ECOLOGICAL NICHE MODELLING OF *FRINGILLA COELEBS* LINNAEUS, 1758 (COMMON CHAFFINCH) USING GIS TOOLS

ANASTASIA ANATOLYEVNA ZIMAROEVA[*], ALEKSANDR VIKTOROVICH ZHUKOV[**], ALEKSANDR LEONIDOVICH PONOMARENKO[**], ALEX MATSYURA[***]

Ecological-Niche Factor Analysis of finches showed that this species has a high marginality in relation to such ecogeographical variables as: the normalized difference vegetation index, the green NDVI, altitude, diffuse insolation, the activity of chlorophyll, the index of wind influence. This species is highly specialized in relation to various vegetation indices. Based on the habitat preference map, we found that *Fringilla coelebs* does not use all its potential pro-spatial niche. In this work a new approach to the study of the ecological niche of the species by using different levels of scale is proposed. Considering the ecological niche of common chaffinch on different levels of scale, we noticed certain features: first, a list of factors that influence the distribution of common chaffinch was significantly altered by changing the scale, secondly, the finer details of relief come to the forefront when scaled down; third, specialization of finch does not change with zooming.

Keywords: *Fringilla coelebs*, Ecological-Niche Factor Analysis, ecogeographical variables, marginality, specialization.

INTRODUCTION

Species-habitat interaction is a main subject of present-day biology and ecology. From the ecological perspective these relationships are formalized through the concept of ecological niche (Hutchinson, 1965). Distribution and niche modelling can unravel species-environment relationships (Guisan & Zimmermann, 2000; Mateo *et al.*, 2010; Peterson *et al.*, 2011) and provides a useful instrument in conservation biology, evolutionary ecology, and biogeography (Koper & Manseau, 2009; Durant *et al.*, 2010; Dolgener *et al.*, 2014).

Ecological-Niche Factor Analysis is based on the assumption that a species is not randomly distributed with regard to eco-geographical variables (Chase & Leibold, 2003; Goberville *et al.*, 2015). A 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; Reineking & Schröder, 2006).

Modern techniques of ecological niche studies provide cues to a number of issues; namely, evolutionary processes, competition, predator distribution and population dynamics. Additionally, the recent 15 years have witnessed an increased number of studies in habitat-suitability modeling, which are aimed at predicting a reasonable probability of a species occurrence with respect to eco-geographical variables (Hirzel & Guisan, 2002; Bütler & Lachat, 2009). Predictive models of species distribution within large geographical areas, with reference to a species' requirements, are recognized to have a wide range of application in landscape ecology, nature conservation biology and wildlife management (Franklin, 2000; Stauffer, 2002; Trigg *et al.*, 2006; Wisz *et al.*, 2008; Zurell *et al.*, 2009).

Ecological – Niche Factor Analysis (ENFA) is a modeling technique based exclusively on the presence data (Hirzel & Guisan, 2002; Fonderflick *et al.*, 2015). It may be employed to determine correlations between eco-geographical variables (EGV) and species distribution patterns, and also to evaluate habitat suitability. In our research, ENFA was used to evaluate a habitat suitability for a certain bird species, namely, common chaffinch (*Fringilla coelebs* Linnaeus, 1758).

ENFA compares in the multi-dimensional space of ecological variables, the distribution of the localities where the focal species was observed, to a reference set describing the whole study area. ENFA generalizes several EGVs into a number of non-correlative factors without losing too much information. Thus, ENFA estimates a species' niche-suitability functions by comparing a species' distribution in the EGV space to that of the whole set of cells (Austin, 2002; Soares & Brito, 2007).

An ecological niche description may be based on the occurrence frequency or vital activity traces of species representatives, together with radio tracing and satellite navigation.

This study focuses on the *F. coelebs* occurrence frequency on the routes of observation. *F. coelebs* is a songbird, from the genus *Fringillidae*, which is quite numerous and widely spread in Ukraine, nesting throughout the country in localities with an abundance of trees. Its biotope is diverse, including man-made landscapes (gardens, parks, orchards, boulevards, cemeteries); light oak forests; birch, willow and pine groves; flooded non-dense forests and island-type forests in the grasslands. *F. coelebs* tends to avoid large wet dark coniferous forests, restricting its habitats to their edges (Fesenko & Bokotej, 2002).

This paper is concerned with the *F. coelebs* ecological niche, viewed on the landscape level in terms of ENFA and EGVs, which were determined through the Earth remote sensing. Here we propose a new approach to the ecological niche analysis, namely, the one based on different scale levels.

MATERIAL AND METHODS

The data were collected 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 (Dolnik, 1982) was employed. Employing this 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 a bird observation technique 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 E – trex was used after the activity was successfully recorded and the bird flew away).

Multichannel space survey and three-dimensional relief models open new possibilities for a species-habitat interaction research and evaluation of growing conditions (Dolgener *et al.*, 2014). This paper is based on the data obtained by Operational Land Imager (OLI), installed on Landsat 8 (http://purl.access.gpo.gov/GPO/LPS82497). The survey was done on May 16, 2014. Coordinates of bird locations are given in Universal Transversal Mercator (UTM), which projects the Earth spherical surface into two-dimensional Cartesian coordinates.

In the context of ENFA, an ecological niche is assumed to be a subset of cells in the ecogeographical space within which the focal species is expected to occur with reasonable probability. This multivariate niche can be quantified on any of its axes by an index of marginality and specialization (Hirzel & Guisan, 2002).

The coefficients m_j of the marginality factor express the marginality of the focal species on each EGV in units of standards deviations of the global distribution. The higher the absolute value of the coefficient m_j, the further the species optimum departs from the mean of the corresponding variable within the study area. Negative coefficients indicate that the focal species prefers values that are lower than the mean with respect to the study area, while positive coefficients indicate preference for higher-than-mean values (Hirzel & Guisan, 2002).

The coefficients of the other factors (specialization ones) receive a different interpretation: the higher the absolute value, the more restricted is the range of the focal species on the corresponding variable. The eigenvalue λ_i associated to any specialization factor expresses the amount of specialization it accounts for, i.e. the ratio of variance of the global distribution to that of the species distribution. Eigenvalues usually rapidly decrease, so that a few initial factors are sufficient to evaluate the species habitat suitability (Demidov *et al.*, 2013).

Accuracy, or adequacy, of the model obtained may be estimated by a degree of its deviation from a randomly chosen alternative. To achieve this, the Monte Carlo method was used. Thus, 300 random distributions, generalized within the study area, were compared to the ENFA data (marginality and specialization). This gave an estimate of the deviation probability between the focal structure and the random alternative.

The digital relief model (Earth Explorer Aster Global DEM) 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: 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 *F. coelebs* presence cells. Statistical computation was implemented in the software Project R “R: A Language and Environment for Statistical Computing” (http://www.R-project.org/). For graphical data Surfer 11 was used.

RESULTS

Spatial distribution of *F. coelebs* within the study area is given in Fig. 1. ENFA provides the *F. coelebs* ecological niche with respect to two factors: marginality and specialization regarding various EGVs.

We project the used and available points in the ecological space on the plane defined by the marginality axis and one specialisation axis (Fig. 2). The environmental variables are represented by an arrow with two components of importance: the length and the direction. The length of the arrow identifies the contribution of a given environmental variable to the definition of the axes of the ENFA, *i.e.*, their influence on the position and volume of the ecological niche within the available habitat. The direction measures how this contribution is decomposed on the marginality or specialization axes. EGVs, mostly associated to the *F. coelebs* presence in relation to the marginality factor (Mar), include: NDVI, Green NDVI, Dem, Diffuse_insol, NDB4, wind (Table 1; Fig. 2).

Our modelling showed that *F. coelebs* gives preference to habitats with higher vegetation, wetness and direct insolation indexes than those of the study area mean, while its optimal diffuse insolation and wind indexes are lower than those of the area mean values. With respect to the altitude above the sea level, *F. coelebs* tends to inhabit sites that are lower than the mean (Table 1).

The next factor, specialization (Spel), shows that *F. coelebs* is essentially linked to various vegetation indexes: GVI (Ratio VI), NDB4 (chlorophyll activity), GR (Table 1). The distance between the centroid of the ecological niche of *F. coelebs* and the centroid of the available habitat was quite high, resulting in a pronounced marginality (X-axis, Fig. 2), *i.e.*, the optimum of *F. coelebs* was rather different from the mean available conditions.

The Monte-Carlo test shows that, statistically, with regard to the focal niche both marginality and specialization axes are likely to differ from a random alternative (Mar = 11.22, p = 0.003; Spel = 237.25, p = 0.01) (Fig. 3).

The *F. coelebs* preference map was computed from ENFA. The habitat suitability map is a grid, with each cell ranging in value from 0 to 100, which correlates with a zero to a high habitat suitability (Fig. 4). The habitat suitability map shows that the *F. coelebs'* most favourable conditions are situated in the centre of the study area.

Distribution of resources used by *F. coelebs* differs from the distribution of resources within the area, especially in relation to such variables as: altitude above the sea level, normalized difference vegetation index, leeward wind influence index, etc. (Fig. 5).

Table 1

ENFA results with regard to the *F. coelebs* ecological niche

Ecological geographic variables	**Within area studied**		**Scaling levels**							
			1000 м		500 м		250 м		100 м	
	Mar	Spe1	Mar	Spe1	Mar	Spe1	Mar	Spe1	Mar	Spe1
NDVI	0.30	–0.11	0.29	–0.06	0.22	–0.01	0.18	0.12	0.17	0.17
NDWI	–0.28	0.14	–0.32	–0.43	–0.25	–0.31	–0.18	–0.08	–0.09	–0.08
GR	0.30	0.28	0.23	–0.02	0.15	0.01	0.11	–0.07	0.09	–0.04
GreenNDVI	0.31	–0.03	0.25	–0.10	0.18	–0.08	0.16	0.00	0.15	–0.07
GVI	–0.25	0.81	–0.21	–0.66	–0.15	–0.67	–0.11	–0.70	–0.09	–0.67
NDB4	0.28	0.39	0.17	–0.50	0.11	–0.62	0.10	–0.65	0.10	–0.67
VI	–0.23	–0.25	–0.27	0.16	–0.24	0.18	–0.19	0.22	–0.18	0.21
W	0.21	0.06	0.35	–0.28	0.29	–0.17	0.18	0.02	0.06	0.01
Dem	–0.33	–0.09	0.17	0.02	0.20	0.03	0.12	0.04	0.07	0.06
Twi_saga	0.22	–0.03	–0.06	–0.04	–0.10	–0.03	–0.07	–0.01	0.06	0.09
TWI	0.05	0.00	–0.11	0.00	–0.12	0.00	–0.15	0.00	–0.30	–0.01
Slope	0.11	0.03	0.03	0.03	0.01	0.04	0.02	0.04	–0.13	0.09
Ruggedness	0.03	0.01	0.08	–0.01	0.07	0.00	0.10	0.00	0.00	0.02
Prof_curv	–0.15	0.01	0.25	0.00	0.32	0.00	0.44	0.01	0.43	0.02
Plan_curv	–0.06	0.00	0.21	0.00	0.26	0.00	0.32	0.00	0.29	0.00
Mass_balance	–0.06	0.00	0.12	0.00	0.15	0.00	0.20	0.00	0.22	–0.01
Ls_factor	0.20	–0.01	–0.03	–0.05	–0.07	–0.05	–0.05	–0.04	–0.19	–0.04
Direct_insol	0.13	0.00	0.19	0.00	0.29	0.01	0.38	0.01	0.42	0.02
Diffuse_insol	–0.23	0.02	0.08	–0.01	0.13	–0.01	0.07	0.00	0.16	0.02
Altitude	–0.14	–0.02	0.17	–0.02	0.24	–0.02	0.19	–0.02	0.12	0.01
Mrrtf	–0.15	0.04	–0.07	0.01	–0.06	0.01	–0.09	0.01	–0.12	0.01
Mrvbf	–0.08	–0.01	0.12	0.01	0.16	0.02	0.15	0.02	0.24	0.02
Wind	–0.23	0.00	0.41	–0.04	0.46	–0.03	0.45	–0.03	0.36	–0.01

Legend: Mar – marginality axis. Spe1 – specialization axis.

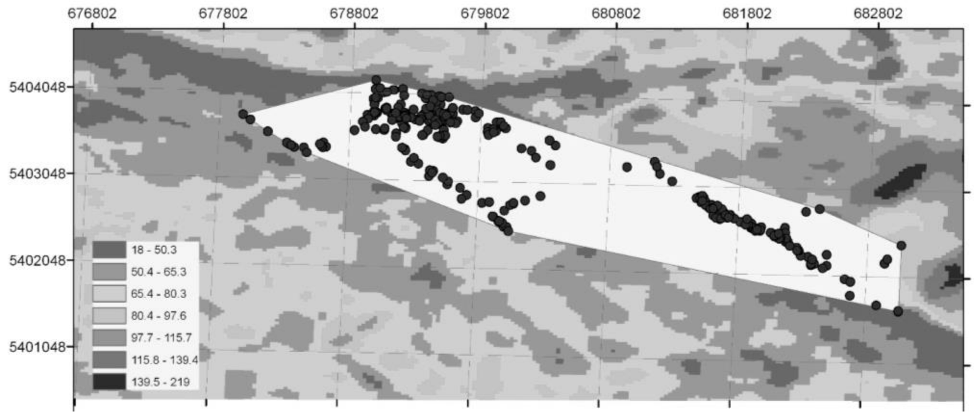

Fig. 1. Spatial distribution of *F. coelebs*. Symbols: coordinates are given in UTM (Zone 36); grey scale shows the altitude above the sea level (m); curved polygon shows the zone where the focal species was recorded during route observations.

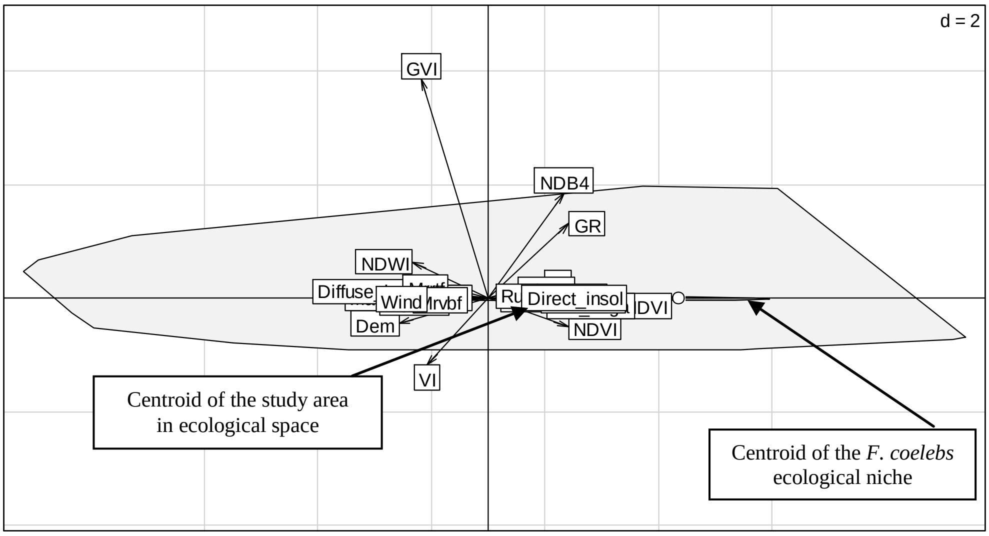

Fig. 2. The ENFA results for the *F. coelebs* ecological niche.

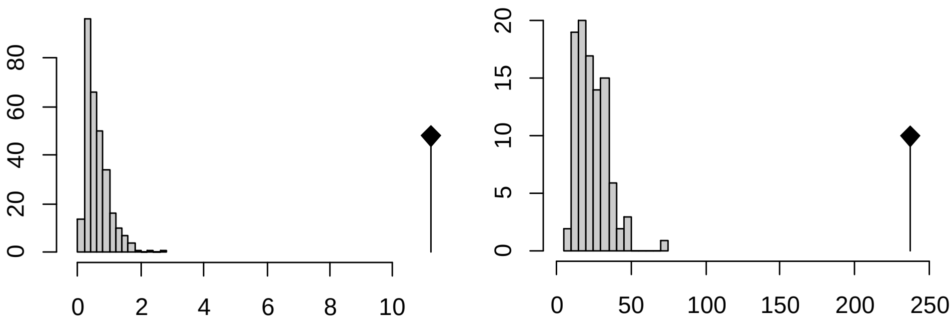

Fig. 3. Simulation results (through the Monte Carlo method) of the marginality (on the left) and specialization (on the right) indexes. Histograms – values of the correlative statistics for the random data; rhombus-containing lines – observed statistics for the experimental data.

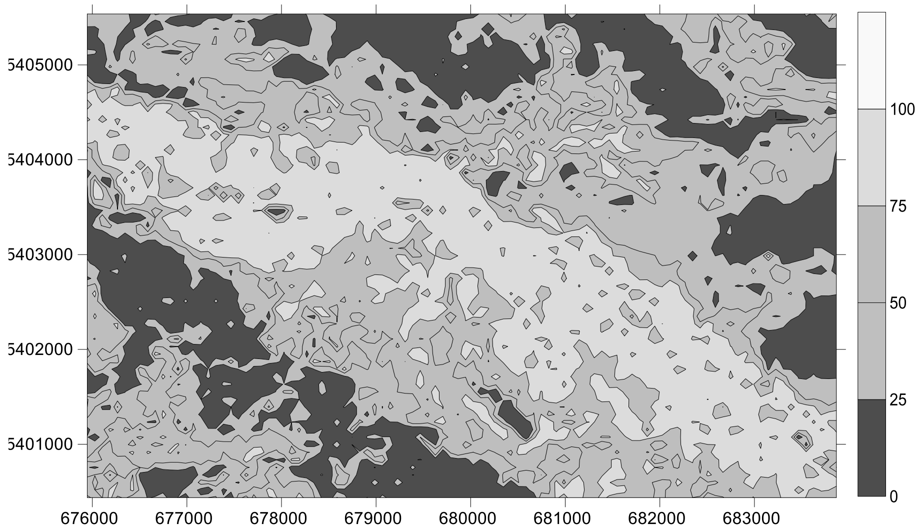

Fig. 4. The *F. coelebs* habitat-preference map (100 – maximal preference, 0 – minimal preference). Symbols: coordinates are given UTM (Zone 36).

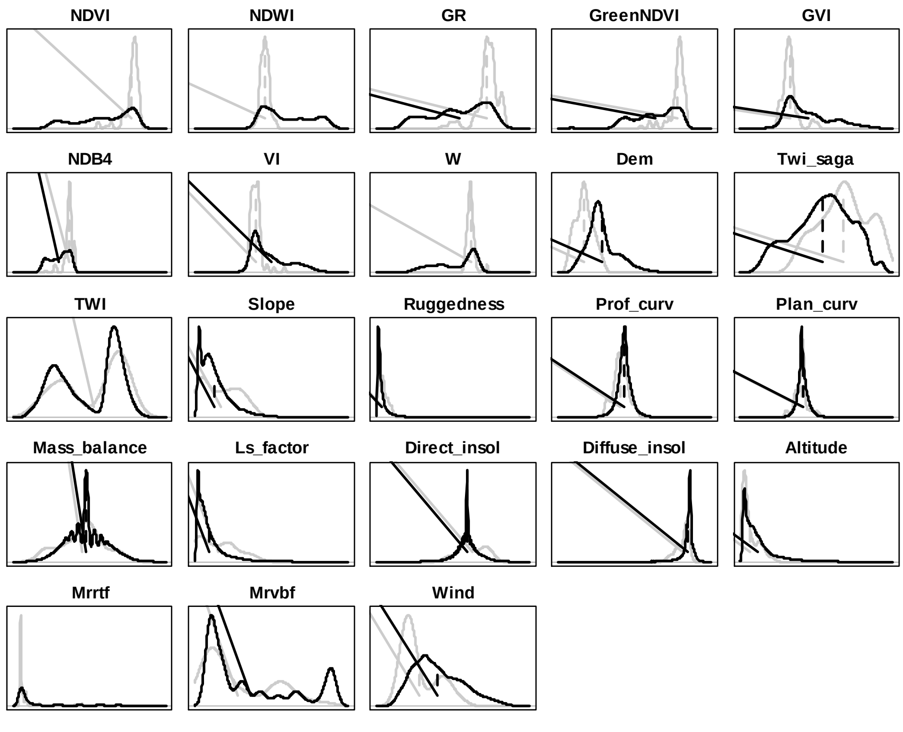

Fig. 5. Distribution of resources (black line) and distribution of used resources (grey lines). The variables values are normalized to 1 which equals the width of the corresponding graph.

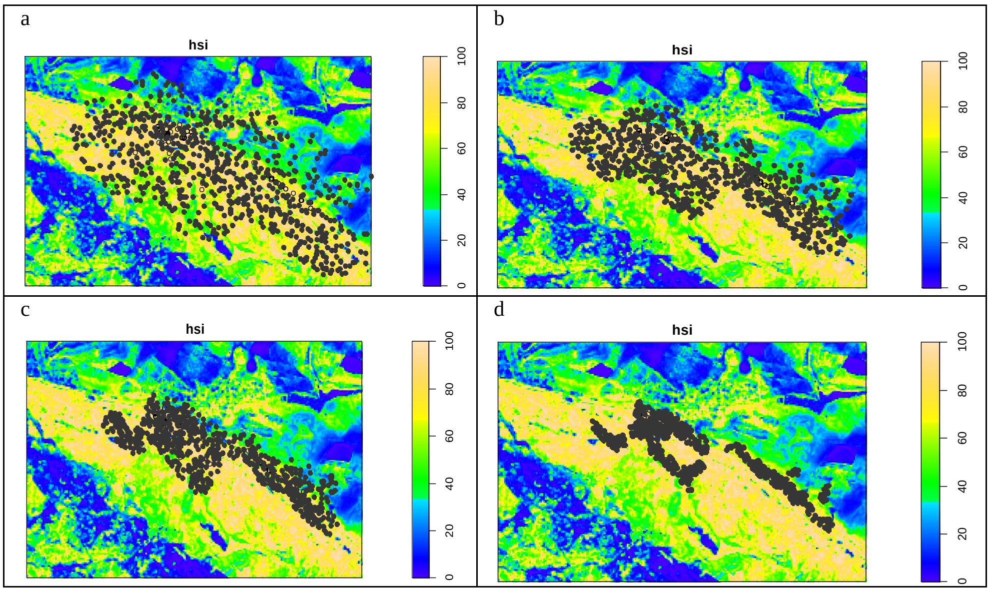

Fig. 6. Distribution of pseudo-absence cells: a – distance to the presence cells not exceeding 1000 meters; b – distance to the presence cells not more than 500 meters; c – distance to the presence cells not exceeding 250 meters; d – distance to the presence cells not more than 100 meters. The scale gradation – see Fig. 4.

The ecological niche of *F. coelebs* was evaluated through the distribution of the pseudo-absence cells at distances not less than 1000 meters, 500 meters, 250 meters, 100 meters from the bird's presence or registration cells (Fig. 6). With scale decrease the significance of all vegetation indexes lessens, i.e. they become less crucial for *F. coelebs'* distribution. By contrast, *F. coelebs'* marginality with respect to the direct insolation variable is gradually increasing with the scale reduction. Further, *F. coelebs* loses its marginality with regard to the altitude above the sea level.

With the more general survey of the study area, the species gives preference to the lower patches of the referent site. At the scale of 500 meters from the presence cells, the species marginality remains positive, i.e. the species prefers higher patches and, with the further decrease of scale, the influence of this factor becomes less significant, though still positive. Likewise, marginality regarding the diffuse insolation index changes from the negative values, when surveyed from a more general level, to the positive ones with scale decrease. Quite the opposite tendency is displayed by the topographical wetness index, which at the largest scale has positive marginality, *i.e. F. coelebs* prefers habitats with greater mean wetness, whereas with scale reduction, marginality acquires positive values. *F. coelebs'* response to wind changes from negative marginality at the largest scale to positive values, if the scale is reduced; incidentally, the maximal marginality with respect to the wind influence index is registered at the scale of 500 meters from the presence cells (0.46) (Table 1).

Marginality of such variables as Prof_curv, Slope, Mass-balance index (used to assess erosion processes), etc. increases with scale decrease (Table 1).

Specialization remains practically the same with respect to all the variables, except for NDWI, NDVI, W (wetness), even if the scale of observation is changed.

DISCUSSION

This study is the first attempt to understand *F. coelebs* habitat preferences using the environmental niche factor analysis (ENFA) approach. The ENFA provides a suitable way to measure habitat selection under a large range of ecological contexts (Calenge, 2008). *F. coelebs'* high marginality in relation to NDVI, Green NDVI, Dem, Diffuse_insol, NDB4, wind proves that these factors are crucial for the species distribution.

The most important specialization factors are various vegetation indices (GVI (Ratio VI), NDB4 (chlorophyll activity), GR). This proves that *F. coelebs'* distribution largely depends on vegetation abundance and its habitats are restricted within a small range of shifts on these variables (Fesenko & Bokotej, 2002).

Computing habitat suitability maps allow us to identify those suitable areas that are not yet or no longer colonized and those critical areas that need to be preserved, such as faunistic corridors (Abade *et al.*, 2014).

On the basis of the niche spatial parameters we may depict a patch most suitable for *F. coelebs,* lighter shades marking the highest degree of suitability. The optimal preference zone may be viewed as a potential niche (Hutchinson, 1965) and the locations where the focal species was observed and registered – as a realized niche. Obviously, not the entire potential niche of *F. coelebs,* with regard to its spatial parameters, is likely to be realized (Fig. 4).

Every species tends to occupy its own inherently suitable habitat, stipulated by its specific requirements to the environment (Hirzel & Guisan, 2002). Thus, since any area proves to provide a number of available resource units, any species may be characterized by a certain degree of use of these resources (Fig. 5).

"Weight of resource availability" is a portion of a study area containing the corresponding EGV. Total_weight of availability constitutes distribution of available resources. Weight of use describes how intensively a species uses resource units. This weight of use may be described as a portion of a species' occurrences, from their total quantity, within the area with the given EGV. Aggregate utilization weight represents the distribution of resources used (Demidov *et al.*, 2013). Therefore, distribution of resources used by *F. coelebs* differs from the distribution of resources within the area.

A new technique proposed in this paper and based on the scale changes enables a researcher to evaluate an ecological niche at different levels of survey.

The *F. coelebs* ecological niche surveyed at different scale levels allows us to make a number of points. First, a list of factors influencing the *F. coelebs* distribution changes essentially at different scale levels. Thus, with scale decrease the significance of all vegetation indexes reduces, i.e. they become less crucial for the *F. coelebs* distribution. This may be explained by the fact that the study area becomes more homogeneous.

Second, with scale decrease there come to the forefront finer details of the relief, which are not evident when the scale is higher. Therefore, decreasing the scale we may evaluate how the ecological niche is influenced by the variables: Prof_curv, Slope, Mass-balance index (used to assess erosion processes), etc.

Third, *F. coelebs'* specialization does not respond to the scale change. This proves that *F. coelebs'* distribution largely depends on vegetation abundance.

A new technique proposed in this paper proves fruitful from an ecological perspective, as it makes it feasible for observers, being on the same level with an object, to change their point of observation while performing their wildlife survey. Different scale levels reveal certain regularities with respect to the species distribution both locally and globally.

REFERENCES

ABADE L., MAC DONALD D.W., DICKMAN A.J., 2014, *Using Landscape and Bioclimatic Features to Predict the Distribution of Lions, Leopards and Spotted Hyaenas in Tanzania's Ruaha Landscape*. Plos one, **9** (5): e96261/

AUSTIN M.P., 2002, *Spatial prediction of species distribution: an interface between ecological theory and statistical modelling*. Ecological Modelling, **157**: 101-118.

BÜTLER R., LACHAT T., 2009, *Wälder ohne Bewirtschaftung: eine Chance für die saproxylische Biodiversität*. Schweizerische Zeitschrift für Forstwesen, **160** (11): 324-333.

CALENGE C., 2008, *A general framework for the statistical exploration of the ecological niche*. Journal of Theoretical Biology, **252**: 674-685.

CHASE J.M., LEIBOLD M.A., 2003, *Ecological Niches: Linking Classical and Contemporary Approaches*. Chicago, The University of Chicago Press.

DEMIDOV A. A., KOBEC A.S., GRICAN JU., ZHUKOV A.V., 2013, *Spatial agroecology and land recultivation: monograph*. Dnepropetrovsk (Publishing House Svidler A.L). (in Russian).

DOLGENER N., FREUDENBERGER L., SCHLUCK M., SCHNEEWEISS N., IBISCH P.L., TIEDEMANN R., 2014, *Environmental niche factor analysis (ENFA) relates environmental parameters to abundance and genetic diversity in an endangered amphibian, the fire-bellied-toad (Bombina bombina)*. Conservation Genetics, **15**: 11-21.

DOLNIK V.V., 1982, *Methods of studying birds' time and energy budgets*. Proceedings of the Zoological Institute, **113**: 3-37. (in Russian).

DURANT S.M., CRAFT M.E., FOLEY C., HAMPSON K., LOBORA A.L., MSUHA M., EBLATE E., BUKOMBE J., MCHETTO J., PETTORELLI N., 2010, *Does size matter? An investigation of habitat use across a carnivore assemblage in the Serengeti, Tanzania*. Journal of Animal Ecology, **79**: 1012-1022.

FESENKO H.V., BOKOTEJ A.A., 2002, *Birds of the Ukrainian fauna: field reference book*. Kuiv (Publishing House Novyj druk) (in Ukrainian).