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Synanthropization of Plant Cover under Conditions of Nature Conservation

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Abstract—General principles of the synanthropization of vegetation in natural reserves are characterized. This process manifests in the appearance of anthropophytes in the flora, the improved status of apophytes, and the formation of synanthropic plant communities in anthropogenic habitats.

The concept of synanthropization of plant cover was first proposed in the late 1960s and was formulated more explicitly in the late 1970s and early 1980s (Falinski, 1972; Kostrowicki, 1982; Olaczek, 1982, Gorchakovsky, 1979, 1984). It has been successfully developed by many botanists, especially in Poland, the Czech Republic, Slovakia, Germany, Russia, Ukraine, and Belarus.

We understand synanthropization as the strategy of adaptation of the plant world to environmental conditions changing or developing as a result of human activity. Manifestations of this process are very different: general simplification of the flora, the gradual disappearance of its regional features (trivialization), substitution of autochtonous components by allochtonous, the simplification of floral composition, a decrease in the productivity and stability of plant communities, and replacement of primary plant communities by secondary and synanthropic communities. Negative consequences of synanthropization manifest themselves on the species, population, and biosphere levels.

Creating a network of natural reserves (national parks, nature reserves, preserves, natural landmarks) is an important measure in protecting the plant world against the destructive anthropogenic effect. However, these areas are exposed to recreational, scientific, and economic activities. There are research stations and the posts of foresters with surrounding territories used for hay mowing and pasturing (although on a restricted scale) and containing a network of roads and paths. Because of this, it is impossible to completely protect these areas from the anthropogenic transformation of vegetation and the invasion of synanthropic plants. The only way to control these processes and reduce their negative consequences is to develop carefully thought-out measures taking into account local natural and socioeconomic conditions. To do this, we should know specific features of the anthropogenic transformation of vegetation in nature reserves located in different regions.

The results presented in this work concern the principles of plant cover synanthropization under conditions of nature conservation in the Southern Urals, in the Il'men State Nature Reserve established in 1920. The territory of the reserve, 303 km^2 in area, includes the Il'men mountain system extending meridionally, with average elevations of about 400–450 m and the highest point at 747 m a.s.l. Pine (*Pinus sylvestris*), larch–pine (*Larix sibirica, Pinus sylvestris*), and birch (*Betula pendula, B. pubescens*) forests of southern taiga type predominate within the reserve boundaries. Before establishing the reserve, its territory had been used for cutting trees to produce charcoal for smelting, and for mining rare and valuable minerals. A railway, the town of Miass with an automobile plant and other industrial works, several villages, and the lakes Bol'shoi and Malyi Kisegach, Chebarkul', Misyash, and Turgoyak with numerous health resorts and tourist camps are now in the immediate vicinity of the reserve. The Miassovo research station and 22 forester posts are located within the reserve boundaries. All these circumstances have certainly affected the current state of the flora and vegetation in the reserve.

This study was aimed at revealing the synanthropic component of the reserve flora, assessing the degree of flora synanthropization, determining the composition, structure, and distribution of typical plant communities in anthropogenic habitats, and estimating the degree of synanthropization of individual plant communities and their complexes in zones of the most intense anthropogenic impact.

We performed a route survey of all habitats exposed to the effect of human activities in order to determine the composition of synanthropic flora in the reserve. The results of previous floristic studies were also used. The vegetation of roads and paths was studied in transects. The roads were arbitrarily subdivided into ruts, the zone between ruts, and the roadside; the paths, into the rut and roadside. Transects were located along the components of roads and paths, and in the adjacent

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territory with intact vegetation. Sampling plots (0.1 m^2) were laid along the transects at 0.25-m intervals. Sampling plots 0.5 to 1 m^2 in area were used to study the synanthropic vegetation near houses.

Synanthropization of the Flora

The first very detailed study of the flora was performed in the Il'men Reserve from 1946 to 1948 by E.V. Dorogostaiskaya (1961). She made a list of vascular plants of this natural reserve, which includes 815 species. Rusyaeva (1985) supplemented this list with 15 species (including nine *Alchemilla* species endemic for the Urals and described by Yuzepchuk), and Erokhina (1996), with 18 species (excluding *Festuca kirilowii* the presence of which in the reserve is doubtful). In the course of our study, we found nine more species growing in the territory of the reserve. Hence, the flora of the reserve currently comprises 857 species. There are seven anthropophytes among the species found after 1948: *Hordeum jubatum* (reported by Rusyaeva), *Poa supina, Atriplex nitens, Malva crispa, Leonurus quinquelobatus, Artemisia absinthium*, and *Galinsoga parviflora* (our data). It is improbable that Dorogostaiskaya failed to notice these plants; more likely, all or most of these anthropophytes entered the territory of the reserve only recently.

Table 1 shows the taxonomic composition of the synanthropic flora of the Il'men Reserve at the level of families. Most species belong to the families Asteraceae, Brassicaceae, Rosaceae, Poaceae, Chenopodiaceae, and Fabaceae. In families Asteraceae, Brassicaceae, and Chenopodiaceae, synanthropic species are mostly represented by anthropophytes; in Rosaceae, by apophytes; and in Poaceae and Fabaceae, by anthropophytes and apophytes in approximately equal proportions.

The degree of anthropogenic disturbance of the aboriginal flora can be characterized by the index of synanthropization, i.e., the proportion of synanthropic species (both anthropophytes and apophytes) to the total number of species known for a certain territory. Another important parameter is the index of apophytization, i.e., as a proportion of apophytes to the total number of synanthropic species. In the Il'men Reserve, these indices are 24.27 and 34.61, respectively.

Table 1. Composition of the synanthropic component in the flora of Il'men' Reserve

No.	Family	Number of synanthropic species	Among them	
			apophytes	anthropophytes
1	Equisetaceae	1	–	1
2	Alismataceae	1	1	–
3	Poaceae	13	6	7
4	Juncaceae	3	3	–
5	Cannabaceae	2	–	2
6	Urticaceae	4	–	4
7	Polygonaceae	6	2	4
8	Chenopodiaceae	12	–	12
9	Amaranthaceae	1	–	1
10	Illecebraceae	2	–	2
11	Caryophyllaceae	11	6	5
12	Ranunculaceae	3	2	1
13	Brassicaceae	26	3	23
14	Rosaceae	20	18	2
15	Fabaceae	12	6	6
16	Geraniaceae	4	2	2
17	Euphorbiaceae	1	–	1
18	Malvaceae	3	–	3
19	Violaceae	3	1	2
20	Onagraceae	2	1	1
21	Apiaceae	8	5	3
22	Primulaceae	1	1	–
23	Convolvulaceae	2	–	2
24	Boraginaceae	7	1	6
25	Lamiaceae	10	6	4
26	Solanaceae	2	–	2
27	Scrophulariaceae	5	3	2
28	Plantaginaceae	4	1	3
29	Dipsacaceae	1	–	1
30	Asteraceae	38	4	34
	Total	208	72	136

Synanthropic Vegetation of Paths and Roads

The pattern of vegetation on the roads depends on their type, the intensity of traffic, the granulometric composition of the soil and ground, conditions of moistening, and the type of plant communities intersected by the road.

Specific environmental conditions develop on the roads and paths laid in a forest. The original vegetation (grass and moss cover, undergrowth) suffers from mechanical damage and degrades or is destroyed completely. The soil becomes consolidated, which leads to increased water evaporation and drainage from the surface, fine earth and humus washout, and the appearance of bare spots. Changes in surface temperature and moisture content become more pronounced. The soil loses humus and mineral compounds but becomes enriched with nitrates.

Denudation of the soil surface and destruction or deterioration of the original vegetation promote the invasion of anthropophytes and apophytes and the formation of completely or partially synanthropic communities. The sites denuded by trampling are mainly occupied by low plants that tolerate mechanical damage, reproduce quickly and intensely by seeds or vegetatively, and are capable of colonizing vacant territories and growing under insufficient or nonuniform soil moistening.

Effects of environmental changes and destruction of the original vegetation also manifest themselves on the shoulders of roads and paths, although to a lesser extent. The thinning forest canopy creates favorable conditions for forest–meadow herbage, and certain synanthropic plants, including relatively tall ones, also invade these sites.

The intensity of anthropogenic effects on individual parts of the road network is nonuniform and changes both during the same growing season and in different years. The nonuniformity of environmental conditions in the roads and paths, primarily on resulting from different degrees of soil consolidation, is responsible for the mosaic pattern and heterogeneity of developing plant communities, which often include species differing in their ecology and cenotic specificity.

The road network in reserves often changes its configuration; the load on it increases in some places and decreases in other places. Completely abandoned roads and paths are also found. The heterogeneity and instability of environmental conditions on the roads results in the mosaic and labile type of plant communities formed there. Floristic composition, the ratio of the species composing these communities, coverage, and other parameters fluctuate depending on the seasonal and annual changes of the load.

Synanthropic plant communities on the roads and paths can only exist under anthropogenic load. Slow regeneration of the original vegetation takes place when this load disappears, but synanthropic plants continue to participate in the stages of progressive successions.

Vegetation of forest paths. The paths running in the forest are subjected to lower anthropogenic loads than forest roads. However, the density of the surface soil layer increases here to 19 kg/cm^2 compared to 6 kg/cm^2 at the adjacent sites. Vegetation in the path is thinned (coverage comprises 20–30%), the plants are mechanically damaged, and their stems are broken. Species composition is simplified. At one site, for example, 17 species were found on the path, whereas 30 species were found on the shoulder, and 40 species were found in the control plot (primary community). The same forest, forest-meadow and meadow species grow on the path and in primary communities: *Trifolium lupinaster, Brachypodium pinnatum, Rubus saxatilis, Fragaria vesca, Calamagrostis arundinacea, Sanguisorba officinalis, Veronica chamaedrys, Antennaria dioica*, etc. Synanthropic species are also found: *Trifolium repens, Polygonum aviculare, Plantago major, Plantago media, Achillea millefolium*, etc.

Forest–meadow and meadow plants dominate on the shoulder; the admixture of synanthropic species is insignificant. Participation of forest species significantly decreases from the control plot to the shoulder and to the rut of the path.

Vegetation of forest roads. The roads are exposed to more significant anthropogenic effects than the paths. The soil is strongly consolidated and trampled down; the density of surface layer reaches 16 kg/cm^2 at the roadside, 22 kg/cm^2 in the area between ruts, and 25 kg/cm^2 in the rut (compared to 6–7 kg/cm^2 in control plots).

The composition and structure of vegetation on the roads depend on the conditions of their use: some roads are used regularly, whereas others are only used in certain seasons. Vegetation is trampled down, thinned, and synanthropizated more strongly on regularly used roads exposed to greater loads. The species composition of vegetation is simpler on the road itself than in the adjacent territory. For example, 10–16 plant species are usually found on the rut and 18–22 between the ruts on the roads exposed to moderate permanent load, whereas 40–50 species are found in the roadside and control plots.

Vegetation in the rut is thinned (coverage 5–15%), low, and composed of almost exclusively synanthropic species: *Poa annua, P. supina, Polygonum aviculare, Trifolium repens, Plantago media*, etc. Coverage between the ruts is higher (20–50%); the vegetation there includes both synanthropic and usual forest–meadow and meadow species. Along with the abovementioned plants typical for the rut, the following species are found here: *Deschampsia caespitosa, Geum urbanum, Poa angustifolia, P. pratensis, Carum carvi, Dactylis glomerata*, etc.

Vegetation in the roadside is closer (coverage 60–80%). It is composed of plants common for the grass cover of forests, with slightly increased participation of forest–meadow herbs and an admixture of synanthropic species, apophytes (*Deschampsia caespitosa, Agrimonia pilosa, Achillea millefolium, Geum urbanum*, etc.) and anthropophytes (*Elytrigia repens, Artemisia vulgaris, Plantago media*, etc.).

Synanthropic Vegetation near Inhabited Places

Economic activity affected territories immediately adjacent to the experimental base and posts of foresters, where the original vegetation is partly or completely destroyed. There are completely abandoned areas and places used for hay mowing and pasturing.

Mono- or oligodominant ruderal communities were formed in places that are not currently in use. A short description of the most characteristic communities follows:

Nettle community (*Urtica dioica*) replaced an abandoned kitchen garden. Herbage consists of cop.$_3$ *Urtica dioica*, sp.-cop.$_1$ *Leonurus quinquelobatus*, sp. *Elytrigia repens, Aegopodium podagraria, Poa angustifolia, Dactylis glomerata, Glechoma hederacea*, etc., a total of 21 species.

Table 2. Proportions and ratios of synanthropic species in some communities of anthropogenic habitats

Community	All species	Synanthropic	Including		Indices	
			apophytes	anthropophytes	of synanthropization	of apophytization
Nettle	21	18	8	10	85.8	44.4
Nettle–hemp	15	14	5	9	93.3	35.7
Thistle	33	30	13	17	90.9	43.3
Knotgrass	10	10	–	10	100	0
Herb–grass hay meadow	63	23	15	8	36.5	65.2
Degraded meadow (pasture)	42	19	10	9	45.2	52.6

Nettle–hemp community (*Cannabis ruderalis* + *Urtica dioica*) is located in an abandoned farmyard. The following species dominate: *Cannabis ruderalis* (cop.$_2$–cop.$_3$) and *Urtica dioica* (cop.$_2$), *Glechoma hederacea* and *Aegopodium podagraria* are less abundant (sp.), a total of 15 species.

Thistle community (*Cirsium arvense*) had formed on idle land, which has remained unplowed for more than 10 years. Grass stand is composed of: cop.$_3$ *Cirsium arvense*, sp. *Bromopsis inermis, Poa angustifolia, Aegopodium podagraria*, sol.-sp. *Phleum pratense, Chenopodium album, Geranium pratense, Elytrigia repens*, etc., a total of 33 species.

Knotgrass community (*Polygonum aviculare*) occupies clearings near inhabited places that are intensely trampled down. The soil in this places is highly consolidated. This is almost a pure thicket cop.$_3$ of *Polygonum aviculare* with a small admixture of common roadside plants sol.-sp.—*Plantago media, P. major, Trifolium repens*, etc. A total of 10 species.

In addition, more or less synanthropic communities are found near inhabited places in the meadows used for hay mowing and pasturing.

The ruderal communities mentioned above are mono- or oligodominant, and their floristic composition is unstable. We agree with Elias (1981) that these phytocenoses should not be classified according to Braun–Blanquet. They should be regarded as stages of succession or secondary communities.

Grass-herb hay meadow. Herbage is dense (coverage 80–85%), high, and is composed of cop.$_1$–cop.$_2$—*Deschampsia caespitosa, Leucanthemum vulgare*, sp.-cop.$_1$—*Prunella vulgaris*, sp.—*Trifolium medium, T. pratense, Lathyrus pratensis, Fragaria viridis, Filipendula vulgaris, Taraxacum officinale, Carum carvi*, etc., a total of 63 species.

Degraded meadow used for pasturing. Herbage is suppressed, thinned (coverage 40–60%), and composed of cop.$_1$–cop.$_2$—*Elytrigia repens, Deschampsia caespitosa*, sp.—*Prunella vulgaris, Glechoma hederaceae, Dactylis glomerata, Aegopodium podagraria, Urtica dioica, Trifolium repens, Taraxacum officinale, Plantago major*, etc., a total of 42 species.

The comparison of these data (Table 2) showed that the knotgrass community exposed to intense trampling has the simplest floristic composition and the lowest index of apophytization, whereas the grass-herb meadow is superior to other communities in species composition and has the highest index of apophytization.

DISCUSSION

Synanthropization of vegetation in preserved territories manifests itself in the appearance of adventive plants (anthropophytes) in the flora, the improved status of apophytes, and the formation of completely or partly synanthropic plant communities on roads, paths, and near inhabited places with strongly disturbed or destroyed natural plant cover, hay meadows, and pastures.

The roads and paths are the main migration routes through which synanthropic plants penetrate natural reserves and disperse within their boundaries. Anthropophytes and apophytes migrate from roadsides to adjacent areas with vegetation more or less exposed to anthropogenic effects.

There are numerous published data on the state of plant world in natural reserves (Marina, 1989; Mel'nikova, 1989; Ovcharenko and Rassokhina, 1989; Starodubtseva, 1987; Saksonov, 1989; Yamlev and Bondev, 1982; Falinski, 1961, 1968; Willard and Marr, 1970). An analysis of the literature provides evidence for a high level of anthropogenic transformation of flora and vegetation in many protected areas.

One of the oldest and well-protected natural reserves in Europe—Belovezhskaya Pushcha—can serve as an interesting example. According to Falinski (1961, 1968), this forest area was exposed to human influence from ancient times. The first evidence of human activity date back to the 10th century, and within the Pushcha itself, to the 16th century. Anthropogenic effects, primarily in the development of road network, became especially prominent from the mid-19th century. They resulted in the penetration of numerous adventive plant species. Anthropophytes account for 24% of the vascular plant flora in the Pushcha, and 2.4% of them are newcomers (neophytes).

The Voronezh Reserve belongs to natural reserves with highly synanthropic flora: Starodubtseva (1987) reported that synanthropic species comprise 40.35% of the total number of vascular plant species. Some introduced plants reproduce successfully and penetrate natural plant communities. Most occasionally introduced species grow in secondary habitats, but some of them settled in natural communities. Note that we also observed the expansion of *Malus baccata* and *Lonicera tatarica* in the Il'men Reserve. These plants penetrate plant communities adjacent to inhabited places, and *Malus baccata* dispersed in the Cheremshanka River valley.

Nukhimovskaya (1984) compared the proportions of synanthropic plants in the flora of 35 nature reserves in Russia and other countries of the former USSR and found that they vary from 1 to 40%. The lowest proportions were found in the reserves of the North (Vrangel Island, Kandalaksha), Siberia (Altai, Stolby, Barguzin, Zeya), Far East (Kronotskii) and Caucasus (Teberda). Conversely, high values of synanthropization are typical for the flora of reserves located in the desert zone. The Il'men Reserve (our study site) belongs to protected territories with moderate synanthropization of the flora (24.27%).

The analysis of published data and the results of our study show that the degree of anthropogenic transformation of vegetation in natural reserves can be estimated from the proportion of synanthropic plants in their floras (indices of synanthropization and apophytization), and the proportion of plant cover occupied by plant communities with different degrees of synanthropization.

High indices of synanthropization are evidence for a strong disturbance of natural plant cover, which leads to a decrease in the competitiveness of many aboriginal plants and facilitates the expansion of both anthropophytes and apophytes.

Index of apophytization is higher in the regions with more severe climatic conditions to which aboriginal plant species are better adapted than aliens. This index is also higher in certain biotopes in which the penetration of apophytes is restricted by unfavorable environmental factors (insufficient humidity, waterlogging, excess of mineral salts, presence of peat layer, etc.). The degree of anthropogenic load is also important: the proportion of apophytes and, consequently, index of apophytization are higher at sites with slightly disturbed plant cover. Representatives of aboriginal flora appear to be more competitive in such places than alien species.

CONCLUSION

The process of synanthropization of plant cover affects all parts of the Earth's surface covered by vegetation. This also concerns nature reserves, which cannot be protected from the invasion of anthropophytes and the expansion of apophytes.

The degree of anthropogenic transformation of plant cover in natural reserves and the level of its synanthropization depend on many natural, historical, and socioeconomic factors. The most important factors are as follows: (1) the type, duration, and intensity of anthropogenic effect on plant cover in a certain territory during the period before establishing protection management; (2) the size of natural reserve, its configuration, position in the zonal system of plant cover, current anthropogenic load; (3) the resistance of plant communities of the reserve to anthropogenic effects; (4) economic development of the territory adjacent to the reserve (the presence of villages or cities, transport communications, industrial works, farms, etc.).

Although the process of synanthropization is universal, it is possible to reduce its intensity and, taking into account local conditions, to prevent its negative consequences. Corresponding measures include: (a) formation of buffer zones around natural reserves; (b) functional zonation of their territory with identification and special protection of compartments containing the most valuable reference vegetation, which represent genetic and cenotic pools of the plant world; (c) rational organization of road network, with main communications running outside specially protected reference plots, (d) control over introduction of alien plants into protected territories.

In this relation, it is important to organize regular monitoring of changes in the flora and plant cover of natural reserves. Indices of synanthropization and apophytization of the flora and individual plant communities can be used as parameters characterizing the state of plant cover and ecosystems in protected territories.

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