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APPLICATION OF A SELF-ORGANIZING MAP (SOM) FOR GROUPING OF OAK ECOSYSTEMS BY DIFFERENT CHARACTERISTICS IN BULGARIA

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Abstract. Neural networks (NNs) can use a lot of heterogeneous data that may lack repeatability and confirmability, as well as analogues in the other systems involved in the analysis, which is typical for the available ecosystem data. NN have hardly been used for the study of plant communities in Bulgaria. In this article, xerothermic oak communities in Bulgaria from up to 180 polygons were studied, and 122 characteristics of the ecotype and plant communities were included in the analysis. After conducting self-training of the SOM, different groups of polygons were obtained with respect to soils, exposure, altitude, climate and mixed characteristics. All the obtained groups correspond to the ecological characteristics of communities, which confirm the capabilities of SOM for grouping the plant communities for different purposes.

Key words: xerothermic oak forests, *Quercus frainetto* Ten., *Quercus cerris* L., Neural Network (NN)

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INTRODUCTION

Neural networks (NNs) are a group of specific computational models for information processing. They are characterized by the use of multiple interconnected artificial neurons. They are often used in practice as nonlinear models for data analysis or a decision-making tool. The NNs are the systems of interconnected nodes that work similar to neurons in the human brain. Using algorithms, they can recognize hidden patterns and correlations in the raw data; grouping and classifying them and continuously learning and improving over time (Mouton et al. 2020). One of the founders of NNs and of the Self Organizing Map (SOM) is Teuvo Kohenen – professor at the Helsinki Academy and founder of a research center on NNs in 1995 (Kohonen 2001; Wehrenset al. 2007). Other famous developments in the field of NNs are: Algorithms, Applications and Programming Techniques , Genetic Algorithms in Search, Optimization, Machine Learning, etc. (*e.g*. Goldberg 1989; Freeman & Kohonen 1995).

In Bulgaria, the NNs have hardly been used to study plant communities. The only development to date was reported at the Scientific Conference on Ecology in 2004 on the topic: "Use of neural networks and genetic algorithms in assessing the condition of chestnut forests in Belasitsa" (Varbanov et al. 2005). This publication presents the first results of experimentally using the SOM neural network (Freeman & Kohonen 1995) to visualize and categorize measurements, as well as genetic algorithms (Goldberg 1989) to investigate the degree of influence of the various indicators on the condition of the chestnut forests in Belasitza (Varbanov et al.
2005).

NNs can use a lot of heterogeneous data, which have no analogues in the other systems included in the analysis, lack repeatability and verifiability, which is characteristic of the available data on ecosystems. SOM is one of the neural network models that has the following advantages:

- Convenience for visual representation of accepted measurements;
- Multidimensional categorization of quantitative and qualitative indicators;
- Contributing to a clearer understanding of the distribution and relationships between features from complex data;
- Identifying a small number of functions and showing the significance of the macro-biological system;
- Anticipating the reactions of the system to external influences;
- Ability to add data at a later stage;
- SOM is the self-learning neural network model that constructs a topological map that indicates the high-dimensional space of the data so as to preserve the relative closeness of the samples (Kohonen 2001);

• SOM was successfully applied to the analysis of chestnut forests in Belasitza mountain, Bulgaria.

The main disadvantage of neural networks is that most of them need training

or self-training before they can be practically used, which requires considerable time, especially for large neural networks.

MATERIALS AND METHODS

According to the climatic zoning (Velev 2002), 72 of the studied sites refer to the continental-Mediterranean area. The average annual temperature is 13- 14.0°C. The average January temperature is positive (1-2°C), and the average July temperature is 24-25°C. The annual temperature range does not exceed 23-24°C. The precipitation regime with an autumn-winter maximum and a summer minimum, is characteristic of the Mediterranean type of climate. The annual precipitation amounts are between 500-600 mm, and in the southern mountainous area they reach 700- 1000 mm. The snow cover lasts for 1-2 days, and in the Struma and Mesta valleys it forms once every few years (**Table 1**). Sixty eight of the studied objects belong to the temperate continental area. The average annual amplitude is from 25 to 26°C. The average January temperature is from -2 to -3°C, and the average July from 25 to 26°C. In this area, the lowest winter temperatures in Bulgaria were recorded (- 38.3°C in the town Trun), as well as very high summer temperatures (45°C in the town Boychinovtsi). The annual amount of precipitation is from 500 to 600 mm, and in the Danube Plain, the Pre-Balkan and the lowlands it reaches 800 mm, with a clear trend of increase towards the south and in height. The rainfall is minimal in February and maximal in June. Eighteen objects belong to the transitional-continental area. The annual temperature range is about 23°C. The average January temperature is -1°C and is characterized by some instability. It is possible to rise to 20°C and also fall to -25°C, -30°C. The average July temperature is 24-26°C, and the maximum summer temperatures reach 40°C. The mild winter, cool spring and hot summer are characteristic of the area. The annual amount of precipitation is 550 mm - 600 mm, and in the region of the Upper Thracian Lowland it is below 500 mm. The snow cover is unstable - there is no constant and continuous snow accumulation.

Table 1. Distribution of the studied objects by climatic regions (ordered by number of investigated objects).

Climatic regions	**Number of investigated objects**	**Average annual temperature [t ºC]**	**Annual sum of precipitations [mm]**	**Dry period [days]**

Continental-Mediterranean area	72	11,3 – 12,5	533 - 650	60-150
Moderately continental area	68	8-11,5	578-1050	30-90
Transitional-continental area	18	10 - 12,9	554-644	80-120

According to the soil zoning of the country (Ninov 2002), the considered sites fall into the Carpathian-Danube soil area and the Mediterranean soil area, which are essential parts of the Subboreal and Subtropical soil sector of Europe. Soil

zoning is four-tiered with separately provided soil sectors, districts, sub-districts and provinces (**Table 2**). The largest number of sites refer to the Sofia-Kraischte and Strandzha soil provinces (29 each), followed by the Central Thrace-Tundzha (28) and Provadiya (24) soil provinces.

Table 2. Distribution of the studied sites by soil-geographical zoning (ordered according to the numbers of the investigated objects).

Soil-geographic region Province	**Number of investigated objects**	**Soil type - FAO**
Sofia-Kraischte	29	Leptosols, Luvisols
Strandzha	29	Leptosols, Chromic luvisols
Middle Thracia-Tundzha	28	Chromic luvisols
Provadiya	24	Chernozems, Luvic phaenozems
Struma-Mesta	9	Leptosols, Chromic luvisols
Ludogorie	8	Luvisols, Phaenozems
Central Pre-Balkan	7	Luvisols, Planosols
Eastern Balkan	6	Luvisols
Eastern Rhodopes-Sakar	6	Chromic luvisols
Srednogorie	6	Chromic luvisols
Western Danube	6	Chernozems, Luvisols, Luvisols
Western Pre-Balkan	5	Luvisols, Planosols

Vitosha - Srednogorie	4	Luvisols
Osogovo-Belasitsa	2	Umbric Leptosol
Pre-Balkan	2	Leptosols
Western Rhodopes	2	Luvisols

The studied areas fall into all three vegetation regions of the country – the European Broadleaf Forest Region, Eurasian Steppe and Forest Steppe Region and Mediterranean Sclerophyllous Forest Region (Bondev 2002). The studied 158 sites fall into 19 districts according to the geobotanical zoning (Bondev 2002) (**Table 3**).

The analysis included 113 to 122 characteristics (described in detail below), from 93 to 180 polygons dominated by *Quercus frainetto* Ten. and *Quercus cerris* L. from different regions of Bulgaria using published literary sources and the National Monitoring System (Bondev et al. 1976, 1994, 1998; Kochev & Tsanova 1978; Bondev & Bogoev 1981; Bondev & Nikolov 1983; Angelov 1986; Meshinev & Nikolov 1986, 1987; Bondev & Georgiev 1987; Lyubenova & Bondev 1987, 1998a, b; Yurukova & Bondev 1990; Bondev & Lyubenova 1992; Lyubenova 1992, 1995a-c, 1996a, b, 2004; Grupce et al. 1993; Gateva 1994; Lalova 1994a, b; Melovski et al. 1994; Ljubenova 1995a-c, 1997, 1999; Ninov 1995; Lyubenova & Sazdov 1995; Lyubenova et al. 1996, 2008;

Ljubenova & Mirchev 1998; Popov 1999; EAA 2000; Lyubenova & Dimova 2000; Kurteva et al. 2002; Broshilova & Broshilov 2008). The data on the structural and functional characteristics of oak ecosystems, obtained through the destructive methods during the period of similar studies under the International Biological Program in Bulgaria (1970-2000), were used for the training of SOM.

Table 3. Distribution of the investigated sites by geobotanical zoning (ordered according to the numbers of the investigated objects).

District in the Geobotanical zoning	Number of inves tigated objects	Association
Strandzha Mt	25	*Quercus frainetto*
Eastern Balkan Mts	18	*Quercus cerris*
Ludogorie	12	*Quercus frainetto - Quercus cerris*

Novi Pazar	12	*Quercus frainetto*, *Quercus cerris*
East Rhodopes Mts	11	*Quercus frainetto*
West Coast of the Black Sea	10	*Quercus frainetto*
Pre–Balkan Mts	9	*Quercetum crataego-festucosum*
Sofia	9	*Quercus frainetto*
Upper Thracian Lowland	9	*Quercus frainetto*, *Quercus dalechampi*
Danube Hilly-Plain	8	*Quercus frainetto* - *Quercus cerris*
Ihtiman-Srednogorie	6	*Quercus cerris*, *Quercus dalechampi*
West Balkan Mts	6	*Quercus cerris*, *Quercus frainetto*, *Fagus sylvatica*
Sredna Gora Mts	5	*Quercus rubra*
Straldzha-Aitos	5	*Quercus cerris*, *Quercus frainetto*
Vitosha Mt	5	*Quercus dalechampi*, *Quercus cerris*
Upper Struma River	4	*Quercus frainetto*
Kotel-Preslav	1	*Quercus frainetto*
Rila Mt	1	*Quercus frainetto*

The preliminary data preparation includes:

1) Qualitative (non-numeric) values are transformed into quantitative, encoded with appropriate numerical values;

2) When values are missing for all characteristics of a given group for a certain area, they are filled with the average value of the respective characteristics of the remaining areas;

3) The values of each characteristic are normalized, *i.e.*, represented in the range from 0 to 1.

4) As a result of the performed preprocessing of the data, each area is represented

by numerical values for 122 characteristics;

5) Part of the data related to cardinal directions is encoded using trigonometric functions sin and cos - (**Table 4**)

During the network training, data for 122 characteristics (designated by f – feature) are presented in the form of vectors for each polygon (c) - a total of 93 to 180. The characteristics and their measurement units (provided in brackets) are as follows: f1- year of investigation; f2-f20 - location (geobotanical district); f21-f22 - latitude and longitude (^{0}); f23-f30 –average temperature (^{0}C), precipitation average (mm), drought period (days), dry period (days), average altitude (m a.s.l.), exposure – sinus and cosinus, average incline (degrees [^{o}].); f31-f40 - soil groups according to FAO; f41-f57 - soil forming rocks; f58 - soil pH; f59 - soil humus (tones ha^{-1}); f60-f69 – associations; f70-f79 – bonitas (I-I), average area (m^2); f72-f74 - origin – average age (years), Slope (0-9, av.), number of layers, average diameter at a breast height (DBH, cm), average height (H, m); f80-f85 - biomass (BM) stock (m^3), overground BM, tree layer BM, bush layer BM, herb layer BM and underground BM (tones ha^{-1}); f87-f91 – average annual overground production (AAOP) of tree layer, AAOP of bush layer, AAOP of herb layer, average annual O2 production (tones ha^{-1}); f92-f94 – average ammual litter-fall and average mulch (both in tones ha^{-1}) and litter-fall coefficient; f95-f97 – overground energy stocks in buch and herb layers and underground energy stocks (kJ ha^{-1}); f98-f100 - annual energy accumulation in tree, buch and herb layers (kJ ha^{-1}); f101-105 – content of calcium (Ca), potassium (K), magnesium (Mg), nitrogen (N) and phosphorus (P) in the phytomass (tones ha^{-1}) and f106- f113 - content of iron (Fe), manganese (Mn), copper (Cu), lead (Pb), zink (Zn), cadmium (Cd), cobalt (Co) and strontium (Sr) in the phytomass (tones ha^{-1}); f114-f122 – mulch and litter-fall and different fractions as leaves, branches – annual and perennial, bark, wood and acorns (tones ha^{-1}).

Table 4. Coding the data on the directions of the world.

Direction of the world	**Sin**	**Cos**
North	0	1
North-East	0,7	0,7
East	1	0
South-East	0,7	-0,7
South	0	-1
South-West	-0,7	-0,7
West	-1	0
North-West	-0,7	0,7

As a result of the performed preprocessing of the data, each area is represented by numerical values for all abovementioned 122 characteristics. When initializing the Neural Network (NN), the data have two main dimensions (feature (f) - 122 and case (c) - 180) and a rectangular shape. Then a NN is generated as a set of neurons organized in a rectangular grid with dimensions 10/10 (or, also 10x10), which means that it is composed of 100 neurons. Each neuron contains a vector of 122

numbers. In the training process, the vector of a given neuron iteratively changes based on the provided data and can eventually represent multiple input patterns or measurements. The part of the interpretation of the obtained results is done through the characteristics variance analysis of the areas in the formed groups. The variance of characteristic x is calculated using the following statistical formula:

$$D[x]=\sum \frac{(x-mean(x))^2}{length(x)-1}$$

where x is the vector of characteristic values, mean (x) is their arithmetic mean, and length (x) is the number of elements in x.

RESULTS AND DISCUSSION

A two-dimensional rectangular Self-Organizing Map (SOM) has been generated with dimensions 10 x10. Each neuron is initialized with a vector of 122 relatively small (in the range from 0 to 0.1) random numbers. To observe changes in the process, the network is visualized by representing each neuron in the form of a "star" histogram based on its vector (**Figure 1**). The attached figure depicts the network after a certain period of self-training. Neurons in which the corresponding input patterns are mapped, are marked with a red diamond in the center of the star. **Figures 2** and **3** illustrate neurons in the process of self-training of the network.

The first major grouping confirms the ecological nature of the studied forest communities: *Quercus cerris* + *Quercus frainetto* communities on Luvisols; *Quercus cerris* + *Quercus frainetto* communities on Cambisols; *Quercus cerris* + *Quercus frainetto* communities on Planosols; *Quercus cerris* + *Quercus frainetto* communities on Vertisols; *Quercus cerris* + *Quercus frainetto* communities on Chernozems; *Quercus frainetto* dominated communities on Fluvisols; *Quercus frainetto* dominated communities on Leptosols; *Quercus frainetto* dominated communities on Alisols; *Quercus frainetto* dominated communities on Regosols and *Quercus cerris* dominated communities on Luvic phaeozems.

The second major grouping confirms the ecological nature of the studied forest communities: *Quercus frainetto* communities on SE slopes; *Quercus frainetto* communities on E slopes; *Quercus cerris* communities on NE slopes; *Quercus cerris* + *Quercus. frainetto* communities on different slopes and medium range of precipitations. The overall trend in the distribution of the communities is that *Quercus frainetto* communities occupy areas characterized by low altitude and average precipitation compared to *Quercus cerris* communities. In the mixed communities, a similar trend is not observed, which is likely due to human intervention in maintaining forest sustainability.

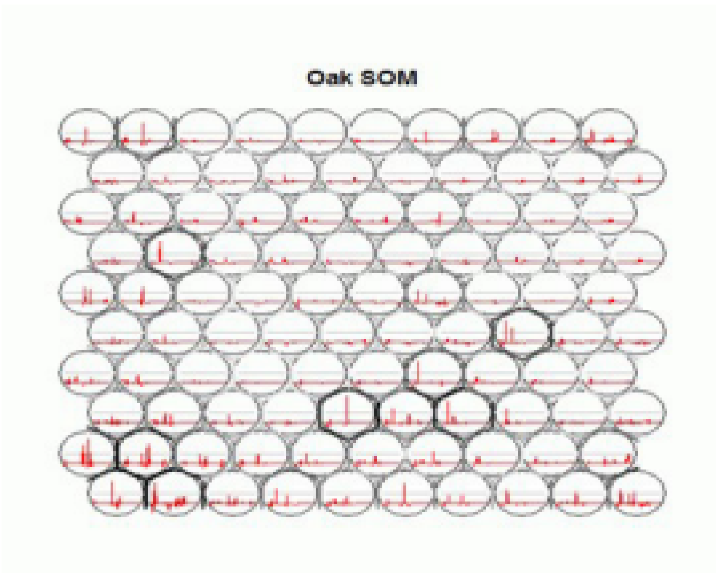


Fig. 1. Example of a SOM Polygon exploration based on 98 features.

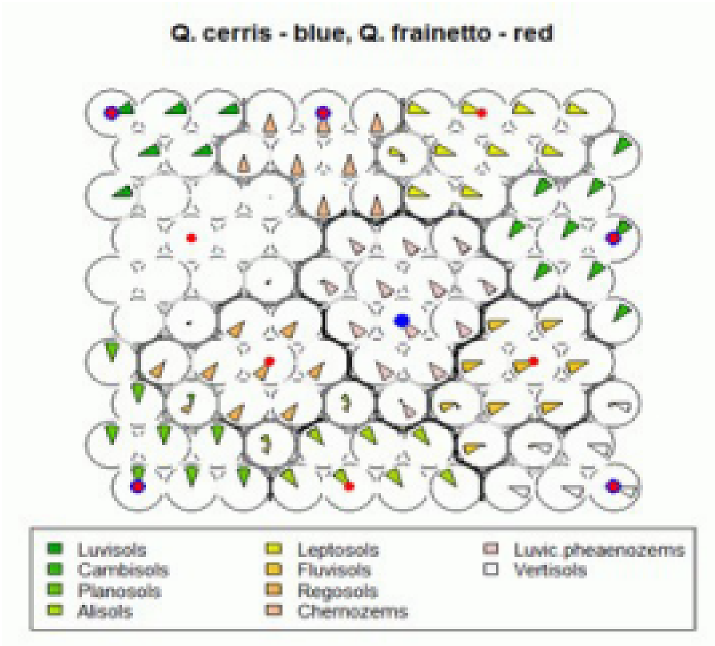


Fig. 2. SOM from the studied polygons based on the soil type data.

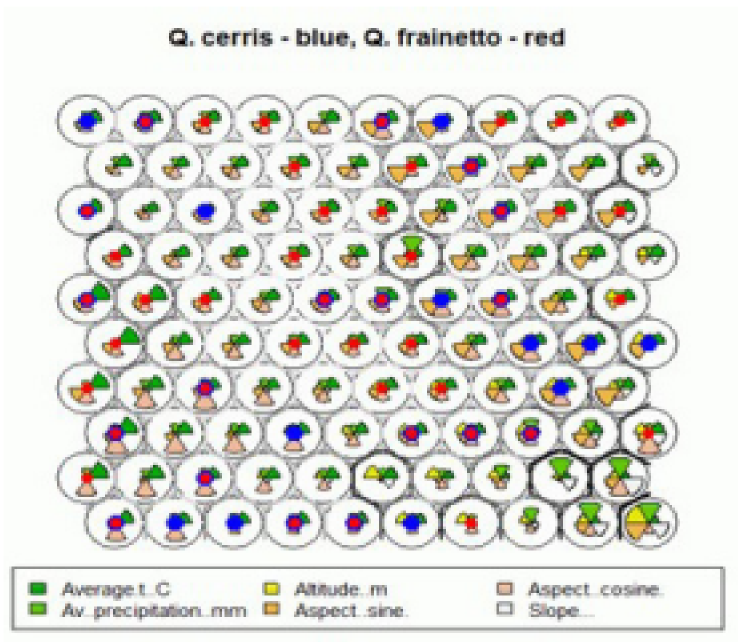


Fig. 3. SOM

from the studied polygons based on the combined climate and topography data.

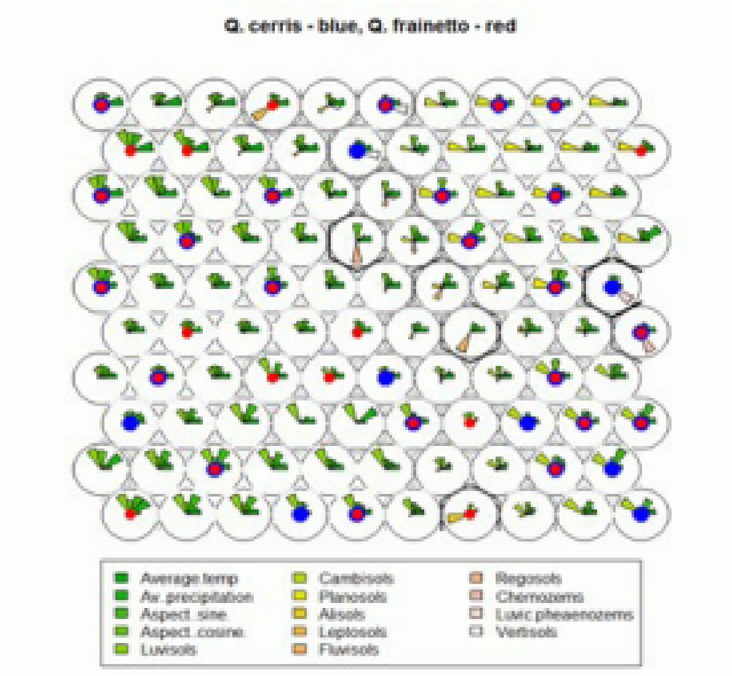


Fig. 4. SOM from the studied polygons based on the soil, climate and topographic data.

Characteristics of the associations	natural - sprout	30-14[4]	0.6–0.7	3	13-17.5	7-19					16.65	12.95	11.1		3.5
	Origin	Average age	Avera	Number	DBH [cm]	Hav	Overg		Under		Mulch	MOB [t	O2 productio	Annua	A*

			geslope	of layers			round BM		ground BM,		[tones ha-1]	ones ha-1]	n, [tones ha-1]	l Litter		
Abiotic characteristics	59-500	0–3°	S, SE	11.4	615–694	88-75		157.6		47.6					3.7	
	Altitude [m a.s.l.]	Incline (slope) [degrees]	Exposure	Average temperature [°C]	Average precipitation [mm]	Dry period [days]		[tones ha-1]		[tones ha-1]					-fall [tones ha-1]	
Soil	*Luvisols*															
Soil-forming roc	clays and marls sand and lime stone sandstone sandstone loess clay andesite															

k	marls loess
Lon-g titude	255155 273014 275713 274606 274140 275008 264827
Lat-i tude	414818 422005 420415 425434 430845 430203 434243
Place	v. Staro Orjahovo, v. Staro Orjahovo, Western Surnena Gora -Karlovo Palamara – t. t. Charmanli, t. Bourgass, v. Tzarevo, t. Montana t. Isperih, t. Varna, Shumen
Poly gon	c18, c46, c74, c76, c77,

	c90, c93, c94, c95, c104
Asso c.	*+ Quercus cerris -* *Quercus frainetto,* *Quercus frainetto,* *Quercus frainetto,* *Quercus frainetto,* *Quercus frainetto* *Quercus frainetto* *+ Quercus cerris* *Quercus cerris,* *Quercus cerris,* *Quercus cerris,* *Quercus cerris* *Brachyodium* *Brachyodium* *monoguna -* *monoguna -* *Crataegus* *Crataegus* *pinatum,* *pinatum*

Table 5. Characteristics of 5th neuron, received by using abiotic characteristics. The abbreviations are as follows: **t** – town, **v** – village

Table 6. Characteristics of 30th neuron, received by using abiotic characteristics. Abbreviations used are as follows: **t** – town., **v** – village,

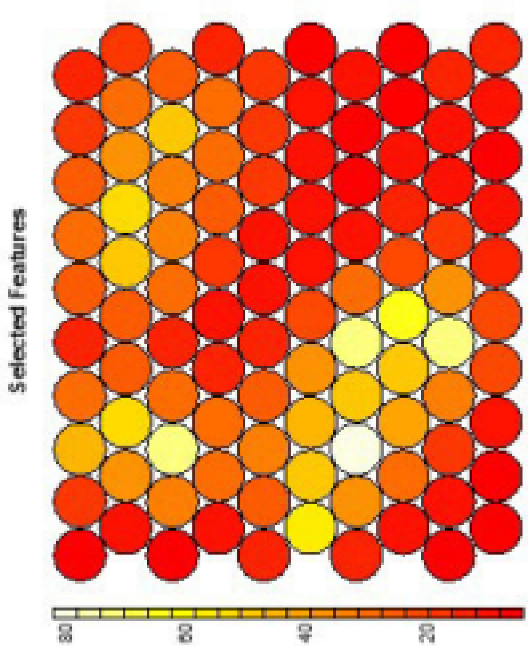
Characteristics of the associations	natural - sprout	35-40	0.7	3	11-16	10-15	44.0	28.0	12.3	7.9	6.8	4.1	3.0
	Origin	Average age	Average slope	Number of flayers	DBH [cm]	Hav	Overground BM [tones ha^{-1}]	Overground BM [tones ha^{-1}]	Mulch [tones ha^{-1}]	MOB [tones ha^{-1}]	O2 production, [tones ha^{-1}]	Annual Litter-fall [tones ha^{-1}]	A*
Abiotic characteristics	868-930	3-10	E, NE	10.1	533-630	40						4.1	
	[m a.s.l.] Altitude	Incline °	Exposure	Tav 0C	Pav, mm	Dry period [days]							
Soil	*Cambisols*												

Soil-forming rock	gneiss-granites quartzite schist mica
Longitude	243101 230760 235601
Latitude	424353 425960 422545
Place	nbh.Pancharevo t. Nova Zagora v. Dragichevo t. Ichtiman v. Debelt v. Rosino (t. Sofia) t. Svoge
Polygon	c178 c169 c173 c177 c58 c68 c96

As so c·	*Quercus cerris+H.* *Quercus virgiliana+* *Quercus cerris+* *Quercus frainetto* *Quercus fraineto* *Quercus cerris* *Quercus cerris* *Quercus dale champii* *bulbosum*

nbh - ???

123



B

Fig. 5. Received mixed neurons based on available characteri

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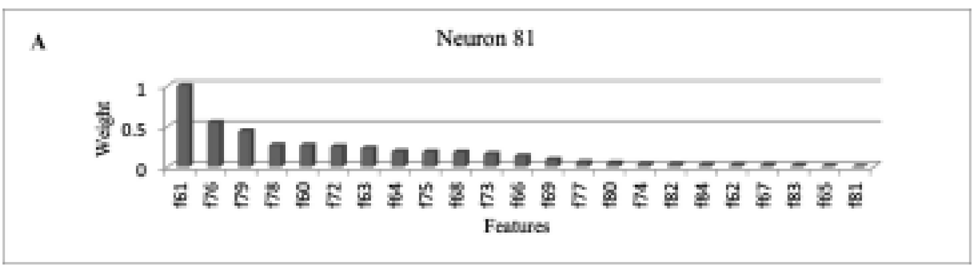
As a result of the self-training using soil, climatic, and topographic characteristics, a map of neurons grouping the objects has been obtained (**Figure 4**). **Table 5** and **6** extract and display all characteristics of the objects falling into neuron 5 and neuron 30. Objects grouped in these two neurons exhibit differences in their abiotic and biotic characteristics.

During further self-training of the SOM network, 23 sequentially selected commonly occurring abiotic and biotic features (designated as “features”) were included for 180 cases (objects), as some cases lack certain functional characteristics. As a result, two maps of neurons were visualized, shown on Fig. 5. Darker gray borders indicate a greater difference between adjacent neurons (**Figure 5A**). Essentially the same information but visualized differently. In **Figure 5B**, the similarity of the obtained neurons is better observed, with the scale on the left indicating the coloring based on the difference between the neuron and its neighbors. In other words, red neurons are very similar to their neighbors. In the lower right quadrant of the map, there is a clustering of very similar cases. Since structural and functional characteristics of forest communities were used to obtain these groupings, and the cases that fall into one neuron are very similar to each other, it is logical to perceive the neurons as separate ecosystems.

In the following table (**Table 7**), each neuron is sequentially shown along with the cases that fall into it. The cases that fall into one neuron are very similar to each other. From **Table 7** it can be seen that 21 neurons contain only 1 case, 17 neurons contain 2 cases, 7 neurons contain 3 cases, 3 neurons c ontain 4 cases, 6 neurons



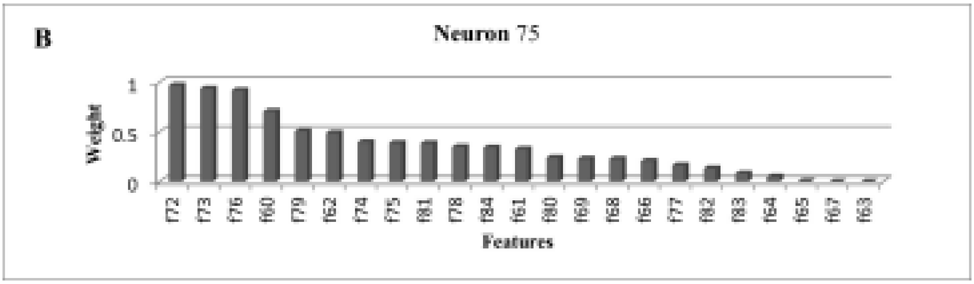


Fig. 6. Importance of case factors in neurons 81 (A) and 75 (B).

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81	1	c93, c101, c102, c53, c58, c67, c70, c72, c80, c91, c92, c103, c163, c167	14
75	1	c36, c59, c60, c77, c79, c81, c82, c85, c87, c89	10
19	1	c17, c61, c62, c71, c73, c74, c75, c76, c121	9
61, 12	2	c95, c136, c140, c66, c68, c84, c86, c88, c94, c148, c154, c155,	7

		c157, c161	
56, 67	2	c14, c23, c37, c38, c51, c54, c16, c52, c96, c97, c98, c166	6
47, 51, 71 2, 11, 13,	6	c143, c144, c151, c159, c160, c134, c135, c138, c141, c152, c132, c137, c146, c150, c158, c10, c174, c177, c21, c45, c104, c105, c170, c9, c44, c171, c172, c173 c11, c12,	5
30, 48, 95	3	c63, c78, c83, c99, c46, c50, c175, c29, c30, c31, c42, c29, c30, c31, c42 c180,	4
3, 7, 17, 18, 39, 50, 91	7	c123, c129, c117, c128, c130, c64, c115, c124, c113, c126, c131, c116, c119, c127, c65, c69, c34, c149, c156, c90, c169	3
49,53, 64, 65, 90, 79, 87, 1, 8, 10, 21, 25, 27, 28,	17	c109, c7, c49, c43, c47, c55, c56, c178, c28, c32, c5, c133, c142,	2

100, 99, 70		c122, c125, c139, c147, c106, c165, c179, c111, c100, c18, c108, c19, c112, c57, c22, c114, c39, c40, c164, c4, c168	
15, 16, 23, 29, 33, 35, 41, 42, 46, 54, 55, 60, 72, 73, 76, 86, 93 6, 14, 4, 5,	2 1	c145 c120 c24 c27 c33 c118 c48 c41 c6 c35 c8 c1	1
Neurons	**o** **f** **n** **e**	**Causes**	**o** **f** **c** **a**

	u r o n s №		u s e s №

Table 7. Neurons and causes·

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contain 5 cases, 2 neurons contain 6 cases, 2 neurons contain 7 cases, 1 neuron each contains 9 and 10 cases respectively, and only one neuron, namely 81, has the largest group of similar cases - 14.

Figure 6 presents the importance of individual characteristics in grouping the cases in neurons 81 and 75, characterized by the largest number of cases (14 and 10, respectively). For neuron 81, features with the highest importance are f61, f76, and f79, representing the characteristics such as association type, average slope, and tree layer height. The features f78, f60, f72, and f63 have almost equal weight - DBHav., forest origin, presence of *Quercus cerris* or *Quercus pubescens* in the stand. For the grouping of cases in neuron 75 important are the origin - f72, f73, f74, as well as the slope, the presence of *Quercus cerris*, age, and aboveground biomass - f76, f60, f75, and f81.

CONCLUSION

The NNs are artificial intelligence trained to process data in a way necessary for humans. In the current development, a specitic type of NN - SOM - was used. A corpus of published data from literary sources and reports from national monitoring, including 122 measurements from up to 180 polygons of xerothermic oak forests in various regions of Bulgaria, was processed. As a result of the analysis and self-training of SOM, 100 neurons were generated, marking 41 groups of structurally and functionally similar polygons. Based on them, satisfactory groups of forest phytocenoses were obtained. The results include a visual topological map of the data, as well as the identification of similar groups and can serve as a basis for the analysis and discovery of patterns in the similarity and difference of xerothermic oak forests from different regions of the country. The conducted analysis revealed that the applied by us characteristics (ecological factors) have different importance as classification units (determining the similarity between them and grouping them) or limiting factors (determining the functional state) for the functioning of the studied oak communities. These original results can serve as a basis for the ecosystem classification of xerothermic oak forests in Bulgaria and their subsequent modeling as structural and functional units of vegetation cover and valuing the provided ecosystem services.

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