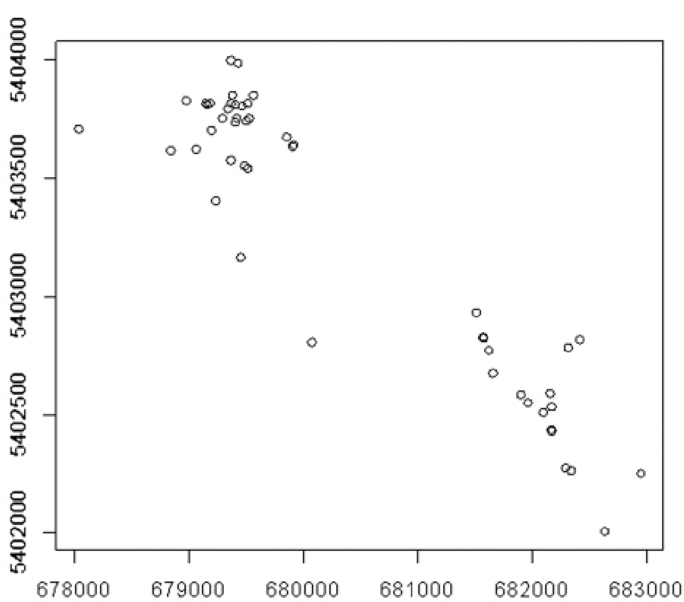

Fig. 1. Spatial distribution of the *P. major* registered presence.
Symbols: coordinates are given in UTM.

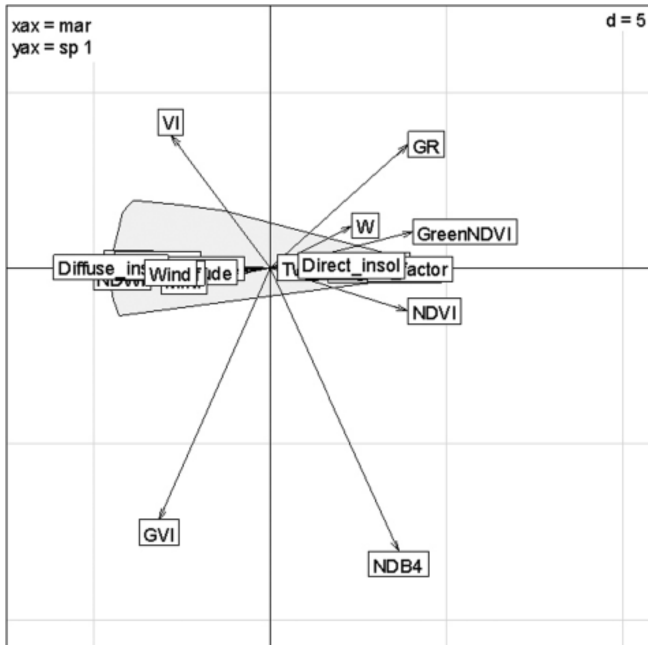

Fig. 2. ENFA results of the *P. major* ecological niche.

level (Diffuse_insol) water content in biomass (NDVI) tend to be lower than the study area mean. Likewise, it has been found that *P. major* prefers those sites that are located at a lower altitude above the sea level than the study area mean (table 1).

With regard to the other factor — specialization — *P. major* is closely linked to various vegetation indexes: GVI (green vegetation index), NDB4 (chlorophyll activity), VI (vegetation index — degree of biomass difference and types of vegetation), GR ("green") (table 1). This paper proves that the *P. major* distribution largely depends on vegetation availability and the species can inhabit areas within a small range of changes on these variables.

The fact that the species greatly specialize on vegetation can have several explanations: first, this research was conducted in wildlife areas, where, unlike anthropogenic landscapes, the species does not change its distribution presence; second, the data were sampled and

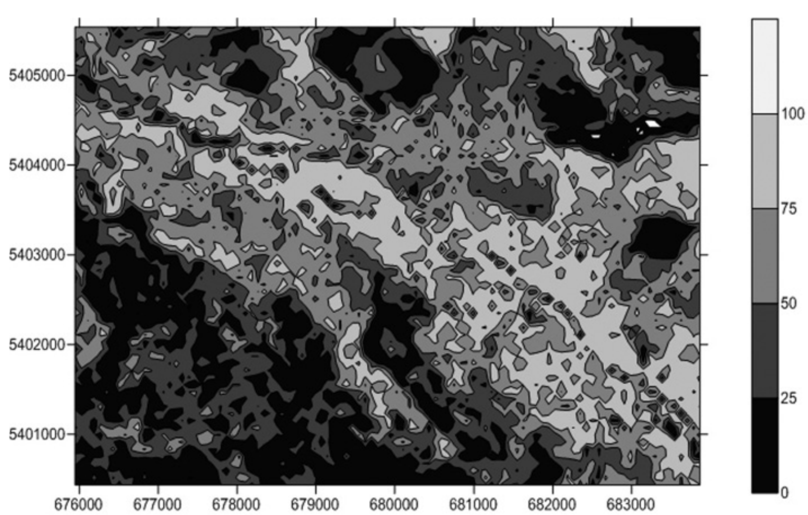

Fig. 3. The *P. major* habitat preference index.

Table 1. ENFA results with regard to the *P. major* ecological niche

Ecological geographic variables	Total		1000		500		250		100	
	Mar	Spe1	Mar	Spe1	Mar	Spe1	Mar	Spe1	Mar	Spe1
NDVI	0.32	–0.10	0.35	-0.05	0.35	0.04	0.35	–0.15	0.36	0.06
NDWI	–0.28	–0.02	–0.35	–0.49	–0.30	–0.30	–0.29	0.03	–0.31	–0.06
GR	0.32	0.29	0.31	–0.24	0.31	–0.26	0.32	0.24	0.33	–0.04
GreenNDVI	0.33	0.08	0.32	–0.04	0.32	0.01	0.33	–0.11	0.35	0.10
GVI	–0.26	–0.59	–0.28	–0.66	–0.28	–0.73	–0.30	0.72	–0.30	–0.64
NDB4	0.30	–0.66	0.27	–0.38	0.27	–0.49	0.29	0.58	0.31	–0.72
VI	–0.23	0.31	–0.30	0.13	–0.31	0.20	–0.31	–0.23	–0.30	0.18
W	0.19	0.10	0.32	–0.33	0.23	–0.17	0.06	–0.03	–0.03	0.00
Dem	–0.27	0.01	0.08	–0.01	0.11	–0.01	0.13	0.01	0.04	0.01
Twi-saga	0.12	0.01	0.03	–0.01	–0.02	–0.01	–0.05	0.00	0.04	0.08
TWI	0.02	0.00	0.02	0.00	–0.02	–0.01	0.02	0.00	0.09	0.01
Slope	0.15	0.00	–0.05	0.01	–0.01	0.01	0.03	–0.01	–0.08	0.07
Ruggedness	0.14	0.00	0.03	0.00	0.10	0.00	0.04	0.00	–0.01	0.02
Prof_curv	–0.16	0.01	0.12	0.00	0.15	0.00	0.16	0.00	0.09	0.01
Plan_curv	0.08	0.00	0.12	0.00	0.15	0.00	0.17	0.00	0.07	0.01
Mass_balance	–0.06	0.00	–0.06	0.00	–0.11	0.00	–0.11	0.00	–0.14	–0.02
Ls_factor	0.23	0.00	–0.09	0.01	–0.06	–0.01	–0.03	0.00	–0.11	0.02
Direct_insol	0.07	0.01	0.07	0.00	0.19	0.00	0.23	0.00	0.28	0.02
Diffuse_insol	–0.24	0.00	0.13	0.00	0.13	0.00	0.11	–0.01	0.15	0.06
Altitude	–0.08	–0.01	0.06	0.00	0.13	0.00	0.13	0.01	0.03	0.01
Mrrtf	–0.15	–0.03	0.00	0.00	0.03	0.00	0.01	0.00	0.03	0.01
Mrvbf	–0.15	0.01	0.22	0.00	0.21	0.00	0.21	–0.01	0.27	0.03
Wind	–0.17	–0.01	0.30	–0.01	0.29	–0.01	0.32	0.00	0.18	0.01

Explanations: Mar — marginality axis, Spe1 — specialization axis.

registered during the nesting period when birds are bound to be particularly dependent on tree vegetation, building nests tree hollows; third, this species lifestyle and nutrition is closely linked to trees, as *P. major* mostly feeds on small invertebrates and their larvae destroying forest pests.

The *P. major* habitat suitability map was obtained through ENFA. This map is represented as a grid, with each cell ranging in values from 0 to 100, which correlates with a zero to high habitat suitability respectively (fig. 3).

The species habitat preference map helps to determine the fundamental and the realized niches of the species within a certain area. Obviously, the *P. major* potential niche is not fully realized with regard to its spatial parameters.

Every species occupies its own position in the ecological space, stipulated by the species environmental requirements. Every area is characterized by a number of available resource units, and every species — by a certain level of use of these resources (fig. 4).

Thus, the *P. major* distribution of the resources used differs from the study area's distribution of utilized resources, especially in relation to the variables such as: normalized difference vegetation index (NDVI), greenery (GR), normalized difference water index (NDWI), biomass difference and vegetation types index (VI), wetness (W), etc.

Frequently, at large scales of survey strict regularities of the species distribution may seem not so obvious, than at lesser scales, therefore the scale of survey is essential for our understanding and interpretation of the factors that influence a species distribution. The

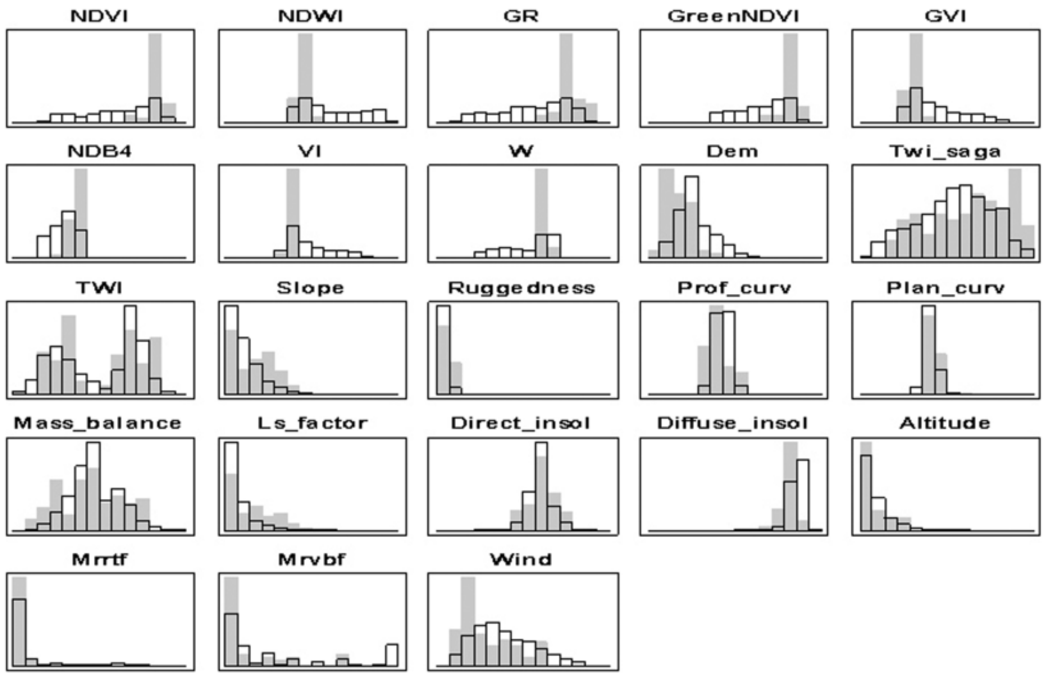

Fig. 4. Distribution of resources (light bars) and distribution of resources used by *P. major* (grey bars).

new technique proposed in this paper enables the researcher to give different interpretations of an ecological niche by changing the scale of survey.

The ecological niche of *P. major* has been evaluated through the distribution of the pseudo absence cells, situated at distances of not less than 1000 meters, 500 meters, 250 meters, 100 meters from the *P. major* presence or registration cells (fig. 5).

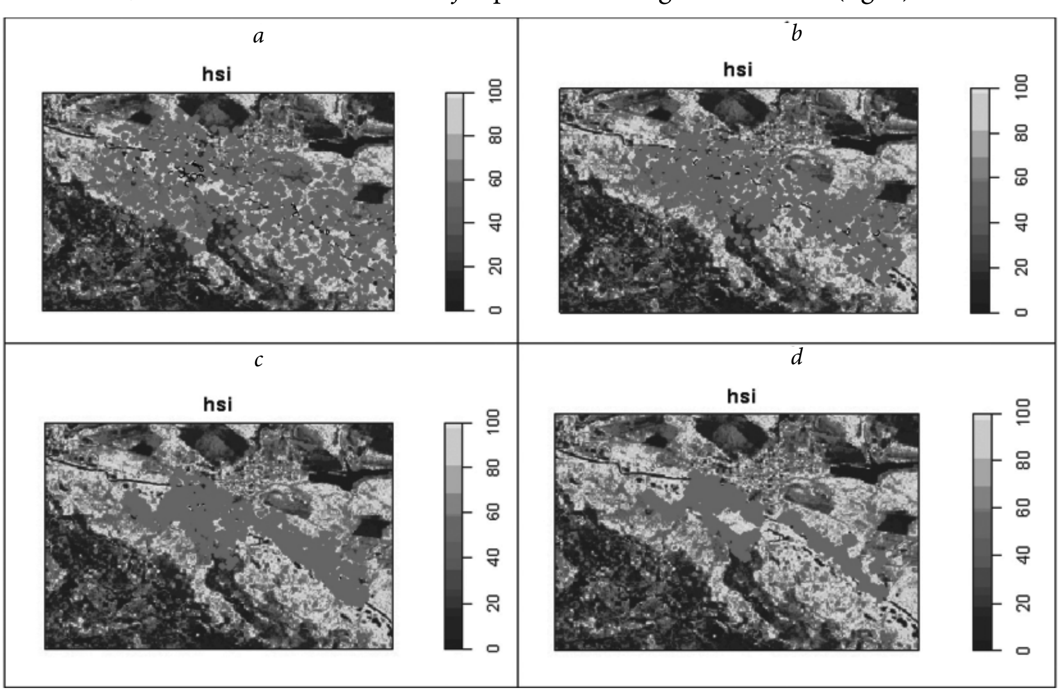

Fig. 5. Distribution of pseudo absence cells: *a* — the distance to the presence cells is not less than 1000 meters; *b* — the distance to the presence cells is not less than 500 meters; *c* — the distance to the presence cells is not less than 250 meters; *d* — distance to the presence cells is not less than 100 meters.

The *P. major* ecological niche surveyed at different scale levels (at distances not less than 1000 meters, 500 meters, 250 meters, and 100 meters) allows us to make a number of points. In particular, a list of factors that influence the *P. major* distribution change essentially at different scale levels. Thus, with the scale decrease, the significance of wetness for the *P. major* distribution reduces, which is explained by the general significance of this factor for the *P. major* habitat suitability. By contrast, the *P. major* marginality index with respect to direct insolation, increases with the scale decrease. Additionally the diffuse insolation influence remains unchanged at different scale levels. Moreover, *P. major* becomes less marginal in relation to the wind influence index, with the scale down. Yet, the vegetation indexes do not decrease and in some cases even increase, with the scale down, which proves an exceptional significance of these factors for the *P. major* distribution. The influence of elevation on the *P. major* ecological niche appears ambiguous. Thus, at a more general survey of the area the species seems to give preference to the lower sites, while at a decreased scale, *P. major* chooses more elevated patches than those of the reference area (table 1).

It has been also noted that, with the scale down, certain factors, which are significant for the *P. major* distribution at a more general survey, lose their weight and influence at a more detailed observation. Here belong: elevation (Dem), topographical wetness index (TWI-Saga), topographical index of ruggedness (Ruggedness), loss of soil factor (LS, ls_factor), etc. (table 1). By decreasing the scale we can differentiate factors more important for the species distribution from those that are less significant.

The *P. major* specialization surveyed at different landscape levels shows that it varies with the scale change. Thus, specialization tends to increase on a number of EGVs when the scale is down (chlorophyll activity — NDB4, Slope). The specialization index decreases on some other EGVs with the scale decrease: biomass difference and vegetation types index (VI), wetness (W) etc. Yet, the species reveals the greatest specialization with regard to the vegetation indexes irrespective of the scale of survey.

Conclusions

1. ENFA has exposed the EGVs with regard to which *P. major* shows the highest marginality: normalized difference vegetation index (NDVI), elevation (Dem), chlorophyll activity (NDB4), diffuse insolation (Diffuse_insol), normalized difference water index (NDWI), etc. With regard to the specialization factor *P. major* appears most sensitive to various vegetation indexes.
2. The species preference habitat map has shown that the *P. major* potential niche is not fully realized. It has been also found that the *P. major* distribution of used resources differs from that of the study area.
3. The *P. major* ecological niche surveyed at different scale levels allows to make a number of points: first, a list of factors that influence the *P. major* distribution change considerably at different scale levels; second, with the scale decrease certain factors, which are significant for the *P. major* distribution at a more general survey, lose their weight and importance at a more detailed observation; third, though *P. major*'s specialization varies to a certain extent with the scale change, nevertheless the species greatest degree of specialization is displayed by the vegetation indexes irrespective of the scale.

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