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COMPARATIVE CHARACTERIZATION OF WOODY PLANT TAXA IN DIFFERENT URBAN HABITATS OF TALLINN, ESTONIA

Abstract. The aim of the study was to analyse the variation of woody plant taxa of urban vegetation with regard to land use and to distinguish different groups of urban habitats. Differences in urban habitats are determined mainly by land use. The variation between urban and suburban on the one hand and urban and forested sites on the other hand formed the most important compositional gradient on the woody vegetation. The number of woody plant taxa is the highest in gardens and the smallest in the yards of the Old Town. The woody vegetation of the urban areas is more heterogeneous than that of the gardens. It was found with the help of the hierarchic-agglomerative method that 11 different habitats fall into four groups, corresponding to the sizes of Sørensen's similarity matrices. The study sites covered an urban gradient from the town centre to suburban and forest-meadow-wetland complex.

Key words: Woody plant taxa, human influence, introduction, urban habitat, urban zone, urban gradient.

The diversity and species composition of urban vegetation are determined by the character and intensity of human influence. Preurban landscapes and vegetation, the evolution, structure, and the predominant functional type of a city, as well as some other factors have also a certain impact.

Urban ecosystems consist of a full spectrum from artificial asphalt road or stone building habitats to managed or natural forest habitats (Olsson, 1978). The large number of plant communities and species may usually be explained by the following factors: (1) growth of towns: towns were founded on the contact areas of different landscapes where the vegetation was more diverse; (2) great diversity of the urban landscape, including different structures of settlements, various uses of open areas, and many small-scale habitats, producing a great variety in the ecological environment; (3) human activities, which, either directly or indirectly, intentionally or unintentionally, continuously favour the invasion of alien species (Sukopp and Werner, 1983; Sukopp, 1987).

A major difference in community composition has been observed between central urban, suburban (semiurban), and the surrounding buffer, predominantly forested zone (between suburban areas and administrative boundaries of a city) with dispersed settlements due to differences in land use (Tonteri and Haila, 1990).

The impact of alien species is especially noticeable among the woody plants of urban areas. Their number sometimes exceeds that of the local spontaneously growing woody plants several times.

Artificial communities of woody plants, which have developed in different habitats, consist of species diverse in their environmental requirements and spreading. Many of them survive thanks to human care on the one hand and the interaction between the adaption of species and environmental conditions on the other.

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Below an analysis of the taxonomic composition of the woody plants of Tallinn, Estonia, and the relations between introduced plants and natural species in 11 habitats is presented. These habitats differ in their origin and later development, environmental conditions, functions, human influence, etc.

The material used in the present work is based mostly on the data collected by the authors and presented in several publications (Elliku et al., 1990a, b).

At the same time, the study is also based on gradient analysis which is used in the case of urban ecological studies of plants and animals.

Taxonomic Analysis of Woody Plants

On the basis of a list of woody plants (Elliku et al., 1990b), studies dealing with the vegetation of Tallinn .(Kukk, 1991; Ploompuu, 1991) and the supplements to them, 637 taxa of woody plants (without the territory of the Tallinn Botanical Garden) have been registered at present within about 1050 ha in Tallinn. At that, not all the roses (*Rosa*), fruit trees, and berry bushes, and all the varieties of spruce (*Pices abies*) and pine (*Pinus sylvestris*) were determined.

These 637 taxa fall into 50 families and 125 genera.

The 637 taxa contained 145 (22.8%) conifers from 13 genera (10.4%). Among the taxa there were 357 species (56.0%), 197 cultivars (31.0%), 42 hybrids (6.6%), 22 varieties (3,4%), 12 forms (1.9%), and 7 subspecies (1.1%) (Table 1).

The origin of the woody plants shows that 98 taxa (15.2%) are from East-Asia, 92 (14.4%) from Europe, 92 (14.4%) from North America, 11 (1.7%) from Siberia, 7 (1.1%) from Central Asia, and 3 (0.5%) taxa from the Caucasus. Woody plants of wide spreading (occurring in at least two of the above-mentioned areas) include 107 (16.8%) taxa and the number of cultivars and developed hybrids is 227 (35.6%).

In our conditions 254 of the taxa (39.2%) can be regarded as life forms of trees.

Of the registered 637 taxa of woody plants 97 (15.2%) belong to the spontaneous Estonian dendroflora. The number of local natural taxa in Tallinn is 70 (11.0%). All the other taxa are introduced woody plants, i.e. alien species and imported developed hybrids and cultivars.

Table 1

Distribution of woody plant taxa

Unit	Number	%	Conifers			Broad-leaved trees, bushes, etc.		
			Number	% of unit	% of conifer taxa	Number	% of unit	% of broad-leaved trees, bushes, etc.
Species	357	56.0	47	13.2	31.4	310	86.8	63.0
Hybrids,	42	6.6	2	4.8	1.2	40	95.2	8.1
incl. natural	10	1.6	—	—	—	10	100	2.0
Subspecies	7	1.1	2	28.6	1.4	5	71.4	1.0
Varieties	22	3.4	5	22.7	3.4	17	77.3	3.5
Forms	12	1.9	6	50.0	4.1	6	50.0	1.2
Cultivars	197	30.9	83	41.9	57.3	114	58.1	23.2
Total	637	100	145	22.8	100	492	77.2	100

Thus, it could be noted that the majority of the urban woody plants are imported plants, which are either directly or indirectly connected with human activities. A small part of these are represented by cultivated spontaneous dendroflora and the majority by anthropophytes (hemerophytes). The predominating taxa among anthropophytes are useful and ornamental plants which have been intentionally imported. Hence, as to woody plants, we deal mostly with cultivated (synanthropic) flora in urban areas.

Similarly to the index of synanthropic fauna (Jedryczkowski, 1979; Klausnitzer, 1987), the importance of the cultivated flora can also be characterized by a corresponding index (W_c):

$$W_c = \frac{H_{wp}}{S_{wp}}, \qquad (1)$$

where H_{wp} denotes the number of the taxa of cultivated (adapted native and alien) woody plants and S_{wp} is the number of the taxa of woody plants in urban areas.

Indices found in the similar way may be used as indicators of introduction (W_i) and horticulture (W_h):

$$W_i = \frac{J_{wp}}{S_{wp}}, \qquad (2)$$

where J_{wp} is the number of introduced (alien) plants in urban areas.

$$W_h = \frac{C_{wp}}{S_{wp}}, \qquad (3)$$

where C_{wp} is the number of cultivars in urban areas.

In Tallinn, the values of these three indices are 0.89, 0.84, and 0.31, respectively.

Peculiarities of the Distribution of Woody Plant Taxa in Different Habitats

The abundant material about the vegetation of Tallinn (Elliku et al., 1990a, b; Kukk, 1991; Ploompuu, 1991) allows us to analyse the taxonomic differences of woody plants within 11 habitats. The character and distribution of the taxa in the subject habitats are shown in Tables 2 and 3. In relatively natural habitats, both spontaneously growing species and planted and naturalized woody plants were counted.

The areas having the greatest number of species in Tallinn are gardens (Table 3). In these gardens there grow 76.8% (489 taxa) of the registered woody plants. Gardens are followed by urban parks and yards and gardens of former suburbs, where respectively 225 and 200 denominations of woody plants grow, i.e. 2.2 and 2.4 times less than in gardens. The number of taxa which grow only in gardens is 228, i.e. 35.8% of all the woody plant taxa in Tallinn.

The smallest number of taxa was detected in the yards of the Old Town and on railways — 75 denominations, i.e. 6.5 times less than in gardens.

The largest number of the taxa of registered conifers can also be found in gardens — 133 denominations (91.7%) — and the smallest number on railways — 2 denominations (1.4%). The relative importance of conifers in the number of the taxa of the corresponding category is the largest in cemeteries — 28.5%, and the smallest on railways — 2.6%.

The distribution of natural taxa, introduced plants, etc. in different habitats is shown in Table 3. The relative importance of spontaneously growing woody plant taxa in Tallinn amounts from 7.2% (gardens) to 57.4% (natural areas) and that of introduced plants in them from 89.5% to 32.2%, respectively.

The values of the indices W_c, W_i, and W_h range from 0.43, 0.32, and 0.03 (relatively natural habitats in town) to 0.93, 0.90, and 0.35 (gardens), respectively (Table 3).

In the relatively natural habitats of town the ratio of spontaneously growing woody plants and introduced plants is 1 : 0.6 and in the gardens this ratio is 1 : 12.5.

Fig. 1 and Table 4 describe the occurrence frequency of woody plant taxa. An overwhelming majority — 329 denominations (51.6%) — of the taxa grow within the limits of only one habitat (frequency 9.1%). Of these 69.3% (228 denominations) can be found only in gardens.

In all the 11 habitats (frequency 100%) 22 taxa of woody plants were registered. Twelve of them are of native origin (54.5%).

Table 2

Distribution of woody plant taxa in different habitats

No.	Habitat	No. of taxa	% of taxa	No. of conifer taxa	% of taxa of habitat	% of conifer taxa
1.	Relatively natural habitats of town border (the forest-meadow-wetland complex situated as green belt and green wedges)	115	18.0	13	11.3	9.0
2.	Forest- and park-like areas (parks of former summer estates situated as "islands" in various urban zones)	165	25.9	25	15.2	17.2
3.	Urban public parks	225	35.3	22	9.8	15.2
4.	Small open green areas	139	21.8	14	10.1	9.7
5.	Green areas of various density and different tall buildings in new districts of free planning	182	28.6	20	11.0	13.8
6.	Park- and forest-cemeteries	123	19.3	35	28.5	24.1
7.	Gardens (mainly privately owned) in different suburbs	489	76.8	133	27.2	91.7
8.	Yards and gardens of dense stands in block complex of former suburbs around the Old Town	200	31.4	25	12.5	17.2
9.	Yards of the Old Town	75	11.8	4	5.3	2.8
10.	Streets	104	16.3	13	12.5	9.0
11.	Railways near railway stations	75	11.8	2	2.7	1.4
	Total	637	—	145	22.8	—

Table 3

Distribution of woody plant taxa characterizing human impact in different habitats

No. of habitat (corresponding to Table 2)	No. of natural taxa		Woody plant taxa cultivated in Tallinn (synanthropic plants)	Introduced plants	Cultivars	W_c	W_i	W_h
	in Estonia	in Tallinn						
1.	78	66	49	37	4	0.43	0.32	0.03
2.	41	28	137	124	27	0.83	0.75	0.16
3.	38	25	200	188	43	0.89	0.84	0.19
4.	31	25	114	108	29	0.82	0.78	0.21
5.	48	33	149	134	27	0.82	0.79	0.15
6.	38	32	91	85	24	0.74	0.69	0.20
7.	51	35	454	438	171	0.93	0.90	0.35
8.	37	24	176	163	37	0.88	0.81	0.19
9.	21	16	59	54	8	0.79	0.68	0.11
10.	29	22	82	75	15	0.79	0.73	0.15
11.	37	31	44	38	2	0.59	0.51	0.03
Total	98	70	567	538	198	0.89	0.84	0.31

To characterize habitats on the basis of more frequently occurring tree species, we used the concept of the average frequency of species (F_a) within one and the same habitat. The higher the index, the bigger the number of taxa of the highest frequency in the corresponding habitat. This index is the smallest in gardens — 30.3%, and the highest in the yards of the Old Town — 80.0%.

In the following analysis of habitats their taxonomic difference (*resp.* similarity) was determined with the help of Jaccard's and Sørensen's coefficients (Masing, 1979):

$$K_j = \frac{c}{a+b+c}, \tag{4}$$

where K_j is Jaccard's coefficient, a — the number of certain taxa in one babitat, b — that in another habitat, and c — the number of common taxa in the compared habitats;

$$K_s = \frac{2_c}{a+b+2_c}, \tag{5}$$

where K_s is Sørensen's coefficient.

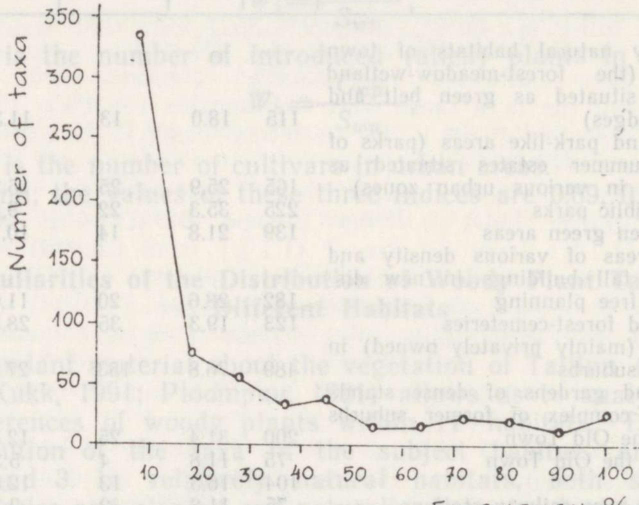

Fig. 1. Distribution of the frequency of woody plant taxa on the basis of 11 habitats.

Table 4

Distribution of taxa frequency

Category and/or number of categories	Frequency, %	Number of taxa of corresponding frequency	%	Average frequency of taxa of corresponding category, %
1.	9.1	329	51.6	53.4
2.	18.2	78	12.2	62.0
3.	27.3	53	8.3	49.9
4.	36.4	33	5.2	65.7
5.	45.5	35	5.5	57.7
6.	54.5	16	2.5	65.1
7.	63.6	16	2.5	30.3
8.	72.7	21	3.3	57.8
9.	81.8	20	3.1	80.0
10.	90.9	14	2.2	72.5
11.	100	22	3.5	68,9

The smallest difference (*resp.* the greatest similarity) was detected between the habitats of new housing districts (Mustamäe, Lasnamäe) and yards and gardens of former suburbs (Kalamaja, Kadriorg, and the area of Süda Street) where Jaccard's coefficient was 0.549 and Sørensen's coefficient 0.709 (70.9%).

The greatest difference (*resp.* the smallest similarity) appears between the woody plants of gardens and railways. Jaccard's and Sørensen's coefficients are here 0.117 and 0.210 (21.0%). Therefore, the scale of Jaccard's coefficients amounts from 0.117 to 0.549 and that of Sørensen's from 0.210 (21.0%) to 0.709 (70.9%).

On the basis of the matrices of Jaccard's and Sørensen's coefficients, dendrograms characterizing the grouping of habitats with the help of hierarchic-agglomerative method (Spath, 1980) were drawn up, where habitats join in the order of coefficient size. Therefore, a dendrogram characterizes the concentration of habitats in the direction of the decrease of their dendrofloristic similarity (*resp.* the increase of their dendrofloristic differences).

As the type of the grouping of habitats on the dendrogram turned out to be the same in the case of both matrices used, we present here only the dendrogram drawn up on the basis of Sørensen's similarity coefficients (Fig. 2), as the maximum coefficients are greater here than Jaccard's.

Fig. 2 shows that dendrofloristically close comparable groups develop from the following habitats (at the distance of 0.5 units):

(1) relatively natural habitats of the town and railways;

(2) cemeteries, small green areas, streets, and yards of the Old Town;

(3) yards and gardens of former suburbs, urban parks, green areas in new districts, and forest- and park-like areas of former summer estates;

(4) gardens.

This indicates that habitats having similar peculiarities of vegetation and/or human influence and also uniformity (similarity) or variety (complexity) of inner diversity, are closer.

There is an exception to this — relatively natural areas (mainly forests) and railways. The relation between them is purely dendrofloristic, although indirectly connected by the peculiarities of vegetation.

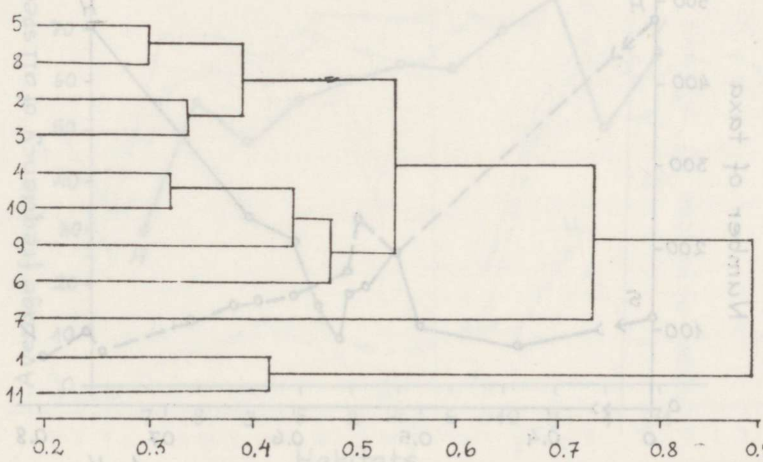

Fig. 2. Dendrogram on the basis of the value of Sørensen's index, obtained by hierarchic-agglomerative method. Numbers on the scale characterize the increase in the difference between various habitats.

Gradient Analysis

The growth of urban ecosystems, their diverse and long-time development, type of constructions, and the peculiarities of the functional use have created an inner zoning which is reflected in diverse land use and zonal use of different categories of green areas. The essence, size, location, penetration into each other, and the abruptness, dispersiveness or sharpness, etc. of the borders vary between ecosystems.

The zones may be differentiated on the basis of the development of settlements, peculiarities of land use, location of green and bare areas, intensity of human impact, etc. (Sukopp, 1982; Klausnitzer, 1982, 1987; Sukopp and Werner, 1983; Haila et al., 1989; Jackowiak, 1990; Tonteri and Haila, 1990).

In Tallinn, the following general zones could be distinguished, which, in some places, are broken up by roads, railways, etc., deeply penetrating into each other, with dispersed or sharp borders, and of different sizes:

(1) Town border zone, mainly covered with forests (the forest-meadow-wetland complex) but also with cemeteries, quarries, dumps, some summer cottages or private houses, and former summer estates.

(2) Disconnected zone of summer cottages and garden towns (Muuga, Merivälja, Mähe, Pirita, Kose, Maarjamäe, Nõmme, etc.)

(3) Zone of mainly 2—5 or 5—9-storey buildings in new dwelling districts of free planning (Õismäe, Mustamäe, Lasnamäe) and industrial areas (Sõjamäe).

(4) Zone of former suburbs (sections with relatively densely situated low buildings and a few parks) and industrial areas.

(5) Park zone consisting of former bastions around the Old Town.

(6) Old Town sections with densely situated buildings together with smaller green areas (uptown and downtown areas).

In all the zones a specific structure of land use and habitats with the corresponding environmental conditions and life communities has developed. Therefore, quantitative and qualitative differences can be noticed when passing from one zone into another. The variations may be expressed in the form of a gradient and studied by gradient analysis (Klausnitzer, 1987; Tonteri and Haila, 1990).

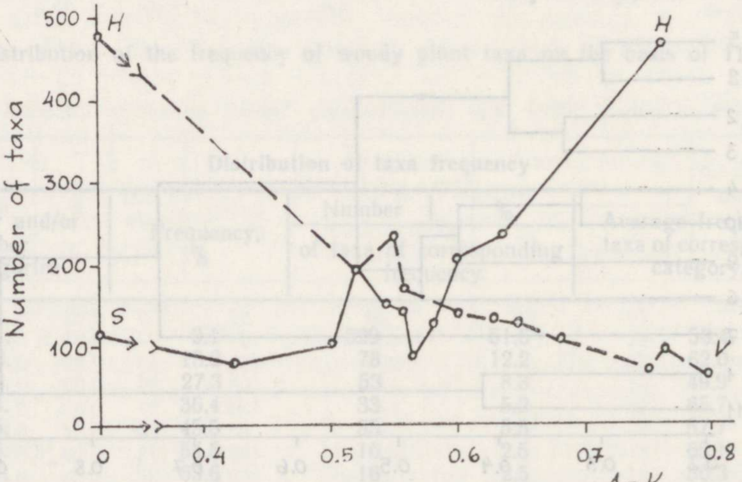

Fig. 3. Dependence of the number of taxa on Sørensen's index on the *S—H* and *H—V* gradients based on the similarity of dendrofloras.

For example, transition from agriculture to gardening has been analysed with the *R—H* gradient (Lat. *rusticus* — village, and *hortus* — garden). *R—M* (Lat. *rupes* — rock, and *murus* — wall) and *A—E* (Lat. *arbor* — tree, and *eremus* — desert) gradients are also well known. The latter characterizes a transition towards the centre of the town, starting from forests and passing meadow communities up to the landscape of the "stone town". This is one of the most thoroughly studied gradients, especially from the aspect of fauna (Klausnitzer, 1982, 1987).

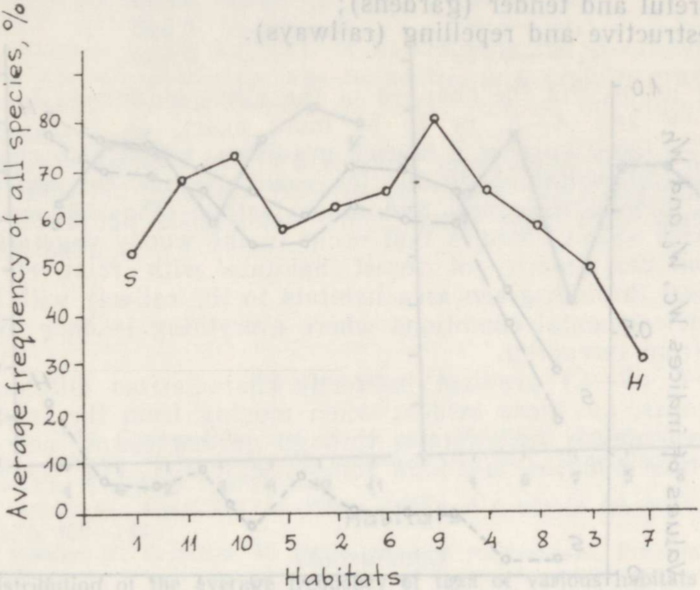

Fig. 4. Distribution of the average frequency of taxa of various habitats on the *S—H* gradient.

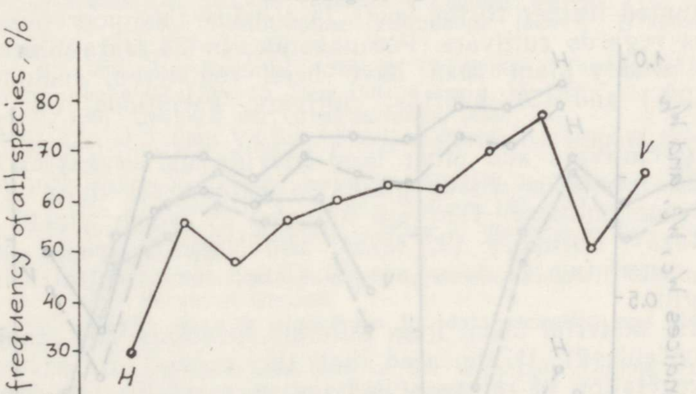

Fig. 5. Distribution of the average frequency of taxa of various habitats on the *H—V* gradient.

Let us see how the number of taxa and the role of natural species and introduced plants change on different gradients. In the case of two gradients, the location of habitats depends on dendrofloristic similarity expressed by Sørensen's coefficients (Fig. 3) and in the case of the other two, on the diversity of environmental conditions and inner variety of habitats, peculiarities of human influence, and other factors.

On all the gradients the following three-grade human influence can be observed:

(1) preserving and careful (forests);
(2) careful and tender (gardens);
(3) destructive and repelling (railways).

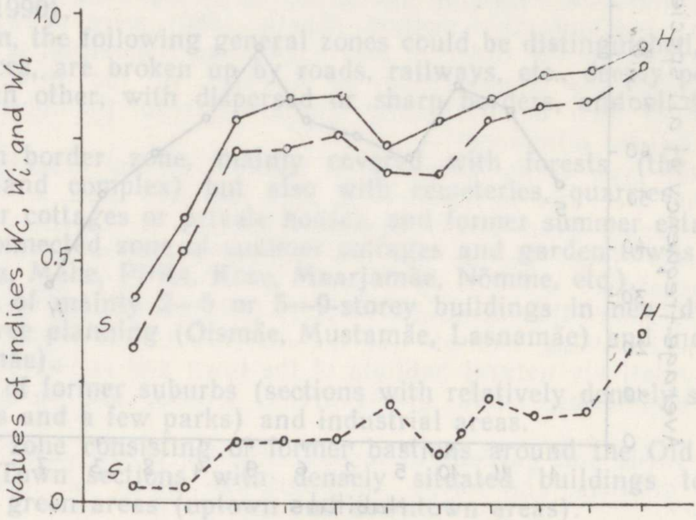

Fig. 6. Distribution of values characterizing man dependence (W_c, W_i, and W_h) on the *S—H* gradient.

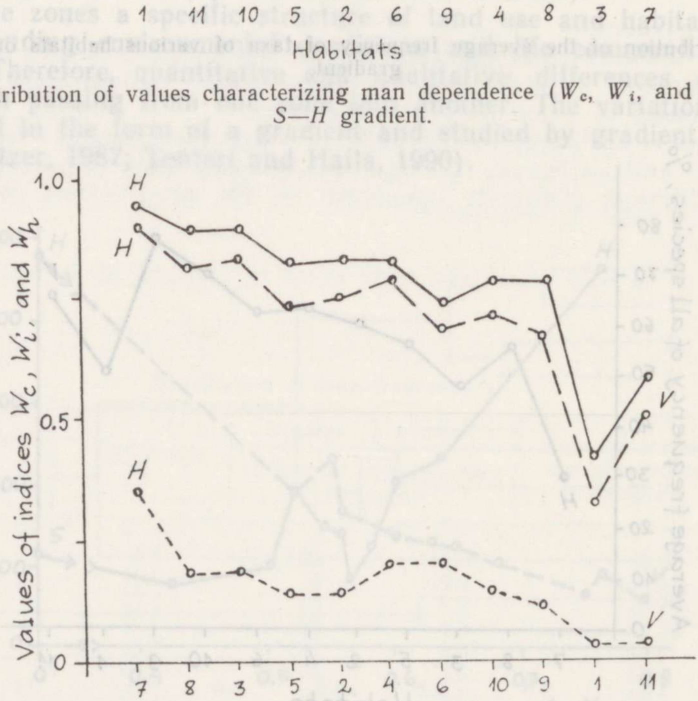

Fig. 7. Distribution of values characterizing man dependence (W_c, W_i, and W_h) on the *H—V* gradient.

Let us start with the analysis of the S—H (Lat. *silva* — forest, and *hortus* — garden) and the H—V (Lat. *via* — road) gradients (Figs. 4 and 5).

The correlations between the number of taxa and Sørensen's coefficients of the S—H ($r=0.526$) and the H—V ($r=-0.985$) gradient are shown in Fig. 3.

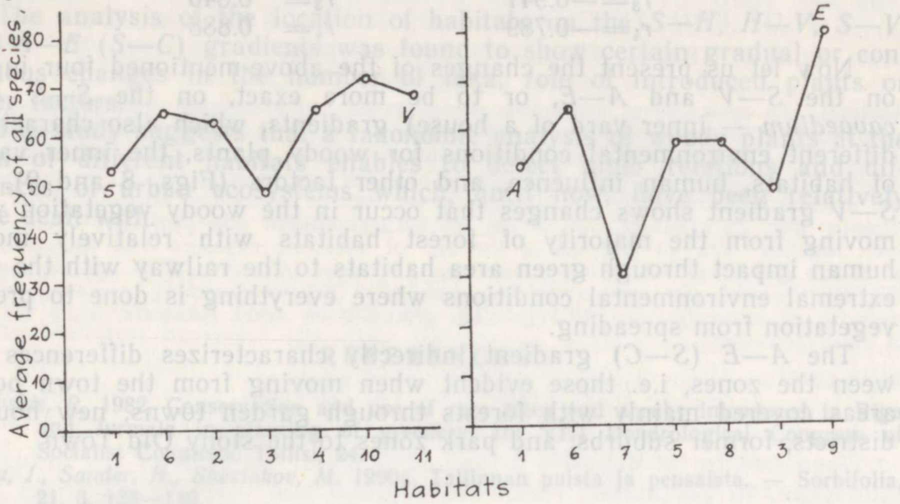

Fig. 8. Distribution of the average frequency of taxa of various habitats on the S—V (on the left) and the A—E (on the right) gradient.

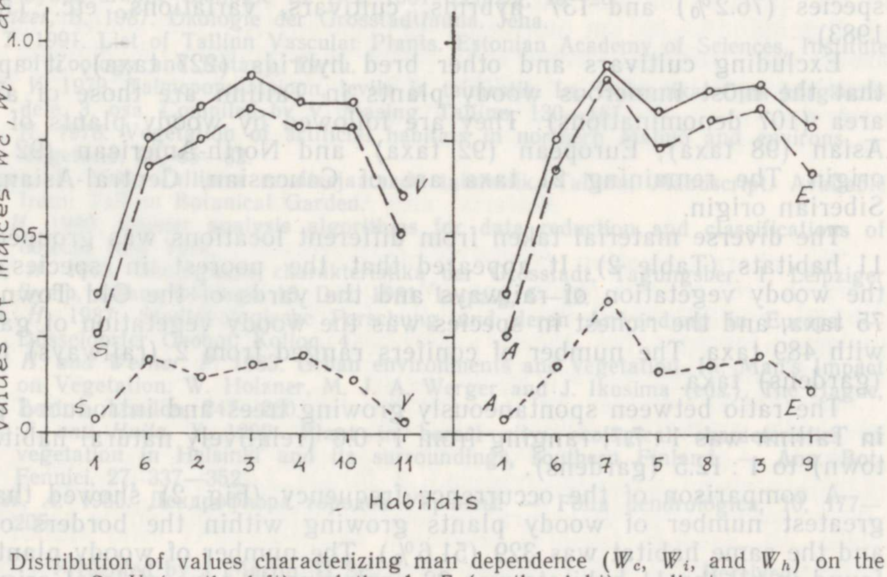

Fig. 9. Distribution of values characterizing man dependence (W_c, W_i, and W_h) on the S—V (on the left) and the A—E (on the right) gradient.

The changes of the average density of a species in the corresponding habitats (F_a), the values of the indices of all the cultivated taxa, introduced taxa, and cultivars (W_c, W_i, and W_h) on the *S—H* and *H—V* gradients are demonstrated in Figs. 6 and 7. The correlative dependencies between them and Sørensen's coefficients on the *S—H* and *H—V* gradients are as follows:

S—H	*H—V*
$r_1 = 0.186$	$r_1 = -0.838$
$r_2 = -0.930$	$r_2 = 0.636$
$r_3 = -0.941$	$r_3 = 0.640$
$r_4 = -0.789$	$r_4 = 0.888$

Now let us present the changes of the above-mentioned four indices on the *S—V* and *A—E*, or to be more exact, on the *S—C* (Lat. *cavaedium* — inner yard of a house) gradients, which also characterize different environmental conditions for woody plants, the inner variety of habitats, human influence, and other factors (Figs. 8 and 9). The *S—V* gradient shows changes that occur in the woody vegetation when moving from the majority of forest habitats with relatively modest human impact through green area habitats to the railway with the most extremal environmental conditions where everything is done to prevent vegetation from spreading.

The *A—E* (*S—C*) gradient indirectly characterizes differences between the zones, i.e. those evident when moving from the town border areas covered mainly with forests through garden towns, new housing districts, former suburbs, and park zones to the stony Old Town.

Conclusions

Until now 637 woody plant taxa have been registered in Tallinn. This number can be regarded as quite respectable.

We can make a comparison with Riga where 593 taxa of woody plants have been registered (Cinovskis, 1982). The woody vegetation of towns situated further to the south is considerably poorer in species, especially as regards cultivars. For example, in 78 Ukrainian towns a total of 576 woody plant taxa have been registered, including 439 species (76.2%) and 137 hybrids, cultivars, variations, etc. (Кохно, 1983).

Excluding cultivars and other bred hybrids (227 taxa), it appears that the most numerous woody plants in Tallinn are those of a wide area (107 denominations). They are followed by woody plants of East-Asian (98 taxa), European (92 taxa), and North-American (92 taxa) origin. The remaining 21 taxa are of Caucasian, Central-Asian, and Siberian origin.

The diverse material taken from different locations was grouped into 11 habitats (Table 2). It appeared that the poorest in species were the woody vegetation of railways and the yards of the Old Town with 75 taxa, and the richest in species was the woody vegetation of gardens with 489 taxa. The number of conifers ranged from 2 (railways) to 133 (gardens) taxa.

The ratio between spontaneously growing trees and introduced plants in Tallinn was 1 : 7.7, ranging from 1 : 0.6 (relatively natural habitats of town) to 1 : 12.5 (gardens).

A comparison of the occurrence frequency (Fig. 2) showed that the greatest number of woody plants growing within the borders of one and the same habitat was 329 (51.6%). The number of woody plant taxa found in all the 11 habitats was 22, including 12 taxa of local origin.

It was found with the help of Jaccard's and Sørensen's indices that the most similar green areas were those of the new districts and yards and gardens of former suburbs ($K_j=0.549$ and $K_s=70.9\%$) and the most different those of gardens and railways ($K_j=0.117$ and $K_s=21.0\%$).

It was found with the help of the hierarchic-agglomerative method that habitats fall into different groups corresponding to the sizes of Sørensen's similarity matrices (Fig. 2). These groups reflect, in addition to their dendrofloristic similarity, also changes in the environmental conditions.

The analysis of the location of habitats on the *S—H*, *H—V*, *S—V*, and *A—E* (*S—C*) gradients was found to show certain gradual or continuous changes in the number of taxa, role of introduced plants or other factors.

The study suggests that a taxonomic analysis of woody plants at the level of different habitats enables to detect inner relations and differences of urban ecosystems which, until now, have been relatively little dealt with.

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