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ECOTONS IN LANDSCAPE'S ORGANIZATION OF THE DRY LAND SURFACE

The article substantiates the conception of ecotones. It has been mentioned that the most part of dry land is covered by various ecotones presented by ecotone landscapes – alternation of forests and tundra, forests and steppes, forests and savannas, etc. It has been noted that under global climate changes ecotones are gaining importance of general background in the context of the whole earth surface and landscape cover in general. Contrary to ecotone landscapes, boundary landscapes were singled out that have extreme values of climate characteristics. Arctic and antarctic deserts, deserts of tropical, subtropical and temperate zones belong to such boundary landscapes. Ecotones can exist not only at the planet level, but also regional and local levels (among altitudinal belts, river valleys, and watersheds). The size of the area covered by ecotones and their importance in the landscape covering of the earth determine the necessity to formulate the principles of a special scientific discipline ecotonistics (ecotone studies). The object of this discipline should be ecotones and the subject is the formation, dynamics and evolution of ecotones.

Keywords: ecotone, landscape, geosystem, anthropogenic component, phytocenosis, ecotonistics.

Денисик Г.І., Кисельов Ю.О., Сонько С.П., Шлапак В.П., Максименко Н.В. ЕКОТОНИ В ЛАНДШАФТНІЙ ОРГАНІЗАЦІЇ СУХОДОЛУ

Мета статті – обґрунтувати ландшафтну концепцію екотонів. Екотони – широкі смугоподібні субширотні утворення на земній поверхні з поступовим переходом від однієї природної зони до іншої. Зазначається, що більшу частину суші займають різноманітні екотони, представлені екотонними ландшафтами – чергування лісів і тундри, лісів і степів, лісів і саван тощо. Показано, що в умовах глобальних змін клімату екотони мають суттєве значення, як у контексті загального фону земної поверхні так і регіональних особливостей ландшафтних структур. На відміну від екотонних ландшафтів виділено прикордонні ландшафти, які

мають екстремальні значення кліматичних характеристик. До прикордонних ландшафтів належать арктичні й антарктичні пустелі, пустелі тропічного, субтропічного та помірного поясів. Екотони можуть функціонувати не лише на рівні планети, а й на регіональному та локальному рівнях (серед висотних поясів, долин річок, вододілів). Виокремлено геоботанічні аспекти екотонів на різних просторових рівнях. Звернено увагу, як на натуральні так і антропогенні екотони, зокрема викликані вирубуванням лісів у гірських районах. Розмір площ екотонів та їх значення в ландшафтному покритті землі зумовлюють необхідність формулювання принципів спеціальної наукової дисципліни – екотоністики. Об'єктом цієї дисципліни мають бути екотони, а предметом – становлення, динаміка та еволюція екотонів. У подальшому необхідні детальніші дослідження екотонних ландшафтів всіх рівнів організації ландшафтної оболонки Землі. Ці дослідження потрібно проводити ландшафтознавцям разом з екологами та фахівцями інших наук дотичних до досліджуваної проблеми.

Ключові слова: екотон, ландшафт, геосистема, антропогенний компонент, фітоценоз, екотоністика.

Introduction. Over a century of systematic development of landscape research, a wide range of theoretical and applied issues related to the spatial differentiation of the earth surface according to natural conditions have been posed and at least partially solved. Considering the natural landscapes (geosystems) as an alternative to the initial invariant of the fundamental transformation of the geographical envelope by man, the authors believe that it is to them (natural landscapes) that anthropogenic can return after our species disappear from the evolutionary arena. Therefore, modern anthropogenic landscapes, which are socio-natural systems, are already from the Paleolithic in the form of noospheric ecosystems "inscribed" in the landscape shell, which will always remain the primary in all attempts of man to get rid of him and his laws [Sonko, 2019]. Ecotonization is probably one of the most fundamental laws of the existence of the geographical envelope, which is confirmed in many works.

Research into the ecotonic organization of socio-natural systems may open new avenues for noospheric nature management.

1. Literature review. The term "ecotone" in 1928 was introduced into ecology by American botanist and ecologist Frederick Clements. By ecotone he understood, a transitional band between two contrasting geosystems, which, by virtue of its origin, cannot be attributed to any of adjacent geosystems, for example, the band between forest and steppe [3]. The whole history of the term "ecotone", its evolution from a purely biological, even phytocenotic concept to a geographical understanding of the term was considered by V.L. Andreeva and A.M. Kovalevskaya. They found that for a long time the issue of boundaries in landscape science was reduced to determining their location. Probably, the first who considered the border a specific and relatively independent subject of geographical analysis, was V.P. Semenov-Tian-Shansky. In 1928, he drew attention to vagueness (continuity) of landscape boundaries and proposed a formal method of isolating the transition lane between natural areas and the conditional linear boundary along that lane. However, these ideas did not find a proper response in the landscape pre-war landscapes [1].

Geographers got interested in the issue of boundaries due to the discussion about the discreteness-continuity of natural and territorial complexes, which unfolded in the mid-1950s. The boundaries of landscapes as ecotones of different widths were explored by Estonian geoecologists Y. Mander and Y. Yakomyagi. According to the perimeter and size of the contacting geosystems, they identified three types of ecotones: a) microecotons (when contacting individual parcels and geotope up to 40m in diameter); b) mesoecotons (contact forest – meadows, swamp – forest, etc.); c) macroecotons (occurring on the border of large forest or wetlands, large reservoirs,

etc.) [Yakomyagi, Kulvik, Mander, 1988].

Studies of ecotones in Ukraine are related, first of all, to works of H.I. Denysyk [6, 7], O.I. Sytnyk [8], O.D. Lavryk [18], L.I. Bezlatnia [2], T.V. Bobra [3], which mainly focuses on the patterns of formation, dynamics and evolution of ecotones in mountain and forest-steppe landscapes.

In the postwar period, the greatest influence on the western and world geography was caused by the works of the German scientists C. Troll (1963), J. Schmitthüsen (1962–1963) and K. Paffen (1967). In the second half of the twentieth century, there were numerous publications with research findings and landscape maps of individual natural and administrative regions (Mayen et al., 1962; Gvozdetsky, 1972; Klein and de Haes, 1994; Andersen et al., 1976; Mucher et al., 2006; Maksymenko, 2018, etc.).

"As a result of the development of the ideas of V.V. Dokuchaev, A.D. Gozhev, C. Sauer, K.I. Herenchuk on the anthropogenic impact on the landscape, since the 1970s, the focus of landscape scientists has gradually shifted towards the study of anthropogenic. The transformation of landscapes, which, according to F.M. Milkov [23] and H.I. Denysyk [5], from natural became anthropogenic." The idea of the cultural landscape was developed by O. Schlüter. A variety of landscaping studios has also been enhanced by the study of the spiritual component of the landscape since the 1990s, as an example of the work by M.D. Grodzinski [14] and O.P. Kovaliov [16]. Finally, from the beginning of the XXI century, in Ukraine, attention is paid to the study of interlandscape (interzonal, inter-zone) boundaries (ecotones), in the process of which their role as separate landscape systems, which are not inferior to the value of background zonal landscapes, is revealed. However, an in-depth and diverse study of anthropogenic landscapes indirectly began to exacerbate the most important problem – predatory nature use by human society. "Both the scientific substantiation of the mechanisms of formation and the classification of existing ones ("iron ore","uranium","forest-field" and other landscapes, gave the producers an effective tool for further advance on the biosphere, as the authors of this article have repeatedly written as well."

2. Methodology. The founder of a comprehensive approach in natural geography is a German scientist A. von Humboldt, who distinguished on the surface of the Earth phytoclimatic in nature, landscape zones in their essence [19], J. Wimmer in his work [34] deepened the proposed in the early nineteenth century by G. Hommeyer [10] the concept of landscape as a picture of the terrain, V.V. Dokuchaev [9] formulated the foundations of the doctrine of nature zones, in 1904-1914. At the same time, in the United States, prominent scientists R. Hartshorn and E. Hentington (1938) denied the possibility of natural zoning. However, R. Hartshorn was one of the initiators of large-scale field studies in the United States, who insisted that the main focus of geography was territorial differentiation, a mosaic of individual landscapes on the surface of the earth. The idea of natural territorial complexes was developed by the German scientist S. Passarge, whose ideas were closest to the Russian school of landscape scientists (H.M. Vysotsky, G.F. Morozov, L.S. Berg, A.A. Borzov, R.I. Abolin) [19].

Thus, foreign landscape studies, slightly ahead of the Russian landscape school in the field of applied, field and instrumental research, is far behind in terms of balance of theoretical concepts on which science stands. The works of L.S. Berg, S.V. Kalesnik, N.A. Solntsev made it possible to specify the concept of "landscape", to establish the scope of this concept, to indicate the features of its territorial expression. L.G. Ramensky and N.A. Solntsev laid the foundations of the doctrine of the morphological structure of landscapes,

whereas V.N. Sukachev and B.B. Polinov distinguished the structural and dynamic aspect in the study of landscapes [19, 20].

The **purpose** of the article is to substantiate ecotone as the main form of land surface organization of land.

Objectives of the article:

– to consider boundaries of physical-geographical zones in the conditions of natural evolution and anthropogenic changes of landscapes;
– to develop idea of continuity of landscape changes in space and time; - formulation of the definition of ecotone as the main form of organization of the earth's surface;
– to substantiate division of landscapes into "ecotone" and "boundary";
– to develop a scheme of landscape organization of the Earth land which is "landscape-ecotone tetrahedron";
– to define the object and subject of ecotonics as branches of landscape science.

3. Case studies. These days significant changes in natural objects take place. On the one hand, there are continuous physical and geographical processes, among which the most important is global warming and the associated spatial displacement of the boundaries of natural areas. On the other hand, the impact of human life on the environment over the past century has become such that it can now be ignored. Due to the anthropogenic factor, the appearance of the vast majority of the landscapes of the Earth, which, according to H.I. Denysyk [6], of natural origin became anthropogenic. At the same time, landscapes remained natural at the core, though they acquired indelible traces of human influence.

It is a good idea to carry out, in addition to the traditional physical and geographical zoning, structural and geographical zoning, which also takes into account anthropogenic transformation of landscapes. Such zoning is carried out for the territory of Ukraine with the isolation of forest, forest and field strips within its borders [8]. This scheme does not dispute, but complements the existing scheme of physical and geographical zoning.

The analysis of the two above mentioned schemes shows the absence of boundaries of structural and geographical bands to the north compared to the traditionally localized boundaries of natural zones (ecotones). We explain this inconsistency with the conservative stance of physical geographers who "do not notice" the results of the latest natural and anthropogenic processes, which together form a new reality, expressed in particular, in the earth-space displacement of ecotones. That is why the concept of anthropogenic landscape science was proposed in 1998 by one of the authors of the article [5], which takes into account the latest tendencies of changes of landscape systems.

In recent years, ecotones have become one of the most widespread objects of landscape research, which is natural in view of the inadequate localization of ecotones and their constant drift in the light of gradual changes in climate and degradation of soil cover. It is also noteworthy that, in current studies, structural-geographical ecotones are regarded not as clear boundaries (such as established boundaries of natural zones for decades) but as broad transitional bands.

However, we see the main basis for the striped, rather than linear, configuration of ecotones in another. We are convinced that there are fundamentally no sharp landscape changes, especially in the plains, where the angle of incidence of sunlight (and therefore the climate) when moving in space changes very slowly. We believe that most landscapes on the Earth's surface are ecotones, gradually moving from one type (subtype) to another. This is well illustrated by the example of the soil cover – the "mirror" of landscapes, which always has a varied pattern

associated with the action of a wide range of zonal, azonal, intro- and extrasonal factors.

Let us illustrate the example of the territory of Ukraine. In its plain part there are four natural zones (mixed coniferous-deciduous forests, deciduous forests, forest-steppe and steppe) and, as mentioned above, three structural-geographical strips – forest-pasture, forest-field and field. If the physical-geographical boundary of the forest-steppe and steppe is traditionally carried out approximately along the line Balta – Kropyvnytskyi – Dnipro – Zmiiv – Kupyansk, then, from the standpoint of structural geography, the area of continuous dominance of field landscapes is shifted to the north by almost 100 km within the forest field [30]. Based on the data of agrometeorological studies [25], we can conclude that the territory of the traditionally separated southern sub-zone of the forest-steppe is today objectively reaching the steppe zone [30].

It is easy to predict that conducting similar agrometeorological and agroclimatic studies in the northern sub-zone of the forest-steppe would also lead to the conclusion that the boundaries of the natural zones are moving. Also anthropogenic factor, in particular through deforestation, makes its adjustments to the ecotone boundaries. Together, the action of natural and anthropogenic factors is complementary, synergistic. On the one hand, the natural process of the steppe on the forest continues; on the other hand, one actively promotes deforestation. As a result, the boundaries of Polissya and the Forest-Steppe are becoming less clear. The distribution of forest vegetation in the Right-bank Forest Steppe ("Podilske Polissya", according to H.I.Denysyk) [6] may suggest extending the boundaries of the mentioned natural zones (ecotone) up to the middle part of the Forest-Steppe. Therefore, the ecotone between the zones of mixed forests and forest-steppe almost imperceptibly passes into the ecotone between forest-steppe and steppe.

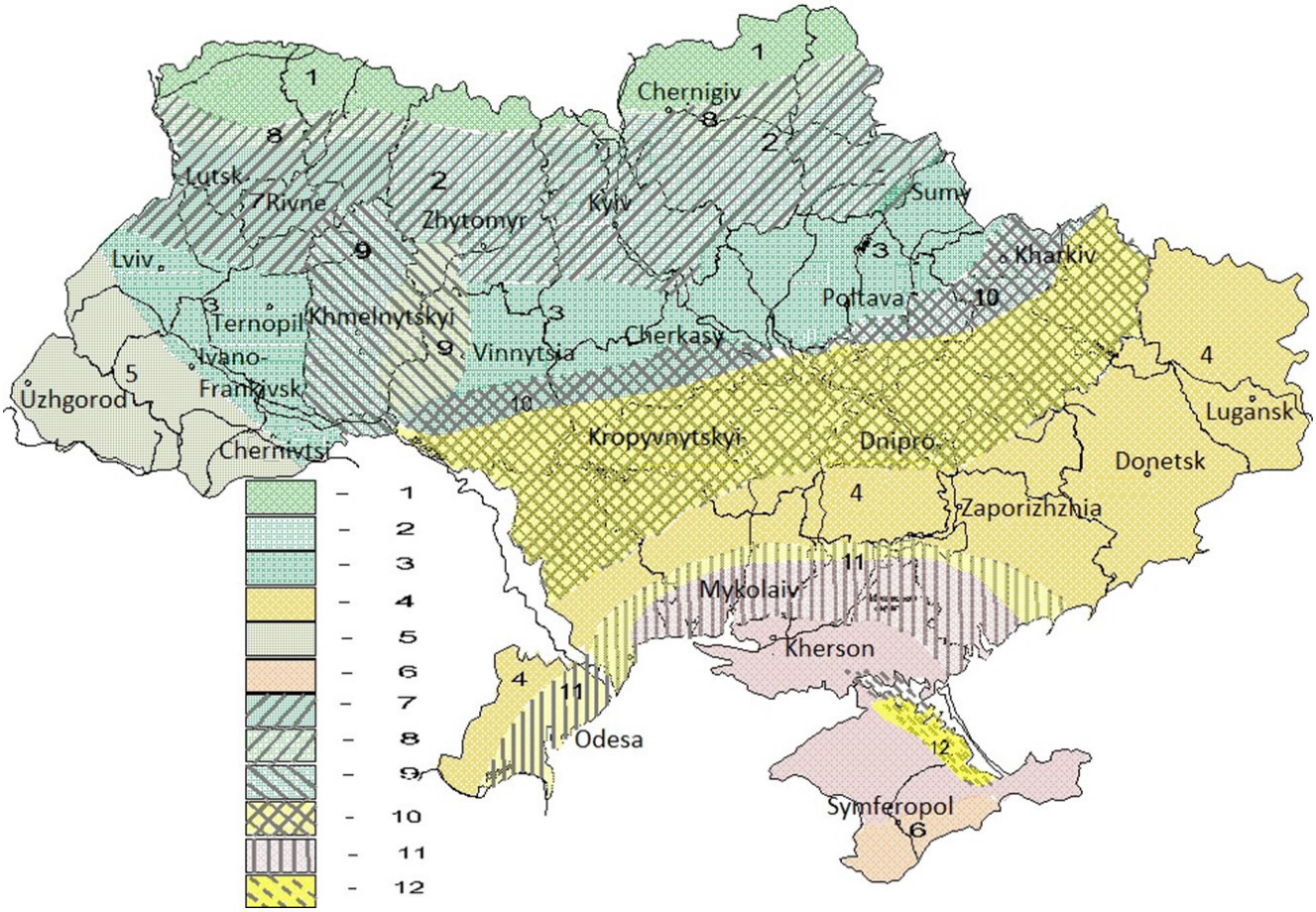
The above examples lead to the conclusion that ecotones predominate over "clean" landscapes in the temperate zone. There is no doubt that ecotone displacement will be detected in landscapes of any region, at least because modern warming is global. Since structural-geographical zoning does not cross out the physical-geographical zoning, at least the entire lane between the boundaries drawn by these zoning schemes can be considered an ecotone.

We believe that ecotone is the main form of terrestrial landscape organization, within which a striped gradual transition from one typological landscape characteristic to another is observed. It is precisely because nature does not have sharp boundaries that in any fragment of the earth space there is a gradual transition from one landscapes to the other – in the wide dimension the zoning is triggered, in the longitudinal sector is triggered. In the mountainous terrain, there is also a gradual change of some altitude zones by others, regardless of the diversity of the landscape structure of the slopes of different exposures. Such ubiquity of changes and transitions suggests that most landscapes on the Earth's surface are ecotones. Hence the constant variability of landscapes over time is associated not only with periodic and cyclic fluctuations, but also with irreversible changes caused by both natural and anthropogenic factors. We mean, in particular, those changes that are dynamic for individual components, but irreversible for the landscape as a whole. These are climatic rhythms of medium duration (600-700 years), which, although they suggest alternation of periods of warming-cooling and aridization-humidization, but even before the end of the next climatic cycle, can cause succession of the landscape. Even the example of an anthropic component in the context of mass migrations during the pre-industrial society can see this. As L.M. Gumilev emphasized, it is climate change (in particular, aridization) that is the cause of the

most massive invasions of nomadic ethnic groups on earth occupied by the settled population [11]. Such were, in particular, the Sarmatian invasion of Scythia-Proukraina in the IInd century till the Xth century, and Mongol-Tatar invasion of Rus-Ukraine in the XIIIth century.

Consequently, the fluctuations of the boundaries of natural zones caused by several hundred-year climatic fluctuations can also be considered as the basis for delineating latitudinal bands located between different boundaries as ecotones. In particular, in the territory of Ukraine it is possible to distinguish ecotones "forest – forest – steppe", "forest – steppe – steppe", "steppe – dry steppe", "dry steppe – semi – desert", etc. (Fig. 1). One ecotone goes to another, the boundaries are vague.

We believe that most of the Earth's landscapes are eco-tonic, intermediate. Exceptions are only those marked by extreme characteristics of a parameter. These are the three types of terrestrial landscapes: 1) Arctic and Antarctic icy deserts that have no equal in minimum heat combined with extremely low evaporation (and therefore excessive moisture) and very low (about 50-100 mm) annual rainfall; 2) tropical deserts (in particular coastal and inland) that are characterized by minimal humidity and rainfall at maximum heat; 3) moist equatorial forests, in which the thermal maximum is combined with the



Natural zones: 1 – mixed forests; 2 – deciduous forests; 3 – forest-steppe; 4 –steppe; 5 – Carpathians; 6 - Crimean mountains

Ecotones: 7 - mixed forests – forest-steppe; 8 - mixed forests – deciduous forests;9 - deciduous forests – forest-steppe; 10 - forest-steppe – steppe; 11 - steppe – dry steppe; 12 - dry steppe – semi-desert.

Fig. 1. Ecotones of the territory of Ukraine

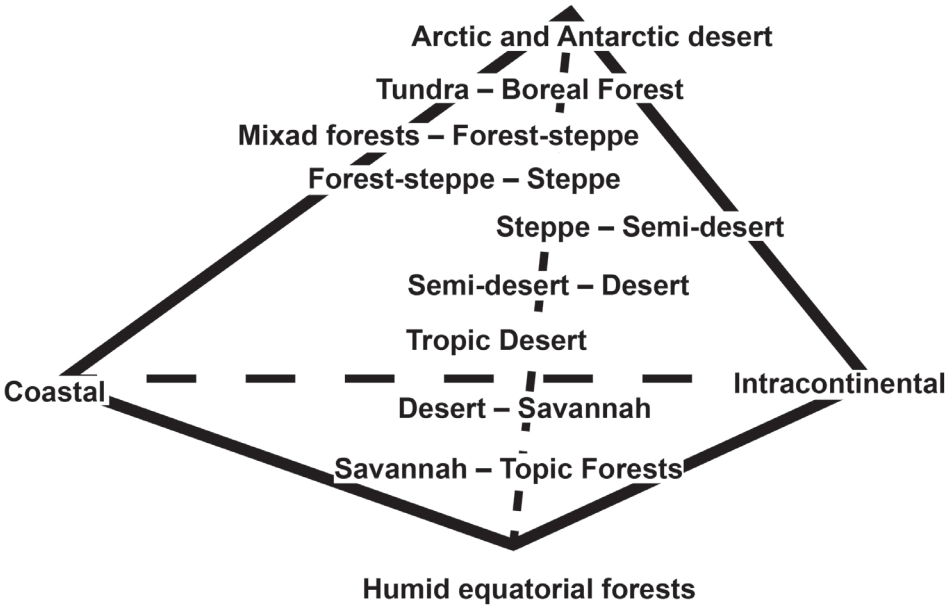


Fig. 1. Landscape-ecotonic tetrahedron

maximum of humidity and precipitation. These types of landscapes, as opposed to ecotonic ones, are called marginal ones.

All the diversity of Earth landscapes can be schematically depicted as a pyramid (tetrahedron), where ecotones ("intermediate" landscapes) are marked on the sides, and "boundary" landscapes at the corners at the base and at the top (Fig. 2). Compared to ecotones, "marginal" landscapes tend to occupy much larger areas (in particular, the icy deserts of Antarctica and Greenland, the Sahara Desert, the equatorial forests of the Amazon, etc.), as if their "basic" character, their formation, were expressed sectoral structure of horizontal land differentiation.

Ecotones are manifested not only on the interzonal (macro- and mesorenal), but also on the intra-zonal, within landscape complexes (microlevel). A striking example would be ecotones in forest landscapes. In particular, as part of the forest plantation, as noted by P.S. Pohrebnyak [26], S.A. Gensiruk [12], A.L. Belgard [2], V.P. Kucheryavy [17] are clearings – open, overgrown trees in the forest; gaps – areas of forest area where there are no trees, but elements of forest vegetation are preserved; forest edges – forest borders with treeless space, may be external and internal; felling – the area where the forest was completely cut down; the wall of the stand is the border of the forest and log cabin; the combustion is the area on which the forest is completely burned, and the waste land is the combustion or logging that has been in a treeless state for more than ten years and where they are formed, as emphasized by V.P. Kucheryavy [17] and H.I. Denysyk [8], V.P. Shlapak, Yu.F. Tereshchenko, T.S. Tsiomra, Yu. M. Melnyk [27, 28] ecotone bands, characterized not only by the width but also by the number of species, where species of both adjacent biocenoses are represented. At the same time, species that do not occur in either biocenosis are often inhabited in the ecotone zone. The ecotone also belongs to the research of N.V. Maksymenko, Ya. S. Zaichenko [22], D.M. Grodzinski [14], T.I. Shyika [29], for example, transition from field to forest, from field to field-protected forest strip, from field to roadside forest strip, covered with tree and shrubbery, as well as plowed plateaus and tillage, where diverse vegetation accumulates. In these cases, the ecotone represents a transition between two or more different physiognomic groups. At the same

time, as H.I. Denysyk [8] established, forest edges are not only a transitional but also a protective barrier (ecotone) between forest and field, forest and steppe. Their destruction impoverished both forest and steppe landscapes. Within the edges, processes develop that are inherent and distinct from forests and steppes. At a short distance (tens of meters) you can see almost all the landscapes that are characteristic of the forest-steppe, and therefore they are not only an integral but also a unique part of the forest-steppe. Without the edges of forest-steppe (its remnants) and forest-field cannot function normally.

Ecotones, as highlighted by V.S. Kansky [15], can be simple with even homogeneous surfaces in both cases; may have an invasion of one biocenosis into another; can characterize forest edges to significantly extend the ecotone without unduly altering the environment; can show the mutual mass penetration of two biocenoses (as, for example, what happens at the edge of the forest); an ecotone can be created by animals that modify the environment.

Forest ecotones, according to research by S.A. Hensiruk [12], M.D. Grodzinski [Grodzinski, 1993], M.A. Holubets [14], H.I. Denysyk [8], N.V. Maksymenko and others. [21] There is a high level of biodiversity, especially when they cover large areas and are stable enough over long periods of time. For example, in the forest-steppe of Ukraine, oak and broad-oak forests include hornbeam, oak (Right Bank) and maple-lime-oak (Left Bank) formations of common oak.

The stability of the formation of forest plantations is explained by the so-called phenomenon of ecotonic effect, that is, the increase of species richness due to overlapping of ecological amplitudes of species of different ecological and systematic groups. The most pronounced ecotonic effect is between ecologically contrasting settlements. The more different the phytocenosis habitat conditions, the better the composition of the ecotone species.

As an "ecotone in time," successive stages can be considered, when both old (changing) and new (emerging) sets of species function simultaneously; from these positions, the effect of reducing biodiversity in climax communities in comparison to earlier successive stages explains. As P.S. Pohrebniak points out [26], the time factor plays a large role in life of forest, though not obvious to an outside observer. The rate of change in forest composition is often so slow, that they can only be identified through complex research and a series of abstractions. At the same time, the most important sign of change is the change of major tree species. Time scales in the forest, as noted by V.P. Kucheriavy [17], have at least three types of changes.

Change of rocks as a consequence of the ontogeny of stands, that is, the development of individual generations of forests, starting from the self-seeding, undergrowth and ending with the old ones that have reached natural maturity, stand.

Change of rocks as a consequence of natural interference of the person and other external factors in the life of the forest and the process of restoration of the natural composition and structure of the forest. These processes are longer than those mentioned above, as they cover at best one, two or three generations of stands.

Rock change is a consequence of large-scale climate change events that occur over long periods of time. The concept of rock change was created by G.F. Morozov [24], who set in motion the categories that seemed unchanged, revealed the interconnection between forests of different composition, and showed that some of them are derived from the others. He revealed the logic of successions and the change of species, including spruce and pine – birch and aspen, oak – soft-wood, pine – oak, pine and oak – spruce, oak – related species (hornbeam) and more.

Given the extremely important role of ecotones in the zonal-sectoral organization of the earth's surface, we anticipate the emergence in the near future of a new branch of landscape research – ecotonistics, which will focus on the study of inter-landscape transitions, in particular configurations of the boundary territory, characteristics that combine the features of adjacent geosystems in this landscape, directions of natural and anthropogenically caused changes, etc.

The object of ecotonics is the ecotones of the earth's surface, the subject is the formation, dynamics and evolution of ecotones. So, continuous changes of the landscape environment, caused in our time by both natural and anthropogenic factors, inevitably cause the displacement of landscape boundaries. In addition, most landscaping systems are not homogeneous in terms of typology, and the transitions between them are rather blurred. This further complicates the drawing of boundaries and suggests the leading importance in the landscape organization of the terrestrial surface of broad boundary strips – ecotones.

Conclusion. The proposed definition of ecotone emphasizes its role as a major form of terrestrial landscaping. As the phenomenon of transience is spatially and temporally continuous, most of the land (especially in the temperate zone) is occupied by ecotones or "ecotonic" landscapes. Opposite them are "border" landscapes, localized in regions with extreme natural conditions. The relationship of the "ecotonic" and "boundary" landscapes on the earth's surface is illustrated by the landscape-ecotone tetrahedron.

Ecotones also occur at the micro level within one zonal type of landscapes. Examples are ecotones within a forest landscape (forest – meadow, forest – forest, etc.). The formation of ecotones in anthropogenic landscapes (transformed to varying degrees by humans) has been taking place since the origin of the reproductive economy, and our studies of the interpenetration of natural and human beginnings in the formation, in particular, of agricultural landscapes indicate that, in terms of geography, this is an almost vast field of research. Thus, ecotone research can become the content of a particular branch of landscape science – ecotonistics, which should focus on the study of natural boundaries in different types of landscapes.

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