MODELLING OF HABITAT CONDITIONS BY SELF-ORGANIZING FEATURE MAPS USING RELATIONS BETWEEN SOIL, PLANT CHEMICAL PROPERTIES AND TYPE OF BASALTOIDES

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ABSTRACT

The paper shows the use of Kohonen's network for classification of basaltoides on the base of chemical properties of soils and *Polypodium vulgare* L. The study area was Lower Silesia (Poland). The archival data were: chemical composition of types of basaltoides from 89 sites (Al_2O_3, CaO, FeO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2 and TiO_2), elements contents in soils (Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, S, Ti and Zn) and leaves of *P. vulgare* (Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, N, Ni, P, Pb, S, Ti and Zn) from 20 sites. Descriptive statistical parameters of soils and leaves chemical properties have been shown, statistical analyses using ANOVA and relationships between chemical elements were carried out, and SOFM models have been constructed. The study revealed that the ordination of individuals and groups of neurons in topological maps of plant and soil chemical properties are similar. The constructed models are related with significantly different contents of elements in plants and soils. These models represent different chemical types of soils and are connected with ordination of types of basaltoides worked out by SOFM model of TAS division. The SOFM appeared to be a useful technique for ordination of ecological data and provides a novel framework for the discovery and forecasting of ecosystem properties.

KEY WORDS: SOFM, basaltoides, *Polypodium vulgare*, ecological modelling, habitat conditions.

INTRODUCTION

Nowadays, particular attention is being paid to search of methods and solutions enabling higher verification possibilities of study results. Researchers use a lot of numerical methods, mainly classical ones (Sokal and Rohlf 2003), but also techniques based on artificial neural networks (ANNs) (Ray and Klindworth 2000; Sokołowski 2002; Tadeusiewicz 2006). Furthermore, Moreno-Sanches (2004) points to the use of various image and numerical techniques, which are precise and practical in ecological studies and Sokołowski (2010) points to the abundance of basic and advanced statistical methods in research. Their use in order to recognize the regularities occurring in phenomenons and processes remaining under the influence of the main reasons (systematic component) and indirect ones (accidental component) (Sokołowski 2010).

In case of environmental studies, ANNs provide an effective alternative to conventional modelling techniques (Scardi 2001). Moreover, Tadeusiewicz (2000) draws attention to the application of neural networks in biotechnology and biomaterials, which offer an attractive solution to lots of problems in many critical applications, and Kosiba (2010; and other references cited by this author) to their superiority to classical and advanced statistical methods in case of ecological studies. One of the ANNs is Kohonen's network (Kohonen 2001), which can be used for ordination and visualization of complex ecological data (Chon et al. 1996; Recknagel 2001).

The soils in the area of Lower Silesia formed from basalts (Adamczyk 2008), are overgrown with common but also unique and protected vegetation (Mróz 2001; Fabiszewski and Kwiatkowski 2002; Stankiewicz and Kosiba 2009; and other references cited by these authors), for example lithophytes, among which the chasmophytes are of particular importance and do not appear beyond those types of soils: *Asplenium septentrionale*, *A. trichomanes*, *Polypodium vulgare*, *Dryopteris filix-mas*, *Sedum acre*, *Thymus pulegioides*, *Hieracium pilosella*. These soils contain different levels of elements, in particular heavy metals and offer special conditions for those plant species.

This paper is the second part of ecological modelling by Self-Organizing Feature Maps (SOFM) on classification of habitat quality (Stankiewicz and Kosiba 2009). It presents the results of calculated SOFM models in assessment of ordination and similarity of habitat conditions and the relations between soils, plants chemical properties and types of basaltoides according to TAS division (Total Alkali Silica).

The aim of the present study was to use *Polypodium vulgare* L. as test plant (chasmophyte) to determine the element levels in soils and types of basaltoides in selected regions of Lower Silesia.

We investigated the hypothesis that the parent rock, here types of basaltoides, would influence the contents of elements in soils and *P. vulgare* plants. We tried to verify that hypothesis by the SOFM technique using as data quantities of elements in soils and leaves of *P. vulgare*. Next, to find out, whether the applied method reflects the habitat quality, and whether the SOFM does provide a picture of influence of types of basaltoides upon chemical properties of the analyzed soils and plant populations.

MATERIALS AND METHODS

Area, data and object of study

The study area was Lower Silesia in Poland (19 948 km^2), and archival data used accordimg to the paper by Kozłowska-Koch (1987), the manuscript of Ph.D. dissertation by Stankiewicz (1996) and the paper by Stankiewicz and Kosiba (2009). The description of Lower Silesian territory in respect of systematics of the Polish soils and classification of these soils according to TAS division are given by Kozłowska-Koch (1987) and Trzciński (1989), respectively. In the latter paper, the object of interest were *Polypodium vulgare* L. populations and soils formed by various types of basaltoides. Everyone of the 20 studied sites (Fig. 1) correspond with 20 soil samples and 20 plant samples of *P. vulgare*.

Chemical analyses of soil and plant

Detailed information on chemical composition of the types of basaltoides from 89 sites (Al_2O_3, CaO, FeO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2 and TiO_2), of the soils from 20 samples (Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, S, Ti and Zn) and plants from 20 samples (Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, N, Ni, P, Pb, S, Ti and Zn), the preparation of material for chemical analyses and the methods of determination of chemical components are presented in papers by Kozłowska-Koch (1987), Stankiewicz (1996) and Stankiewicz and Kosiba (2009), respectively.

In consideration of the current Regulation of the Ministry of Environmental from the 9th of July 2004 in matter of wild growing and protected plants (Dz. U. nr 168, poz. 1764), samples for chemical analysis were not taken. However, according to earlier Regulations of the Ministry of Environmental Protection, Natural Resources and Forestry

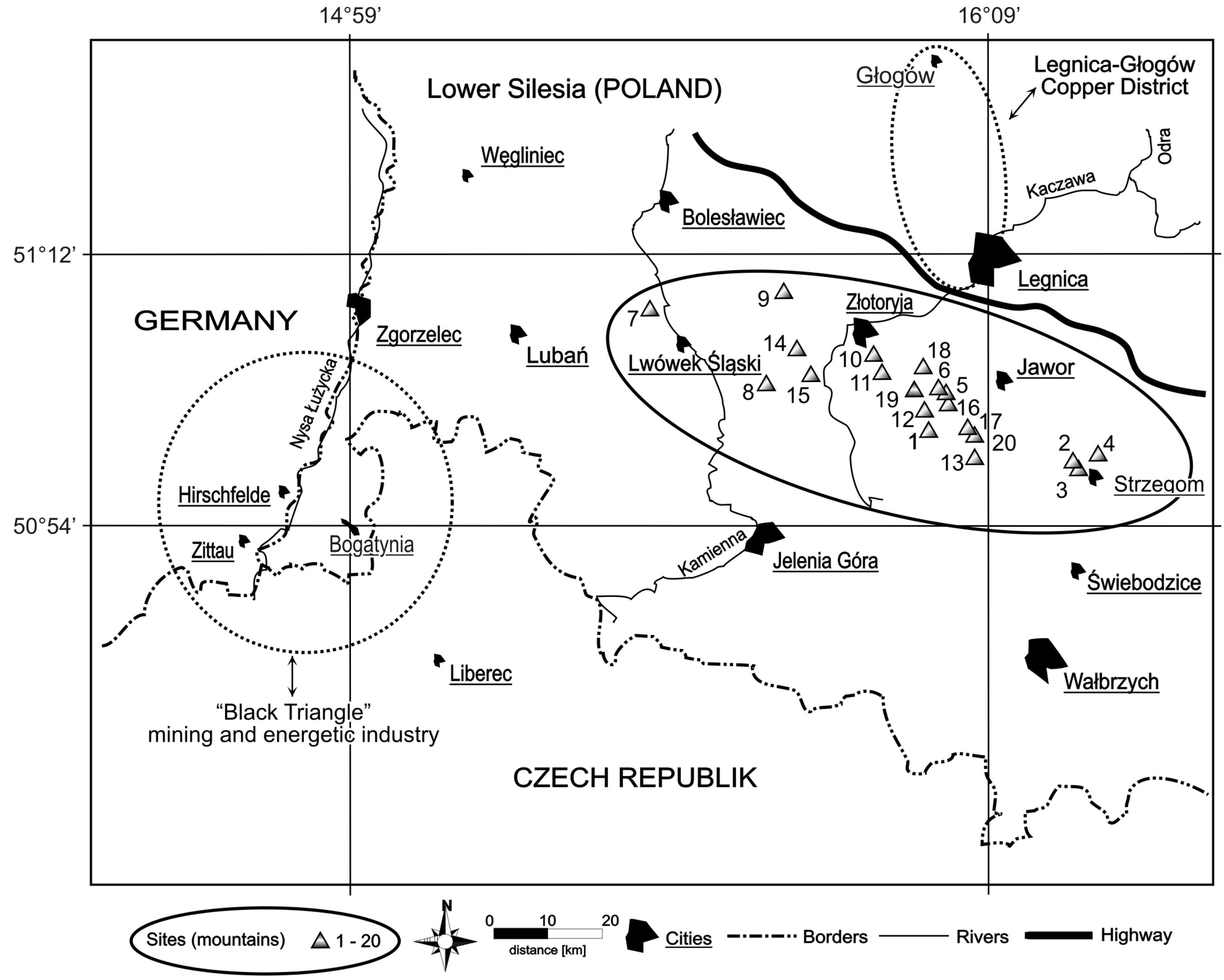

Fig. 1. Localization of sampling sites in the area of Lower Silesia.

it was possible and among others for that reason, archival data were used.

Statistical analyses

The obtained results of chemical analyses of soil and plant samples were expressed as arithmetic mean, standard deviation (±SD), minimum, maximum and variability coefficient (V) values. On the basis of archival data the statistical analyses were performed. The fitting distribution of the empirical data was verified to the normal one by the Shapiro-Wilk's test, and the homogeneities of variances were checked up by Levene's test. In case of normal distribution of investigated features the statistical-mathematical verification of results was based on parametrical tests, whereas in case of deviation from normal distribution non-parametrical tests were used. Hence, the one-way ANOVA with the F-test (ANOVA) and Kruskal-Wallis (K-W) test of ranks ANOVA for many independent samples were used, and the relationships between elements contents in soils and plants are presented by Spearman's correlation coefficient (r_S).

The SOFMs for each examined case were used, i.e. for classification of types of basaltoides according to TAS division, for classification of soils and populations examined in respect of contents of chemical elements. Generally, the structure of the SOFM consists of two layers of neurons connected by weight, the input layer consists of 20 input neurons and every neuron is represented by 11 chemical components of basalts, 11 and 16 chemical elements of soils and plants, respectively. Finally, the Kohonen's topological map 5×5 has been designed. The output layer consisted of 25 neurons visualized by hexagonal cells. The obtained Kohonen's topological maps showed the neurons or groups of neurons activated by the particular investigated cases. The scheme of SOFM with Kohonen's algorithm, details on training of the network and references are presented by Stankiewicz and Kosiba (2009).

The verification of the obtained results was carried out at significance level of 0.05 according to the statistical methods and principles given by Sokal and Rohlf (2003). For all calculations, the STATISTICA 9.0 program (StatSoft, Inc. 2009) was used.

RESULTS AND DISCUSSION

Analysis of variance and relationships

The examined soils (Table 1) and *P. vulgare* populations (Table 2) differ significantly between themselves in respect of elements contents (ANOVA, $F = 86.2 \div 1404.8 > F_{0.05;\ df1 = 19,\ df2 = 40} = 1.3$ and K-W, $\chi^2 > \chi^2_{0,05;\ df=19} = 30.1$, respectively). Results showed a wide range of variability coefficients between the soils (from 14% for Ti to 46% for Cd and Cu) and between populations (from 3% for K to 71% for Cd).

Average values of elements contents in soils and plants do not exceed the range values in different types of surface soils and various plants (Markert 1992; Kabata-Pendias

TABLE 1. Descriptive statistical parameters of elements' contents in soils ($mg*kg^{-1}$) from sites in Lower Silesia area.

No. of sites	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	S	Ti	Zn
01	0.23	28	29	123523	369	0.29	21	31	913	1229	183
02	0.21	26	25	41410	342	0.28	18	38	1407	1259	195
03	0.21	21	20	42497	331	0.26	28	38	1380	1257	175
04	0.23	28	29	119202	373	0.30	26	30	892	1241	181
05	0.20	31	31	99751	403	0.25	33	37	1384	1424	189
06	0.40	14	27	120287	185	0.20	46	29	660	1434	192
07	0.49	12	26	110550	163	0.20	41	36	631	1420	190
08	0.45	17	33	100834	213	0.18	31	23	811	1956	177
09	0.53	13	28	102990	161	0.24	48	30	759	1435	169
10	0.58	15	31	101910	177	0.27	46	33	773	1579	185
11	0.62	28	11	41418	413	0.25	22	31	865	1441	81
12	0.61	21	7	55762	404	0.25	28	24	908	1413	79
13	0.66	26	8	55776	396	0.22	21	28	1024	1414	80
14	0.46	17	48	104075	218	0.19	32	23	834	1802	182
15	0.21	26	25	42496	340	0.28	27	38	1431	1251	194
16	0.13	12	15	57621	173	0.20	43	8	841	1556	127
17	0.12	11	14	68420	162	0.18	41	7	820	1455	119
18	0.42	18	43	84639	253	0.22	35	21	493	1601	170
19	0.44	15	46	94357	214	0.20	32	22	1086	1662	173
20	0.43	16	47	97599	203	0.17	30	17	796	1863	169
Mean ±SD	0.4 ±0.2	20 ±6.5	27 ±12	83256 ±29312	275 ±97	0.23 ±0.04	33 ±9.1	27 ±9.2	935 ±271	1485 ±209	157 ±41
Min.	0.1	11	7	41410	161	0.17	18	7	493	1229	79
Max.	0.7	31	48	123523	413	0.30	48	38	1431	1956	195
V [%]	46	33	46	35	35	17	28	34	29	14	26
p						*					

Notes: V – variability coefficient; p – significance level; * – significant at p<0.05

TABLE 2. Descriptive statistical parameters of elements contents in leaves (mg*kg^{-1}) from *Polypodium vulgare* populations in Lower Silesia area.

No. of populations	Ca	Cd	Co	Cu	Fe	K	Mg	Mn	Mo	N	Ni	P	Pb	S	Ti	Zn
01	2483	0.39	0.05	11.3	365	13266	2464	34	0.77	11997	1.0	2198	1.3	3535	1.6	35
02	2532	0.40	0.06	11.6	372	13532	2514	35	0.79	12237	1.0	2242	1.3	3606	1.7	35
03	2601	0.09	0.05	8.6	375	13007	2493	31	0.82	11994	1.1	2293	1.1	3654	1.6	22
04	2001	0.92	0.06	14.5	323	12798	2200	34	0.74	10000	0.5	1847	2.3	3094	1.6	43
05	2845	0.17	0.06	10.9	397	13994	2699	37	0.77	13996	1.3	2455	0.4	3857	1.8	38
06	2921	0.15	0.02	9.1	405	13941	2368	17	0.38	11623	0.8	2178	0.5	3518	1.8	40
07	2892	0.15	0.02	9.0	401	13803	2344	17	0.38	11507	0.8	2157	0.5	3483	1.8	40
08	2761	0.14	0.02	8.6	383	13179	2238	16	0.36	10987	0.8	2059	0.5	3325	1.7	38
09	2599	0.40	0.03	9.9	375	13094	2001	15	0.62	10005	0.8	1900	0.9	3161	1.8	36
10	2620	0.40	0.03	10.0	378	13199	2017	15	0.62	10085	0.8	1915	0.9	3186	1.8	36
11	2798	0.47	0.06	1.8	393	13505	2491	38	0.75	13501	1.4	2200	1.1	3538	1.8	20
12	2882	0.48	0.06	1.8	404	13910	2566	39	0.77	13907	1.4	2266	1.1	3644	1.9	21
13	2885	0.48	0.06	1.8	405	13924	2568	39	0.77	13920	1.4	2269	1.1	3648	1.9	21
14	2646	0.41	0.03	10.1	382	13331	2037	15	0.63	10186	0.8	1934	0.9	3218	1.8	37
15	3008	0.04	0.03	1.3	414	14073	2190	20	0.66	10715	0.9	2137	0.8	3473	1.6	38
16	2989	0.09	0.02	4.3	417	14385	2622	17	0.71	13861	2.6	2510	0.2	3966	1.9	29
17	2847	0.09	0.02	4.1	397	13700	2497	15	0.68	13201	2.5	2391	0.2	3777	1.8	27
18	2898	0.31	0.04	22.2	401	13687	2196	23	0.59	10210	1.3	1995	0.6	3280	2.0	30
19	2949	0.04	0.03	1.3	406	13797	2147	20	0.65	10505	0.9	2095	0.8	3405	1.6	37
20	3001	0.32	0.03	18.5	410	14002	2301	19	0.59	11201	1.3	2304	0.8	3669	2.3	36
Mean ±SD	2758 ±237	0.30 ±0.21	0.04 ±0.16	8.5 ±5.6	390 ±21	13606 ±417	2348 ±208	25 ±9	0.65 ±0.27	11782 ±1451	1.2 ±0.5	2167 ±182	0.8 ±0.5	3502 ±234	1.8 ±0.2	33 ±7
Min.	2001	0.04	0.02	1.3	323	12798	2001	15	0.36	10000	0.5	1847	0.2	3094	1.6	20
Max.	3008	0.92	0.06	22.2	417	14385	2699	39	0.82	13996	2.6	2510	2.3	3966	2.3	43
V [%]	9	71	43	66	6	3	9	38	21	12	46	8	54	7	10	21
p								*								

Notes: V – variability coefficient; p – significance level; * – significant at p<0.05

2001a), and are in most cases similar to natural elements contents. Statistically significant positive relationships were found between elements contents in soils and plants ($r_S > r_{S\ 0,05;\ df=18} = 0.44$): Cd 0.58, Co 0.85, Cu 0.57, Mn 0.90, Mo 0.61, Ti 0.45 and Zn 0.71. The contents of the elements in *P. vulgare* plants increases with higher contents of these elements in examined soils. According to Kabata-Pendias (2001a), the occurrence of various elements in the earth's crust is strongly differentiated. Their distribution and contents in soils is among other, connected with the types of basaltoides, with course of the process of soil formation, the occurrence of other elements, pH of soil, but also by other environmental factors which influence their level in soils. Several anthropogenic factors are known to affect the behavior of various elements in soils. Due to current anthropogenic pollution most regions are able to be enriched with some elements (Suchara et al. 2007; Kosiba 2010), especially trace (heavy) metals in the top layer of soil in the south-western industrial area of Poland (Fig. 1) (Kabata-Pendias 2001b). In order to evaluate the agricultural and ecological risks, the pool of easily bioavailable metals in a soil should be also taken under consideration. However, these forms of metals are very variable under changeable conditions of the soil-plant transfer chain. In most cases easily bioavailable forms of metals are functions of both their total contents in soils and of soil properties.

Self-organizing feature maps

For supervised learning of the network used was the same procedure and the same size of the hexagonal topological map as in case of SOFM prepared in Figures 2 and 3 (Stankiewicz and Kosiba 2009). In addition the individual map in Figure 4 presents the ordination of examined sites in respect of soils chemical properties. It is included in the final SOFM model on Figure 3. The authors showed the similarity of ordination of the analysed soils in respect of ele-

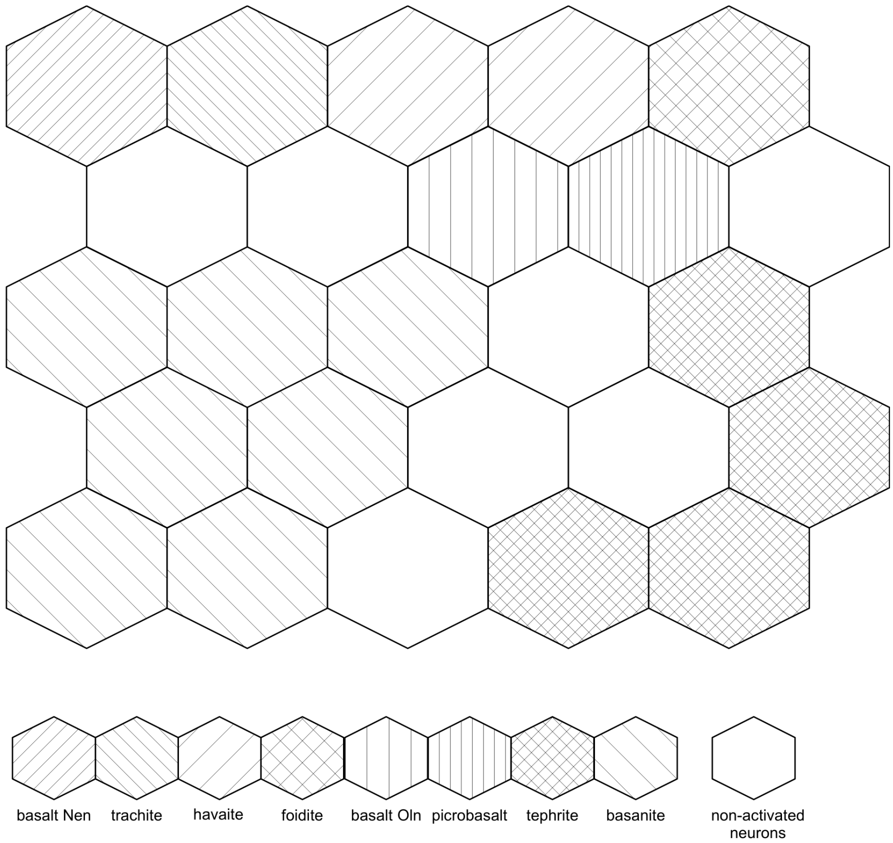

Fig. 2. SOFM of ordination of types of basaltoides in respect of chemical composition according to TAS division.

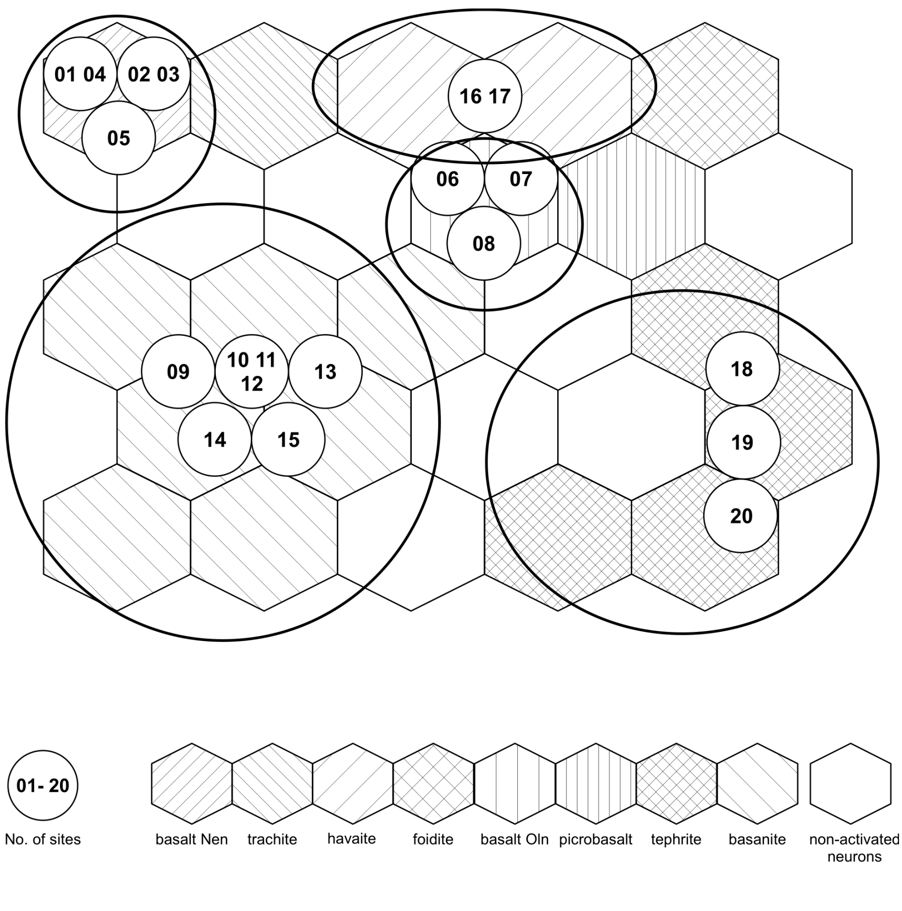

Fig. 3. SOFM of ordination of sites in respect of elements contents in soils on topological map of TAS division.

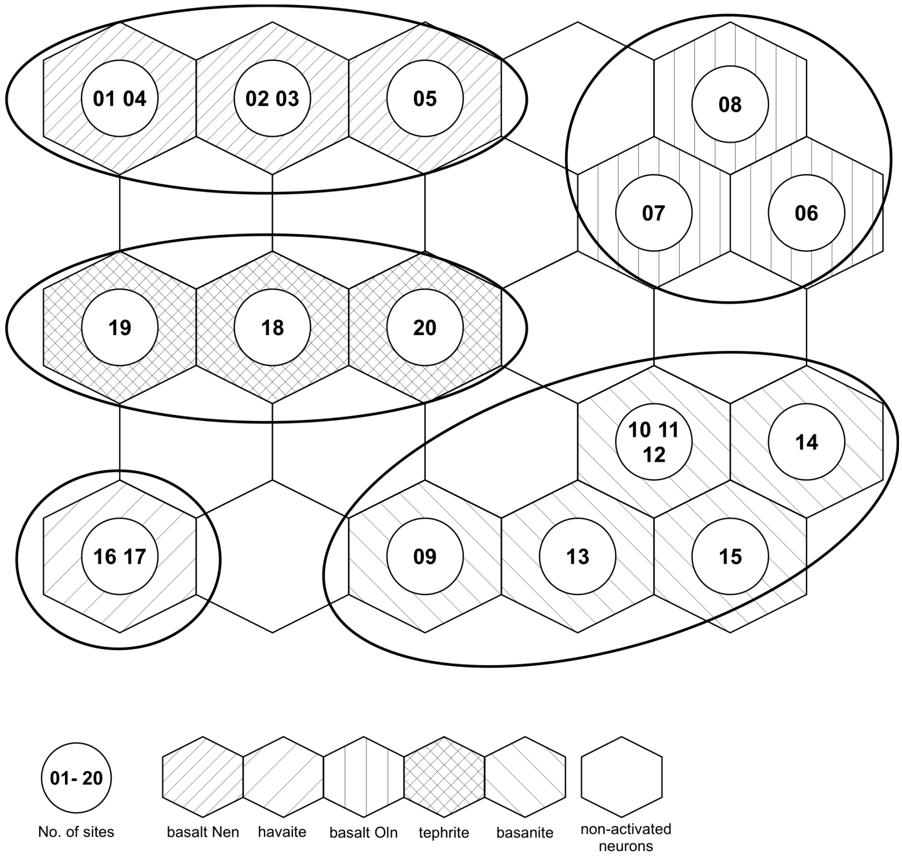

Fig. 4. SOFM of ordination of sites in respect of elements contents in soils on the topological map formed by some types of basaltoides.

ments contents with chemical properties of the types of basaltoides according to the TAS division. The obtained results of these two worked out SOFM models (Figs 2 and 3) show, that the types of basaltoides exert a significant influence on content of analyzed elements in them and confirm the result of the previously carried out studies on the territory of Lower Silesia, among other by Kabata-Pendias (1965), Bogda (1973), Białowolska (1980) and Kozłowska-Koch (1987).

The archival results obtained by chemical analyses of soils and plants of *P. vulgare* were used in our paper for construction of new individual and final SOFM models. In that way, the new Kohonen's topological maps were obtained, i.e. 5×5 on which the neurons or groups of neurons activated by the particular sites are clearly visible.

Constructed was an individual SOFM model illustrating the ordination of populations of *P. vulgare* in respect of contents of the studied elements in leaves of that plant (Fig. 5). It was found that the sites and populations/group of sites and populations on topological maps (Figs 4 and 5, respectively) show a similar ordination in relation to the same and various types of basaltoides. In the resulting SOFM (Figs 4 and 5), each cell represents a neuron. Sampling soils sites and populations within one neuron are the most similar, and soils and populations in neighboring neurons are more similar than soils and populations in more distant neurons.

These two maps clearly show, that soils of examined sites developed of basalt Nen (sites: 01-05) are grouped together and are separated from the other group of soils developed of basalt Oln (sites: 07-08), basanite (sites: 09-15), havaite (sites: 16-17), tephrite (sites 18-20) (Fig. 4). The same neighbourhood of neurons and ordination showed populations of *P. vulgare* growing in sites developed of basalt Nen, basalt Oln, basanite, havaite and tephrite (Fig. 5).

In effect, on the basis of results of earlier topological maps (Figs 2 and 3) as well as maps of sites and populations (Figs 4 and 5), constructed was the SOFM model for ordination of *P. vulgare* populations in respect to TAS division (Fig. 6). The results of SOFM reveal to a differentiated ordination of the populations of *P. vulgare*. Such an ordination, as shown earlier, is influenced by the significant differentiation of the examined soils and populations in respect of elements contents (Table 2) and the significant relationships of the system soil-plant (Cd, Co, Cu, Mn, Mo, Ti and Zn). Within one neuron the populations are most similar, whereas in the neighbouring ones less or least similar, in cases they occur in distinct neurons. The SOFM decidedly separates the particular populations, at the same time joining them into groups including the populations of highest similarity as regards both quantity and quality of the chemical composition of leaves, and these are the groups of populations: 01-05, 07-08, 09-15, 16-17 and 18-20. Neurons/groups of neurons of the populations clearly correspond with neurons/groups of neurons of types of basaltoides (Fig. 3) and TAS division (Fig. 2), i.e. basalt Nen, basalt Oln, basanite, havaite and tephrite.

In the SOFM model derived from examined sites in Lower Silesia, based on elements contents in soils and *P. vulgare* neighbouring neurons from groups which are occupied by plants growing on the soils developed of different types of basaltoides. The elements contents in these plants depend on chemical composition of types of basaltoides and correspond to TAS division.

A similar modelling of environment or habitat conditions with the use of SOFM was applied by Giraudel and Lek

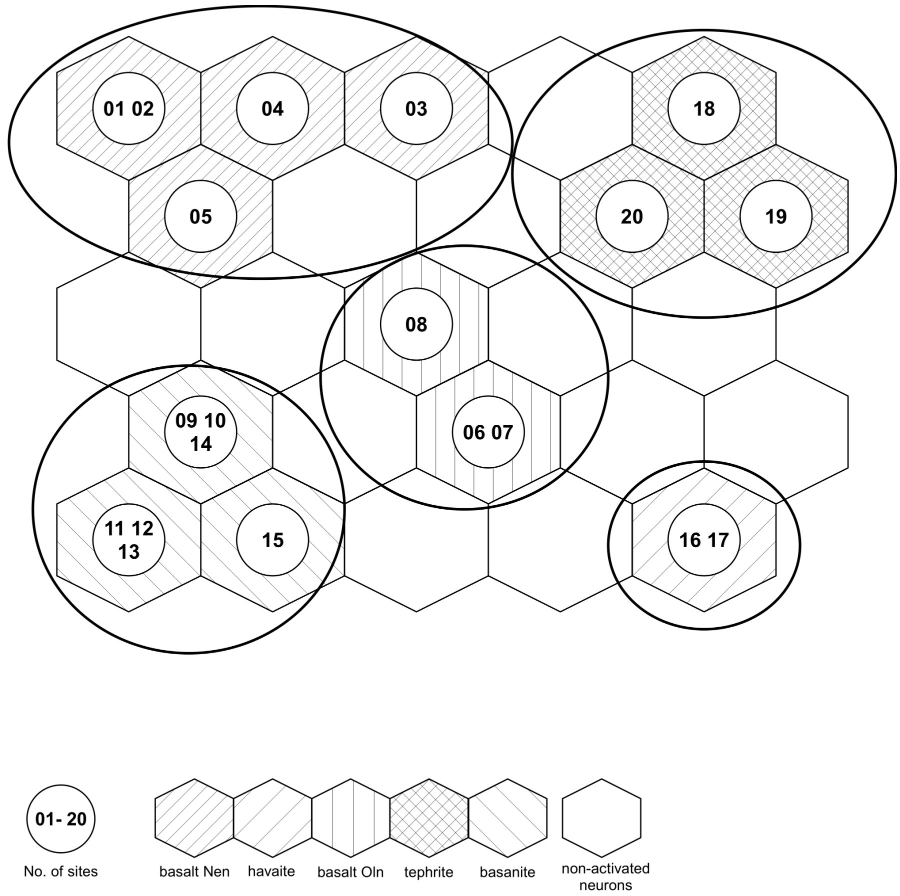

Fig. 5. SOFM of ordination of *Polypodium vulgare* populations in respect of elements contents in leaves on the topological map of types of basaltoides.

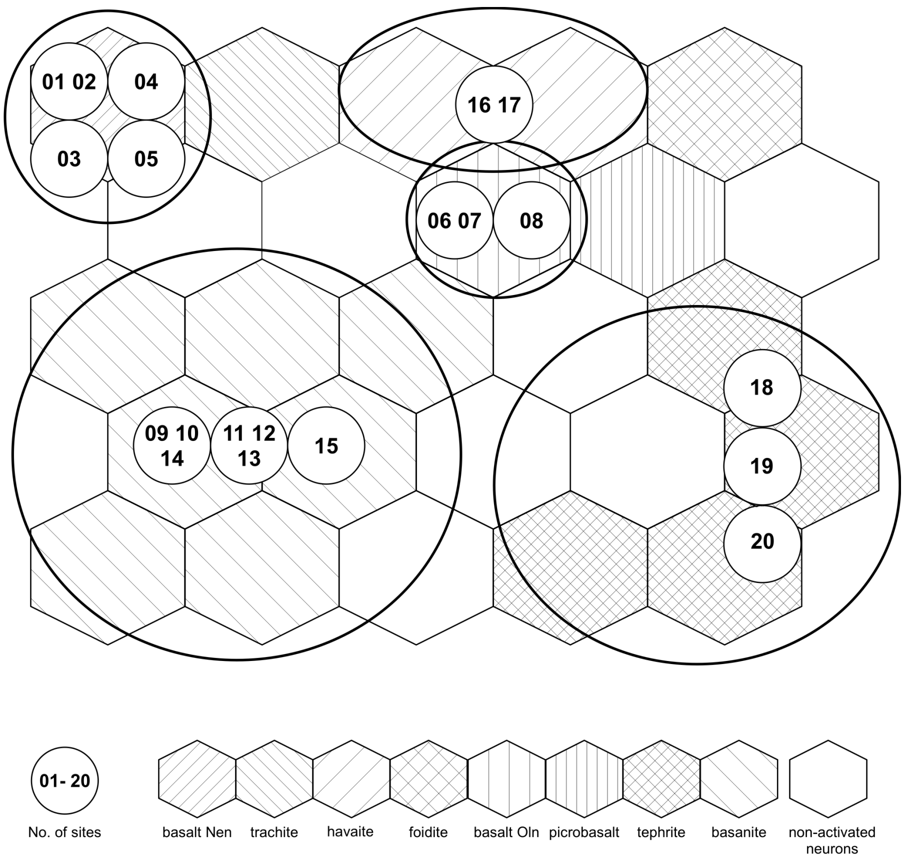

Fig. 6. SOFM of ordination of *Polypodium vulgare* populations in respect of elements contents in leaves on the topological map of TAS division.

(2001) for ordination of ecological communities, Lee and Scholz (2006) for wetlands, Kosiba and Stankiewicz (2007) for *Utricularia* species microhabitats, Samecka-Cymerman et al. (2007) for classification of the relation between chemical compositions of aquatic bryophytes and streambeds, Samecka-Cymerman et al. (2009) and Kosiba

(2010) in bioindication studies with various species of mosses growing around pollution sources.

The role of neural networks in ecological modelling (as well as in other kinds of environmental modelling) for ecologists and other practitioners is that there is plenty of space for experimentation and for creative use of computational tools. From a more general point of view, owing to the flexibility of self-organizing feature maps (and also other neural networks), application of SOFM in the studies proved the importance of the technique and can be used in various fields of applied ecological studies.

CONCLUSIONS

On the basis of results and all the points showed above it can be concluded, that:

– the analysed soils are significantly differentiated in respect of chemical properties which are conditioned by the type of basaltoides formed by parent rock,

– the soils and populations of *Polypodium vulgare* are characterized by a high variability of the analysed elements,

– as "marker" elements of the computed relationships of the system soil-plant one may accept: Cd, Co, Cu, Mn, Mo, Ti and Zn. The higher contents of these elements in soil corresponds with a significantly higher contents in leaves of *Polypodium vulgare* populations.

Self-organizing feature maps analysis of literature data show the effects of types of basaltoides on chemical composition of examined soils and *Polypodium vulgare* populations, and confirms that:

– the research has demonstrated that SOFM can be used to classify the types of basaltoides using quantity and quality data of soils and can be used as estimators for environmental conditions,

– the worked out model of SOFM for *Polypodium vulgare* populations in respect of chemical properties is in concordance with the model of ordination of types of basaltoides according to TAS division,

– SOFM seems fully usable in ecology and proper for phenomena and processes taking place in natural environment. It can perfectly complete various techniques for exploring data and for achieving community ordination and provide a visual way to find structures. Thus, it ought to be taken into account as a possible tool of estimation of various plants and their habitats.

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