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REFLECTION OF THE ECOLOGICAL NICHE OF MUTE SWAN *CYGNUS OLOR* (GMELIN, 1803) IN GEOGRAPHICAL AND ECOLOGICAL SPACE

Kunakh O. M., Zhukov O. V., Holoborodko K. K.

INTRODUCTION

Geese live in all landscape-geographical zones. The biology of most species is associated with fresh, saline, and brackish water bodies. In nature, a rather limited number of habitats meet the nutritional requirements of gooseflies, primarily monotypic thickets of monocotyledons (in which meristem does not suffer from pinching), which are in the initial stages of growth. In winter, cereal meadows slightly south of the snow line are ideal for this purpose. In more southerly areas they grow quickly and coarsen, while to the north they are under snow or don't grow. Alternatively, succulent underwater parts of semi-aquatic grasses, reeds, sedges in shallow wetlands south of the freezing zone of water bodies. The results obtained earlier indicate that mute swan occupies only a part of the ecological space represented by the study area[1].

Relief is a set of different in its morphology, genesis and age forms and elements of the earth's surface, and is a reflection of their spatial relationships. Relief analysis is a means of cognition of the landscape based on the Digital Elevation Model. The spatial distribution of topographic attributes can be used to indirectly measure the spatial variability of hydrological, geomorphological and biological processes[2]. Landforms, or units of landforms, are important landform parameters,

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[1] Andrushenko A.Y. and Zhukov A.V. (2016) 'Scale–dependent effects in structure of the wintering ecological niche of the mute swan during wintering in the gulf of Sivash', *Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University*, 6/3, P. 234–47.

[2] Moore I.D., Gessler P.E., Nielsen G.A., and Peterson G.A. (1993) 'Soil Attribute Prediction Using Terrain Analysis', *Soil Science Society of America Journal*, 57/2, P. 443–52.

each of which carries information about physical, chemical, and biological processes and parameters[3].

Sivash (Rotten Sea, Sivashi) – a shallow lagoon-type bay in the western part of the Azov Sea – is located in the southern part of Ukraine in the area of transition of its main continental part to the peninsula – the Crimea. The length of Sivash from south to north is 115 km, from west to east – 160 km, its total area with islands and shoals is about 2600 km². The gulf is characterized by a very complex configuration of the shoreline, the instability of the water surface, which is caused by runup and surge processes, and significant differences in the physical and biochemical parameters in different parts. The Sivash natural complex occupies the territories of Northern, Southern, Central and Western and Eastern Sivash. Areas with conditionally non-transformed geocomplexes account for 5.06%, weakly transformed – 14.29%, substantially transformed – 28.91%, and completely degraded – 14.8% of the territory. Water-accumulative geomorphological elements of marine origin include sandy-shell spits, hummocks and Sivash lowland. Sandy-shelly spits, hummocks and islands are widespread along the northern coast. The genesis of the spits is closely related to the geological structure of the shoreline, the shallowness of the sea, and the physical and geological processes that occur on the coasts. It is formed predominantly by sandy and sandy-shell deposits. More than 10 thousand hectares are on the islands, which serve not only as nesting places for a large number of near-water birds, but also as accumulations of migratory species. Vegetation cover of the coastal zone plays an important role in the development of wind-driven shores of Sivash Bay. The following types of vegetation are distinguished: solonchak vegetation, solonchak vegetation (short-, medium– and long-term flooding), aquatic vegetation (coastal areas and shallow water), sagebrush-grass steppe vegetation (coastal areas with cliffs higher than 4 m, which limits flooding of coastal areas by dew). It is reasonable to distinguish two types of island systems: islands of continental origin and islands and spits of accumulative origin, as the hydrology of islands is one of the main factors of vegetation distribution. It is shown that the maximum species diversity of nesting birds is characteristic of the most mosaic biotopes with good foraging and protective conditions.

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[3] Malinowska E. and Szumacher I. (2013) ‘Application of the catena concept in studies of landscape system dynamics’, *Miscellanea Geographica*, 17/4, P. 42–49.

1. Materials and methods

The studies were conducted in winter seasons within Sivash Bay in the period 2012–2016. During the study all goose species were counted, regardless of biotope and location. Three main counting methods were used: transect counts, point counts and absolute counts. Transect counts were conducted in zonal landscapes and were conducted on shuttle automobile routes within 10×10 km squares, and in wetlands along the shoreline. The width of the survey corridor was 7–8 km in good visibility, 2–4 km during rain and snowfall, and up to 500 m in fog (within these limits it was maximum for large species, and minimum for small birds and individuals that were in closed habitats with limited visibility). We surveyed the study area using an off-road vehicle, which allowed us to drive over thawed soil and moderately deep snow, including passage through large puddles and snow drifts. Point counts were conducted during stops while surveying monotonous open areas and different water bodies. In all cases territories and water areas were surveyed with 12-X binoculars and 60-X telescopes. Depending on the length of the day and quality of illumination, surveys were conducted during all daylight hours from 7:00–7:30 a.m. to 3:30–16:00 p.m. In addition to species affiliation, the number, biotope, geographical coordinates of single birds and centers of large accumulations, as well as, if possible, the age and sex of birds were recorded. The census data were recorded in special cards, plotted on maps at a scale of 1:200000, and then transferred to the geographic information database created in the ArcMap 10.0 software product. Statistical calculations were performed using the Project R "R: A Language and Environment for Statistical Computing"[4]. Two groups of data were considered as ecogeographic predictors. The first group includes the digital elevation model (DEM) and its derivatives[5]. The second group includes a set of vegetation indices derived from the Landsat 8 satellite image[6].

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[4] Andrushenko A.Y. and Zhukov A.V. (2016) 'Scale–dependent effects in structure of the wintering ecological niche of the mute swan during wintering in the gulf of Sivash', *Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University*, 6/3, P. 234–47.

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2. Ecological-niche factor analysis (ENFA)

Analysis of the obtained results shows that data on numbers of mute swan aggregations follow log-normal distribution (Fig. 1). The arithmetic mean of the number of aggregations was 532.1±203.1 ind. and the median was 129 ind. with a range of variation from 5 to 8000 ind. Arithmetic mean of a random quantity, the distribution of which differs significantly from normal law, is a biased estimate of the mean of the general population. The geometric mean is a consistent estimate of the mean when the random variable obeys the log-normal law. In our case, the geometric mean is 147.6 indices, and 95% of the clusters range from 91.7 to 237.4 indices. The coefficient of variation of natural data on the number of aggregations is 250.3%.

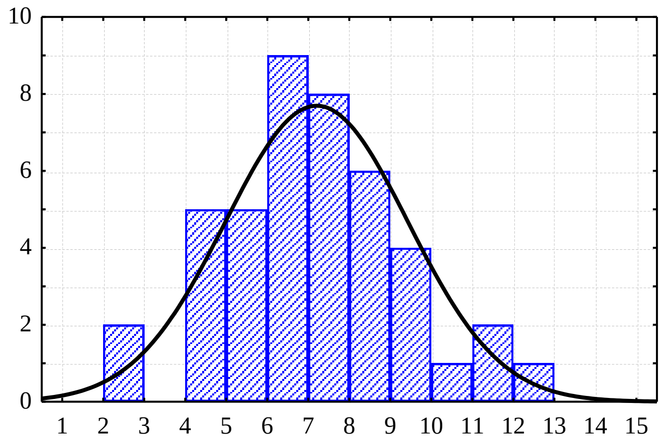


Fig. 1. Histogram of abundance distribution of mute swan (data are logarithmed on the basis of 2)

Figure 2 presents information on the spatial distribution of mute swan wintering aggregations in Sivash Bay. It should be noted that the resulting picture depends both on the real distribution of animals (objective component), and on the nature of the organization of the territory survey route (subjective-methodological component). Rapid estimation of the obtained results indicates the gravitation of mute swan accumulations to the coastal areas, which is quite natural and trivial for a waterfowl species. However, the question about the factors determining the spatial location of clusters and their numbers remains open. It can be assumed that the nature of such factors may be very diverse. In our study, we will focus on finding out the character of relief influence on the spatial location of mute swan accumulations during wintering.

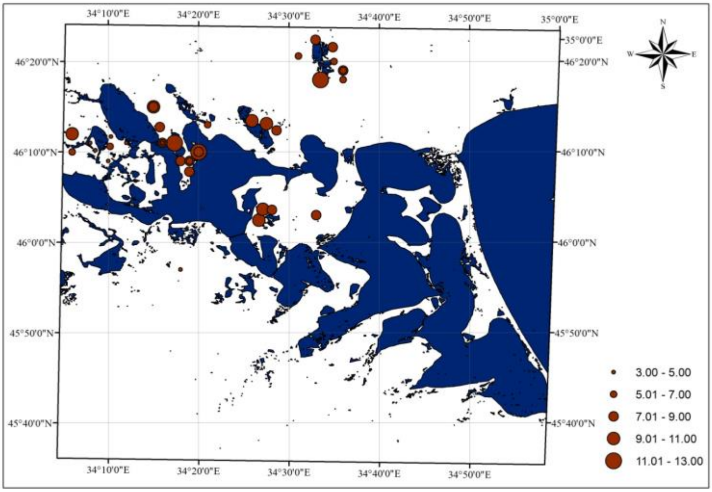


Fig. 2. Location of mute swan sightings (abundance is shown in logarithmic scale)

In the first stage, a total ENFA analysis was performed: all points of the raster that described the study area were used as pseudo-absence points. Figure 3 shows some of the eco-geographic variables that were applied to describe the ecological niche. We omit a discussion of the properties of the landscape environment that are reflected by the chosen list of ecogeographic variables, leaving only the phenomenological aspect of the set of predictors. We assume that these predictors may in some way describe ecological features of mute swan habitat.

An important result of even a cursory acquaintance with the spatial variation of ecogeographic variables is the conclusion that these indicators describe a level of landscape variability that may be essential for structuring the ecological niche of the species under study. Another important feature is the apparent discrepancy between the territory within which the presence of the species is established and the rest of the space. In a sense, the boundaries of the frame that covers the territory under study are rather conditional and subjective. But it is this subjective choice that determines the list of data that make up the points of pseudo-absence. Nevertheless, as a first step of the research, this approach is appropriate. The results of the ENFA-analysis (one of the variants of GNESFA) allow us to visualize the ecological niche of mute swan (Fig. 4).

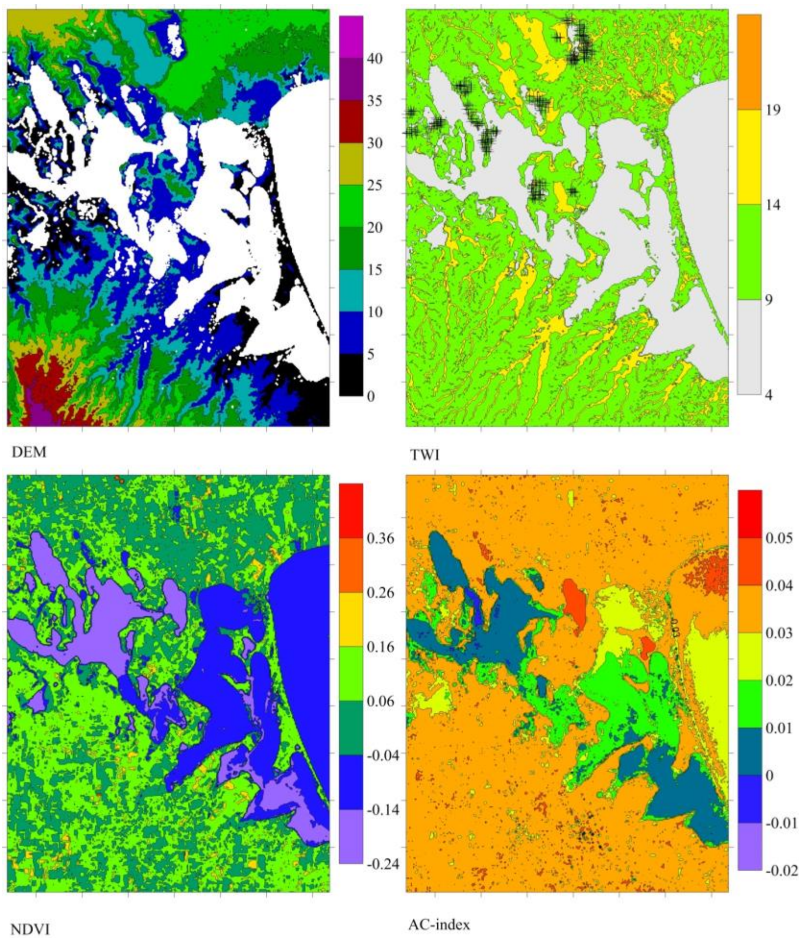
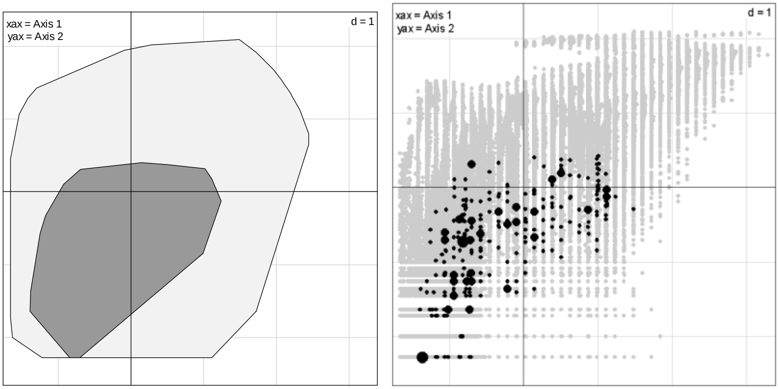


Fig. 3. Spatial variation within the studied polygon of some ecological and morphological predictors. The points of mute swan sightings are marked with a plus sign



A B

Fig. 4. Results of ENFA-mapping of the mute swan ecological niche during wintering: A – niche representation as a polygon; B – niche representation as occurrence points; abscissa axis – marginality, ordinate axis – specialization; dark ellipsoid (or dark points) – ecological niche, light ellipsoid (or light points) – – space of ecological factors

The results obtained indicate that the mute swan occupies only a part of the ecological space represented by the study area. This space within the ENFA-approach is described by the axis of marginality and axes of specialization, of which we consider the first two (Table 1). Since this stage of the study is the first approximation of the assessment of the properties of the ecological niche, we do not raise the question of the statistical significance of the axes yet.

The most sensitive markers of marginality of ecological niche of mute swan, established as a result of total ENFA, are relief height, distance from the nearest water body, erosion index LS and landscape diversity index. This indicates that the most favourable habitat conditions for Mute Swan offer the biotopes within the study area, which are located in low relief areas, close to water bodies, characterized by rugged microrelief with a high risk of erosion processes. The general landscape environment should be characterized by a high level of relief diversity, which in general for the anthropogenic-transformed region corresponds to the remnants of the biogeocenotic cover with a minimum level of transformation. It should be noted that the marginality of the ecological niche by vegetation indices is low, which indicates a low differentiating level of vegetation cover indicators for determining the ecological properties of the studied species at the total level.

Table 1

Correlation of the ecological niche axes of the whooper swan and ecogeographic predictors according to the results of the total ENFA

Ecogeographic predictors	**The axes of the ecological niche**		
	Marginality	**Specialization 1**	**Specialization 2**
Geomorphological predictors			
DEM	–0.22	–0.01	–
$WATER_{dist}$	–0.55	–	–
TWI	–0.17	–	–
TPI	0.04	0.01	–
MBI	0.10	–	–
LS	0.53	–	–
VRM	0.09	0.54	0.68
Vegetation predictors			
NDTI	0.05	–0.08	0.08
GREEN_NDVI	0.09	–0.75	–0.63
MNDW	0.09	–0.24	0.08
AC_INDEX	–0.17	–	–
CHLOR_A	0.08	0.05	0.01
HYDRO	0.06	–	–0.01
LSWI	0.16	–	0.17
NDB4B3	–0.02	–0.12	–0.16
NBR	0.15	0.26	–0.27
SHDI	–0.07	–	–
SH_LAND	0.43	–	–
SHAPE_AM	–0.16	–	–

Somewhat more important is the role of vegetation indices for determining the properties of ecological niche specialization axes. Aspects of specialization are the vegetation indices greenNDVI and NBR, as well as the geomorphological index VRM, a vector measure of terrain ruggedness. It can be assumed that the above predictors reflect the specific habitat conditions of the Eurasian swan within relatively little transformed natural areas. The obtained characteristics of the ecological niche made it possible to construct a map of mute swan habitat preference within the study area (Fig. 5). On the one hand, it is trivial to identify the upland positions of relief for the waterfowl species as the least preferred for wintering. More interesting is the result that biogeocenoses directly close to water areas turn out to be preferred by mute swan to a significantly different extent.

3. A mapping of ecological niche of animal in ecological and geographical space

Thus, the considered procedure allows to obtain a mapping of ecological niche of animal in ecological and geographical space. We have established that to describe the ecological niche of mute swan the remote sensing data, namely vegetation indices and digital terrain model and its derivatives are applicable. The factor analysis of the ecological niche allows us to visualize the niche in the space defined by the axes of marginality and specialization. The display in the geographical space of the niche is made in the form of a map of spatial variation of the habitat preference index. It is important to note that the specified procedure allows to form an integral and continuous representation of the degree of preference of certain stations by mute swan on the basis of point counts on the basis of a set of data obtained by means of remote sensing of the Earth.

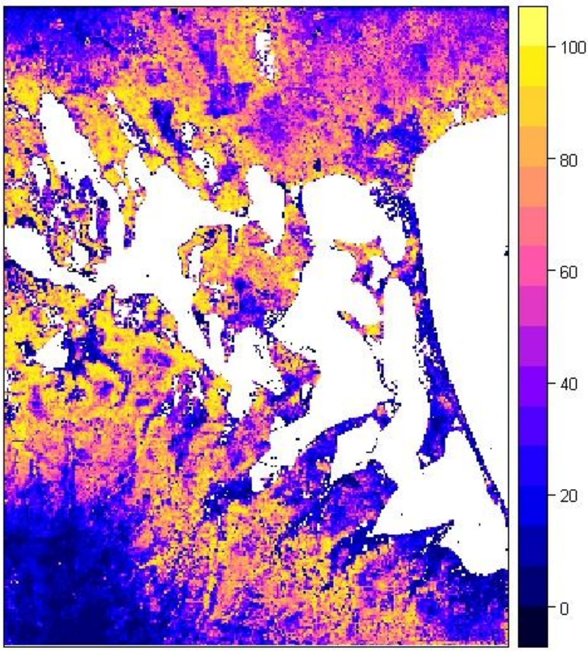


Fig. 5. Habitat suitability index of mute swan during wintering (in %)

The map of habitat preference can be used for the development of measures for the protection of this species. We distinguish its hierarchical scale-dependent organization as an important property of the mute swan ecological niche. To model scale-dependent effects, we applied the following methodological technique. The pseudo-absence points were not placed uniformly over the entire study area, as was done in the situation with the total variant of ENFA, but according to some rule. The pseudo-absence points were placed randomly, but at a distance not exceeding some boundary condition with respect to the experimentally determined points of species presence. There were 30 such boundary conditions ranging from 250 to 27,000 m. As an example of the location of pseudo-presence points, Figure 6 shows variants with boundary conditions of 2000, 5000, 10000, and 27000 m.

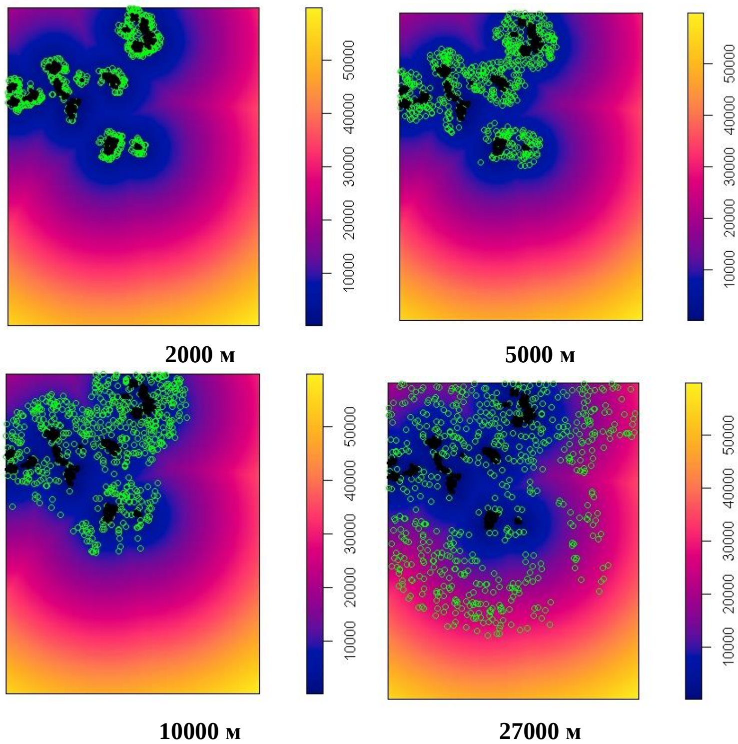
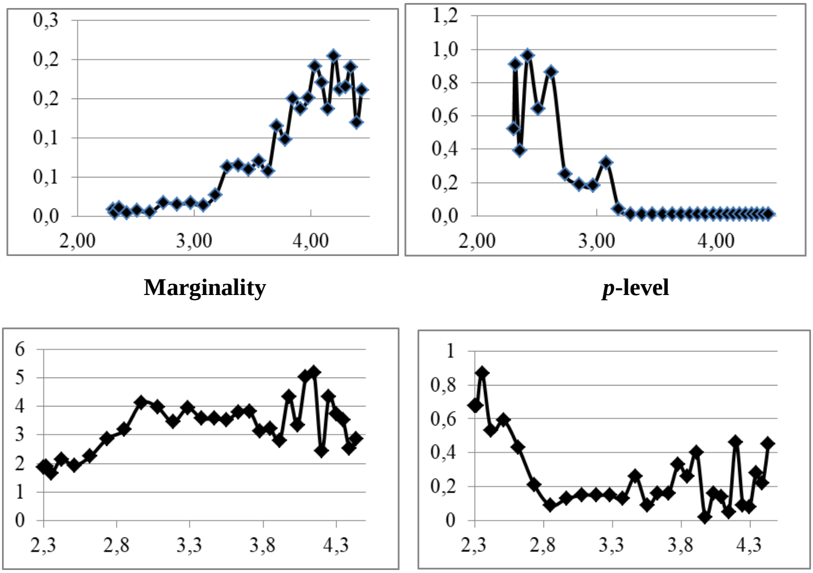


Fig. 6. Simulation of random placement of pseudo-absence points at distances of no more than 2000, 5000, 10000, and 30000 m from mute swan presence points

For each pseudo-absence point option, the characteristics of the corresponding ecological niche property assessment were calculated. The Monte Carlo method was also used to assess the reliability of the difference from zero of the global values of marginality and specialization for the corresponding assessments of ecological niche properties.

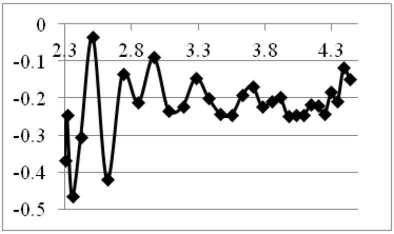


Marginality **_p_-level**

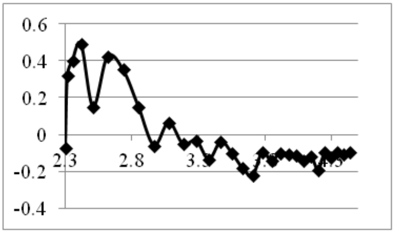
Specialization **_p_-level**

Fig. 7. Variability in the values of marginality and specialization, as well as their significance levels, depending on the boundary distance of the location of the points of the pseudo-absence (in m, logarithmic scale)

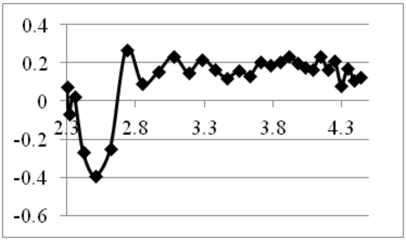
The presented methodological technique allows for the evaluation of ecological niche properties to gradually expand the range of conditions that are formed in the immediate vicinity of the meeting places of birds in nature. The results indicate that the global and partial marginal statistics strongly depend on the scale of the ecological niche consideration. Marginality of ecological niche estimates as a whole tends to increase as the boundary distance increases, and after a distance of about 10000 m, it reaches a plateau. This suggests that differentiating the ecological niche of the mute swan are the conditions that form within a radius of about 10 km from its localization sites. There is a statistically significant difference from the null alternative of marginality estimates for distances that begin to exceed 900–1200 m. Varying conditions within a radius less than this are not significant for the choice of preferred stations by the mute swan. The behaviour of the statistic which describes global specialization of the ecological niche is less monotonous in the range of boundary distances than the behaviour of marginality. Up to a boundary distance of 900-1200 m, there is an increase in specialization values, after which this index plateaus. It should be noted that at distances greater than 7000 m, specialization begins to vary very strongly near the stationary average level of this index. The level of statistically reliable difference in specialization from zero is observed from a distance of 700–800 m. However, at distances greater than 3000 m, very often the obtained estimates of the ecological niche are characterized by statistically unreliable values of specialization. Along with the variation in the boundary distance gradient of global statistics that describe marginality and specialization, there are rearrangements in the role of various ecogeographic predictors in determining these ecological niche properties. As an example, the figure shows the variation in some ecogeographic predictors. The results indicate that the role of elevation varies greatly depending on the boundary distance. In general, birds prefer locally lower terrain areas, but at a distance of 325 m the role of this predictor is close to zero. The topographic moisture index changes its value for the ecological niche exactly the other way round at a distance of 900 m: at smaller distances, the species prefers more moisture-enriched areas, and at larger distances, on the contrary, less moisture-enriched ones. The topographic moisture index depends on two terrain properties: slope angle and local catchment area. Obviously, in a generally level terrain, the slope angle will not be a significant differentiating factor. Within some immediate vicinity, elevated TWI may be characteristic of limited depressions of relief, which may be periodically flooded bottoms of estuaries. At the same time, they may be isolated from the catchment of a higher level, so when we increase the scale of consideration of the ecological niche, we will note that birds prefer biotopes with a lower TWI index value.



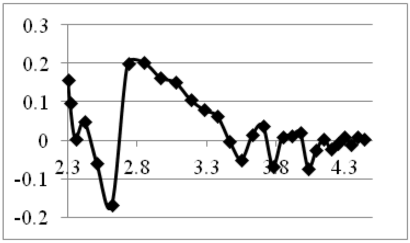
DEM



TWI



NDVI



AC-index

Fig. 8. Variability of marginal values of some ecogeographic predictors depending on the boundary distance of pseudo-absence points location (in m, logarithmic scale)

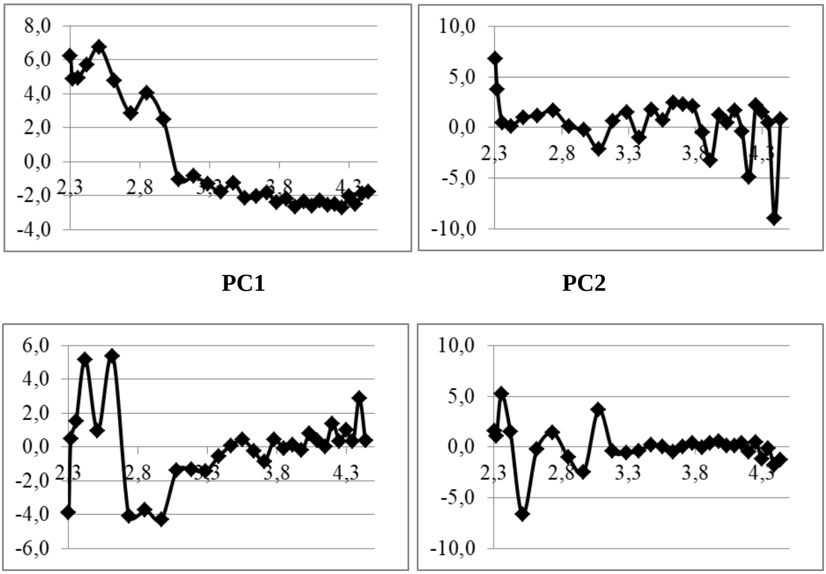
The role of the NDVI index also changes diametrically opposite when the boundary distance of pseudo-absence points increases. At distances up to 500 m, mute swan prefers localities with sparse vegetation cover. When examining the ecological niche at larger scales, we obtain information that indicates this species prefers denser thickets than exist in the area. A similar inversion is observed for the AC-index with the peculiarity that the stationary state which occurs after a distance of 2000 m indicates that this index is no longer involved in the formation of the marginality of the ecological niche. Obviously, enumerating the value of each ecogeographic variable for the formation of ecological niche marginality in the gradient of the boundary distances of pseudo-absence point locations does not bring us any closer to understanding the general mechanisms of ecological niche transformation at different scale levels. The dynamics of the variability of the role of various ecogeographic predictors has a certain degree of generality, which gives grounds for reducing the dimensionality of the space in which the corresponding dynamics is mapped. This task can be accomplished by means of principal component analysis. Application of principal component analysis allowed us to establish that eight principal components with eigenvalues exceeding 1 are sufficient to describe the variability of the ecogeographic role in the formation of marginality and specialization of the mute swan ecological niche (Table 2).

Table 2

Results of the analysis of the principal components of variability of the role of ecogeographic predictors in the formation of ecological niche marginality in the boundary distance gradient of pseudo-absence points location

Ecogeographic predictors	**PC1**		**PC2**		**PC3**		**PC4**	
	Mar	**Spe**	**Mar**	**Spe**	**Mar**	**Spe**	**Mar**	**Spe**
Geomorphological variables								
DEM	–	–	–	–0.81	–	–	–0.72	–
$WATER_{dist}$	0.66	–	–	–0.89	–	–	–	–
TWI	0.80	–	–	–0.77	–	–	–	–
TPI	–0.49	–	–	–0.84	–	–	–0.72	–
MBI	–	–	–	–0.57	–	–	–	–
LS	–0.77	–	–	–0.72	–	–	–	–
VRM	–0.77	–	–	–0.86	–0.38	–	–	–
Vegetation indices								
NDVI	–0.75	–0.72	–	–	–0.54	0.41	–	–
NDTI	–0.41	–	–	–0.56	–0.62	–	0.61	–
GREEN_NDVI	–0.81	–0.42	–	0.71	–0.47	–	–	–
MNDW	–	0.72	–	–0.40	0.84	–0.37	–	–
AC_INDEX	–	–0.42	–	–0.57	–0.77	–	–	–
CHLOR_A	–0.78	–	–	–	–0.51	0.40	–	–
HYDRO	–0.77	–	–	–0.64	0.43	–	–	–
LSWI	–0.84	0.61	–	–	–	–0.38	–	–
NDB4B3	0.61	–0.68	–	–	–	0.43	–	–
NBR	–0.81	–	–	–0.55	–	–	0.45	–
SHDI	0.55	–0.51	–	–	–	–	0.56	0.43
SH_LAND	–0.71	–	–	–0.76	–0.46	–	–0.39	–
Eigenvalues	9.88		8.34		5.23		4.43	
Explained variance, %	25.99		21.95		13.78		11.66	

These components describe 91.65% of the total variability of the feature space, i.e., they describe the phenomenon under study completely enough. Principal components 5-8 are characterized by a low level of generality, i.e., they describe the variation of one or more variables. Therefore, we consider only the principal components 1–4. The principal component 1 describes 25.99% of the total variation of the trait space. This component reflects variation in marginality in almost all variables and specialization in many vegetation indices. The values of principal component 1 are reversed when the boundary distance exceeds 1200 m (Fig. 9). Up to the boundary level of 900 m, principal component 2 has only positive values. With further increase in the boundary distance, this component, at the general level of positive values, exhibits regular and constantly increasing outliers into the negative region. Such dynamics indicates an unstable structure of the system of indicators, which reflect the peculiarities of the organization of the ecological niche in the aspect of its specialization at different scale levels.



PC1 **PC2**

PC3 **PC4**

Fig. 9. Dynamics of the values of the principal components 1-4 depending on the boundary distance: abscissa axis – boundary distance (km, logarithmic scale); ordinate axis – values of the principal components

The principal component 3 describes 13.78% of variation in the feature space and is associated with a predominant variation in the ecological niche, which is reflected by vegetation indices. Vegetation indices are characterized by a special value in the characterization of the ecological niche at boundary distances up to 2000 m, while at a distance of 500 m there is an inversion of values of this component, which indicates a significant restructuring of factors that determine the ecological niche of mute swan at different spatial levels.

The principal component 4 describes 11.66% of variation in the feature space. This component is predominantly associated with marginality on individual ecogeographic predictors – elevation, topographic position index, NDTI, NBR, landscape and relief diversity. The role of these indicators in determining the structure of the ecological niche is relevant at boundary distances up to 1500 m, after which their importance is leveled.

CONCLUSIONS

Mute swan uses biogeocenoses of Sivash Bay as hibernation places[7]. The question of interest is whether this area is ecologically homogeneous for this species or represents heterogeneous habitat, in which areas with a greater or lesser degree of suitability for life of this species are distinguished. It can be hypothesized that markers of landscape heterogeneity obtained from remotely sensed data can act as information-valuable predictors that characterize habitat heterogeneity for mute swan. The methodological basis for addressing this issue is the ecological niche theory and the concept of general ecological niche analysis[8]. Predictors are represented by two groups: digital elevation model and its derivatives, and vegetation indices. Based on each group of predictors, indexes of geomorphological and vegetation diversity of landscape cover were calculated. The total analysis of the ecological niche, carried out according to the classical procedure, is a very rough approximation of the ecological niche structure. Nevertheless, it showed that the selected predictors can be used to describe the ecological niche of the mute swan. In addition to subjective reasons, such as some arbitrariness in determining the framework of the studied polygon, the obtained result is influenced by the objective dependence of the properties of the ecological niche on the scale of its consideration. This is quite biologically explainable, since at different spatial levels different factors

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act as key ones. We were able to show this using the procedure of limiting by some distance the random placement of pseudo-absence points of the species. In the gradient of this distance, both total and private marginalization and specialization of the ecological niche show regular dynamics. At different boundary distances we can obtain quite different, but statistically reliable, estimates of the ecological niche structure of mute swan on the basis of landscape ecogeographic predictors. At some distances, smooth quantitative changes of ecological niche estimates change qualitatively. This suggests a discrete structuring of mute swan ecological space.

SUMMARY

The ecological niche is an important concept in modern ecology. This research presents the methodological approaches for representing the ecological niche in the geographical and ecological spaces. The main focus was on the ecological properties of the niche as a hierarchical structure. The results can be used in the management of protected areas.

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Information about the authors:
Kunakh Olga Mykolaivna,
Doctor of Biological Sciences, Professor,
Professor at the Department of Zoology and Ecology
Oles Honchar Dnipro National University
72, Gagarin avenue, Dnipro, 49000, Ukraine

Zhukov Olexander Viktorovich,
Doctor of Biological Sciences, Professor,
Professor at the Department of Botany and Horticulture
Bogdan Khmelnitsky Melitopol State Pedagogical University
20, Hetmanska str., Melitopol, Zaporizhzhia region, 72318, Ukraine

Holoborodko Kyrylo Kostiantynovych,
Candidate of Biological Sciences, Associate Professor,
Associate Professor at the Department of Zoology and Ecology
Oles Honchar Dnipro National University
72, Gagarin avenue, Dnipro, 49000, Ukraine