EVALUATION OF PHYTOPLANKTON COMPOSITION OF THE PELAGIC REGION OF DOĞANCI DAM RESERVOIR (BURSA, TURKEY) BY ARTIFICIAL NEURAL NETWORK (ANN) AND CLUSTERING TECHNIQUE

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Abstract. This study was carried out in four stations in the Doğancı Dam Reservoir in the northwestern part of the Anatolian Region of Turkey. Within this study, phytoplankton composition were evaluated by using artificial neural network and clustering technique. For this purpose, phytoplankton algal flora and some physico-chemical parameters were investigated in water samples taken from four different stations in Doğancı Dam Reservoir. A total of 75 taxa belonging to the divisions of Bacillariophyceae (45), Chlorophyceae (12), Cyanophyceae (12), Dinophyceae (2), Chrysophyceae (2) and Euglenophyceae (2) were detected in the algal flora of the pelagic region. In terms of species diversity in the phytoplankton, Bacillariophyceae members were dominant, followed by Chlorophyceae and Cyanophyceae members. As a result of the research, the type list determined is the first report on the phytoplankton composition of the dam reservoir and it is thought to be beneficial in terms of future water quality and water pollution research. Cluster analysis is a classification method that is used to arrange a set of form into clusters. The aim of this method is to classify a set of clusters such that cases within a cluster are more similar to each other and to submit summary information of the data to researchers. For predicting phytoplankton biomass, in this study, ANN was combined with a clustering technique. This case study demonstrated the good performance of ANN models in describing phytoplankton dynamics, and the potential of coupling ANN with a clustering technique to describe the spatial heterogeneity of natural ecosystems.
Keywords: *Bacillariophyta, clustering technique, phytoplankton, Turkey*

Introduction

Reservoirs contain a significant portion of the fresh water on the planet and are special ecosystems because of their unique features (Reid et al., 2019). Reservoirs are artificial lakes built on streams for electricity production, drinking water supply, irrigation, fishing, flood control and recreation and where water accumulates in the basin formed by a barrier structure (Cantonati et al., 2020).

Doğancı Dam, which is one of the important water resources in Bursa city, was set up for the purpose of drinking water supply (Coşkun, 2022). Doğancı Dam was built on Nilüfer Creek between the years 1975 and 1983. The body volume of the dam is 2.520 hm^3, the height from the river bed is 85 m, the lake volume at the maximum water level is 43.30 hm^3, and the lake area at the normal water level is 1.55 km^2. It provides 110 hm^3 drinking water per year (Anonim, 2014).

Water, which is the basic element for all living things, also forms a habitat for aquatic organisms. Phytoplankton is considered to be the primary producers of aquatic systems and is the first link in the food chain. Phytoplankters, which are the fastest responding to the changes occurring in aquatic environments, are of great importance in terms of their ecological functions. Since the composition of phytoplankton reflects the

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ecological status of the aquatic system, they are used as indicator organisms in much water quality and water pollution studies (Gökçe, 2016 and Rimet, 2016).

Simple regression models have been widely used to predict phytoplankton biomass. However, their model fits are generally unsatisfactory due to the non-linear relationship between Chl-a and other environmental variables (Huang et al., 2015). As an alternative to regression and mechanistic models, artificial neural network (ANN) models were demonstrated to have high potential in modeling highly non-linear and complex natural systems (Huang et al., 2015 and Tamaddon-Jahromi et al., 2020). The limitation of ANN in spatial modeling may be overcome by coupling with clustering techniques (Dietrich et al., 2013).

There is much literature that examined the systematic and ecological characteristics of algae in lakes, ponds and reservoirs of various regions of Turkey (Dalkıran et al., 2016; Rangel, et al., 2016; Bilous et al., 2016; Cui et al., 2021; Ulańczyk et al., 2021). But in return, limnological researches are limited in literature about Doğancı Dam Lake, which is selected as a research area.

This is a study on phytoplankton composition of the Doğancı Dam Reservoir. The purpose of this research is to determine the phytoplanktonic algae flora taxonomically by creating a list of available species and to determine the phytoplankton functional groups. The phytoplankton composition of the species list dam lake given as a result of the research is thought to be beneficial in terms of being a resource in future water pollution and water quality research.

The other purpose of this study is an attempt to use ANN to predict phytoplanktonic algae abundance in Doğancı Dam Reservoir. This involves the use of artificial neural network (ANN) and clustering method (self-organizing maps (SOM)). SOM has been used in ecological modeling to find similarity between datasets and is an excellent tool in the visualization of multidimensional data. From this point of view, the rarity of the studies carried out on Doğancı Dam Reservoir, this study will be a case study.

Finally, information of the distribution and abundance of this significant link in the food web will allow us to both understand and contribute to the restoration and protection of our aquatic ecosystems.

Methodology

Study area

The Doğancı Dam Reservoir (DDR): The DDR is a very small reservoir located in the north-west part of Turkey. The drainage area of the reservoir is located between the 44˚36′ and 44˚57′ northern latitudes and the 32˚08′ and 32˚62′ eastern longitudes. The maximum operation level of the reservoir is 333.80 m above the Mediterranean Sea level. The characteristics of the reservoir at this water level are as follows: the surface area is 1.58 ha, the total water volume is 37.80 hm^3, and the total drainage area of the dam outlet is 446.9 km^2. The Doğancı Dam Reservoir is located on the Nilüfer River and the Sultaniye Stream (Büyükfidan et al., 2008).

Field sampling and analytical methods

Water samples were collected from four different stations. Study area and sampling locations are shown in *Figure 1*. The measured secchi depth was determined as 2.8 m (2nd station) at the lowest and 4 m (1st station) at the highest. The secchi disc depth was

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measured as 2.40 m and 3.10 m at the 3rd and 4th station, respectively. Polyethylene bottles (2000 ml) were rinsed with distilled water and filled with reservoir water. Phytoplankton samples were taken with the plankton bucket. The phytoplankton sampling time interval was the winter season of 2014. All samples collected were brought to Uludağ University, Department of Environmental Engineering. The total organic carbon (TOC), pH, water temperature (T_{water}) and dissolved oxygen (DO) were analyzed in the Dobruca drinking water treatment plant laboratories; the Secchi disc depth (SDD), suspended solids (SS) and chlorophyll-*a* (Chl-*a*) were measured in the Uludag University laboratories. SDD was measured by the Secchi disc method (Windaus). SS and Chl-*a* were analyzed according to standard methods (Round, 1973). The meteorological data (open-water evaporation (E), heat flux density (H) and air temperature (T_{air})) were obtained from the Meteorological Service. Selected meteorological parameters were provided from three meteorological stations from 40 km area. After the samples were fixed in the laboratory environment, they were sent to Gazi University Faculty of Education, Department of Secondary Science and Mathematics Education, Biology Education Department to determine the phytoplankton functional groups. The diagnosis and identification of algae were carried out in the department laboratory (Prescott, 1962; Germain, 1981; Husted, 1985; Dillard, 2007; Round, 1973).

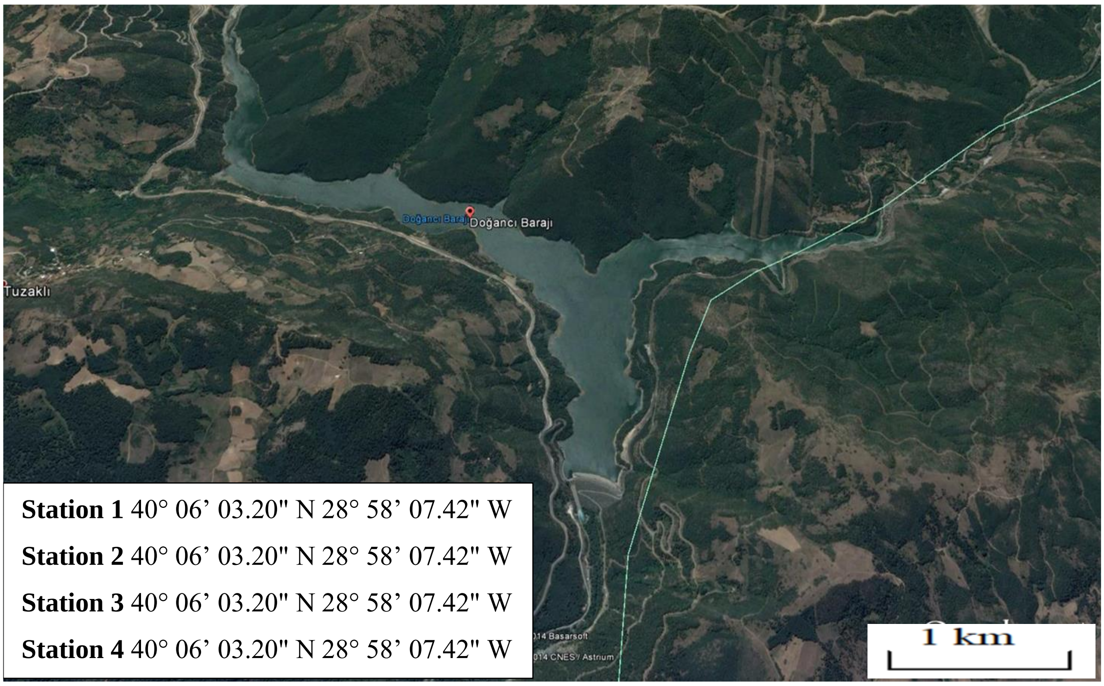

Figure 1. *The view of study area of Doganci Dam Reservoir and sampling stations*

Artificial neural network software (ANN) and clustering technique

An artificial neural network (ANN) is a computational structure inspired by the study of biological neural processing (Rao and Rao, 1995). An ANN is a data modeling tool that is capable of capturing and representing complex relationships between inputs and outputs. The network is composed of large numbers of highly interconnected processing elements, which are called “neurons” and are tied together with weighted connections. Each neuron works as an independent processing element and has an associated transfer function, which

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describes how the weighted sum of its inputs is converted to the results in an output value. Each hidden or output neuron receives a number of weighted input signals from each of the units of the preceding layer and generates only one output value (Feldmann et al., 2019).

For clustering problems, the self-organizing feature map (SOM) is the most commonly used network. The SOM-algorithm is based on unsupervised learning, which means that the desired output is not known a priori. The goal of the learning process is not to make predictions, but to classify data according to their similarity. In the early 1980s Kohonen proposed a neural network architecture in which the classification is done by plotting the data in n dimensions onto a, usually, two-dimensional grid of units in a topology-preserving manner (Kohonen, 1995). The former means that similar observations are plotted in each other's neighborhood on the 2-D-grid. The neural network consists of an input layer and a layer of neurons. The neurons or units are arranged on a rectangular or hexagonal grid and are fully interconnected. Each of the input vectors is also connected to each of the units (Miljković, 2017; Li et al., 2017).

The Neural Network Toolbox of Matlab by Mathworks Co. (Beale et al., 1992) was used in all calculations.

Results and discussion

The reservoir water quality is a complex function of its morphometry and watershed characteristics, including climate, hydrology, geology, morphology and land uses. Rational planning and operation of water supply systems requires recognition of the cause-effect relationships that influence water quality and, therefore, influence the feasibility and costs of supplying water while meeting the state and federal standards and criteria (Vaughan et al., 2017).

Light and temperature are two critical factors complementing each other for the activity rate of photosynthesis and phytoplankton (Khan et al., 2018 and Pala et al., 2021). Accordance to Reynolds (1993), the ideal temperature for the growth of algae is 25 °C. However, some algae species prefer lower or higher temperatures. Algae mostly permit temperatures between 10 and 30 °C (Bulut et al., 2011 and Pala et al., 2021). The average temperature of the Doğancı Dam Reservoir was 13.43 ± 0.21 °C during the sampling period. The highest temperature was 15 °C, and the lowest temperature was 12.1 °C. According to the obtained results, temperature is at a suitable temperature for growth of phytoplankton in the Doğancı Dam Reservoir.

In the Doğancı Dam Reservoir water column, pH values varied between 8.05 and 8.36, and the average measured value was 8.17 ± 0.05. Based on these values, the pH values > 7 indicate that slightly alkaline conditions are dominant in the reservoir. The productivity of alkaline water is high, while acidic water has a low efficiency (Sun et al., 2018). In the current study, these results were in the same ranges stated by Okbah and Hussein (2006), El-Alfy et al. (2020) and Alprol et al. (2021).

The dissolved carbonate in the soil, which is carried by the rain water, is believed to cause alkaline conditions in the Doğancı Dam Reservoir. No inverse relationship was found between the pH and oxygen. This condition is thought to be caused by the continuous flow of the reservoir. Specifically, the floating surface of the dam allows for water oxygenation. During the fall season and depending on the temperature, the autumn circulation period is considered to be effective. The DO value varies between 6.84 ± 0.38 and 10.28 ± 0.49 mg L^{-1}, and the average measured value was 8.31 ± 0.56 mg L^{-1}.

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The TOC is a measure of carbon dioxide in the water caused by the oxidation of organic carbon. The increased amount of organic matter is an indicator of water pollution. Organic substances cause the growth of bacteria, fungi and algae in water (Bhateria and Jain, 2016; Fural et al., 2019). The TOC values in drinking water supplies should be in the range of 0.1-25 mg L^{-1}. In this study, the TOC stay at acceptable limit values of Turkish Water Pollution and. Control Regulations (TWPCR), which indicates that there is no organic contamination.

The secchi disk depth is a measure of the clarity-light transmittance of the lakes. The most important parameter affecting light transmission is suspended solids. In the literature, it is reported that the relationship between suspended solids and light transmittance is a valid way in very productive lakes and has been used for a long time in estimating phytoplankton density. When the phytoplankton production is at a high level, the light transmittance will decrease and the depth of the bench will be low (Madden, 1992). The average secchi disc was calculated as 3.24 ± 0.58 m. The highest value of SDD was measured as 4 ± 0.07 m.

Factors affecting the amount of suspended solids in the water are phytoplankton density and rain/flood waters reaching the lake. Suspended solids increase the turbidity of the water and reduce light transmittance. They prevent the sun rays from reaching the aquatic plants, affecting photosynthesis, reducing the dissolved oxygen in the water. In addition, they collapse to the bottom and negatively affect the living environments of benthic creatures living at the bottom (Lima, 2021). The average calculated suspended solid value was 1.64 ± 0.21 mg L^{-1} in dam reservoir.

Chlorophyll-a is a photosynthetic pigment that is present in all phytoplanktonic organisms. The production of nutrients through photosynthesis and chemosynthesis is possible thanks to chlorophyll. In other words, primary production (primary production) in lakes is carried out by chlorophyll plankton and litoral plants (plants located in shallow parts of lakes) (Çevlik, 2013). In ecosystems, a ring called the food chain occurs as a result of feeding one of the living creatures over the other. Phytoplanktonic creatures and plants are the first link of the food chain in a freshwater ecosystem. The amount of chlorophyll-a is therefore the most important indicator of phytoplankton biomass and productivity in a lake. The average calculated Chl-*a* concentration was measured at 4.33 ± 0.49 mg m^{-3}. The Chl-*a* concentration indicates the mesotrophic property of the Doğancı Dam Reservoir (Sharma, 2018). In Doğancı Dam Lake, the region where the lake is divided into 2 branches and where the 4th station is located is the most efficient, and the region where the 1st station close to the dam is located has the least efficiency.

The temperature, humidity, solar radiation, rainfall and wind speed data were the measurable point values that revealed meteorological situation in the region. The variations in open-water evaporation level, heat flux density and air temperature were examined using data from the meteorological station near the reservoir.

Phytoplanktonic composition

A total of 75 taxa belonging to Bacillariophyceae (45), Chlorophyceae (12), Cyanophyceae (12), Dinophyceae (2), Chrysophyceae (2), and Euglenophyceae (2) classes were identified in Doğancı Dam Lake. Pelagic region algae members are mainly Bacillariophyceae (%61), Chlorophyceae (%16) and Cyanophyceae (%16) in terms of species diversity. The list of the The list of recorded taxa of phytoplankton in the Doğancı Dam Lake is given in *Table 1*. The distribution of phytoplankton groups was shown in *Figure 2*.

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Table 1. *The list of recorded taxa of phytoplankton in Doğancı Dam Reservoir*

Blue-green algae (Cyanophyceae)	**Diatomae (Bacillariophyta)**
Aphanizomenon flos--aqua (L.) Ralfs	*Aulacoseria granulata* (Ehrenberg) Simonsen
Chroococcus minor (Kützing) Nageli	*Coscinodiscus rothii* (Ehrenberg) Grunow
Lyngbya birgei G.M.Smith	*Cyclotella ocellata* (C.Agardh) Kützing
Chroococcus varius A.Braun	*Cyclotella meneghiniana* Kütz.
Microcystis punctata Meyen	*Melosira varians* Ag.
M. aeruginosa (Kützing) Kützing	*Amphora ovalis* (Kützing) Kützing
Nostoc commune Vaucher	*Achnanthes lanceolata var. elliptica* Grun.
Oscillatoria tenuis (Agardh) Gomont	*Achnanthes lanceolata* (Breb.) Grun.
Oscillatoria granulata Gardner	*Anamoeneis sphaephora* Grun.
Spirulina major (Kützing) Gomont	*Cocconeis pediculus* Ehrenberg
Spirulina pirinceps W.West&G.S.West	*Cymbella ventricosa* Agardh
	Cocconeis placentula Ehrenberg
Dinophyta	*Cocconeis pediculus Ehrenberg*
Ceratium hirundinella (O.F.Müller) Bergh	*Cymbella affinis (Kützing)* Grunow
Peridinium cinctum Ehr.	*Cymbella amphicephala* Naeg.ex. Kütz.
	Cymbella cymbiformis (Ag.) Ag.
Green algae (Chlorophyceae)	*Cymbella helvetica* Kütz
Ankistrodesmus falcatus (Corda) Ralfs	*Cymbella lanceolata* Ag.
Chlorella vulgaris Beyerinck	*Diatoma vulgare Bory*
Coelastrum microporum Nageli in A. Braun	*Diatoma elongatum Bory.*
Oocystis borgei J.Snow	*Fragilaria delicatissima (W.Smith) Lange-Bertalot*
Pediastrum boryanum (Turpin) Meneghini	*Fragilaria construens (Ehrenberg) Hustedt*
Closterium littorale Gay.	*Fragilaria ulna (Nitzch) Ehrenberg*
Cosmarium botrytis Menegh.	*Gyrosigma acuminatum (Kütz.) Rabh.*
Scenedesmus communis E.H.Hegevald	*Gyrosigma attennuatum Bory.*
Scenedesmus bijuga (Turp) Lagerh	*Gomphonema olivaceum (Lyng.) Kütz.*
Spyrogyra varians (Hass.) Kütz.	*Hantzschia amphioxys (Ehrenberg) Grun.*
Spyrogyra gratiana Kütz.	*Meridion circulare Ag.*
Staurastrum gracile Ralf	*Rhoicosphaenia curvata (Kützing) Grunow*
	Pinnularia brebissonii (Kütz.) Ralph.
	Pinnularia sublinearis (Grunow) Krammer
Chrysophyta	Pinnularia borealis *Grun.*
Dinobryon sertularia Ehrenberg	*Navicula cincta (Ehrenberg) Ralfs in Pritchard*
	Navicula cryptocephala Kütz.
	Navicula cryptotenella Lange-Bertalot
Euglenophyta	*Navicula lanceolata (Agardh) Kützing*
Euglena elongata Schewiakoft	*Navicula pupula Kütz.*
Trachelomonas sp.	*Navicula radiosa (Agardh) Kützing*
	Navicula venata Kützing
	Nitzschia palea (Kützing) W. Smith
	Nitzschia acularis (Kützing) W. Smith
	Neidium iridis (Ehr.) Cleve
	Neidium dubium Becker
	Surirella ovata Kützing
	Tabellaria fenestrata (Lyngbye) Kützing

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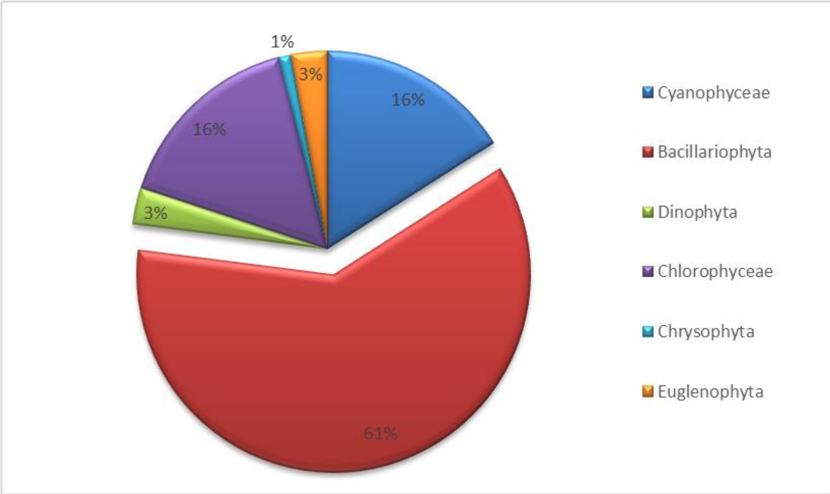

Figure 2. *Percentage distribution of phytoplanktonic divisions.*

The clustering results of sampling sites

A SOM with 10 × 10 neurons was created. The components planes (CPs) are visualized in *Figure 3*. For the clustering of the SOM prototypes, the K-means algorithm method and the hierarchical algorithm method were utilized and assessed in order to find the most appropriate clustering method for this modeling study.

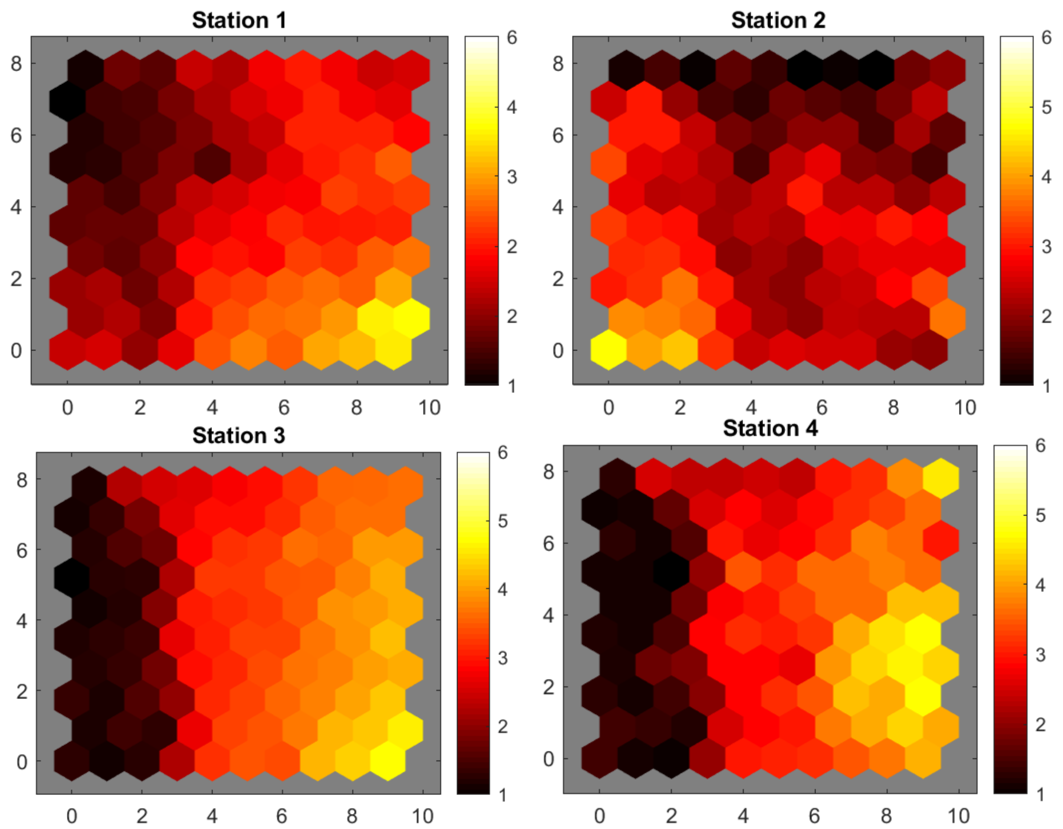

Figure 3. *Visualization of the SOM's planes for each station, where the colorbars indicate the mapping of the taxa (1. Diatomae (Bacillariophyta), 2. Euglenophyta, 3. Chrysophyta, 4. Green algae (Chlorophyceae), 5. Dinophyta, 6. Blue-Green Algae (Cyanophyceae))*

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In this study, a SOM algorithm presented good applicability to a time-series of phytoplankton abundance. Applications of SOM to dam lake phytoplankton communities as well as cyanobacterial dynamics are still scarce, despite there were many scientific studies that related with phytoplankton through ANN algorithms (Huang et al., 2017; Nazeer et al., 2017). Some scientific papers using SOM for addressing total phytoplankton biomass changes in lakes can be found. The SOM model in this study was successful for clustering complicated dataset of cyanobacterial blooms and species changes,

Bacillariophyta members are frequently found in aquatic ecosystems due to their high ecological tolerance, and they constitute the most important organisms by contributing to primary production. When the dominance value has calculated between the classes, the Bacillariophyta class was determined as dominant in the stations. The least common class is Dinophyta has been found to be.

Conclusion

The ecological conditions of aquatic environments can be determined by analyzing the organism communities living there. Because each aquatic organism has its own habitat preferences and they choose the best conditions to live. This study, in which members from phytoplankton of Doğancı Dam Lake were identified, aims to contribute to the quality of the dam lake and to the Turkish algal database.

In line with the data obtained:

Doğancı Dam Lake phytoplankton is mainly members of Bacillariophyceae, Chlorophyceae and Cyanophyceae in terms of species diversity.

Bacillariophyta members are frequently and widely encountered in aquatic ecosystems due to their high ecological tolerance, and they constitute the most important organisms by contributing to primary production. (Morkoyunlu et al., 2017). The fact that the highest number of taxa was observed in the Bacillariophyta division was a finding supporting this situation.

Continuing the researches in which phytoplankton is examined in detail is thought to be effective in controlling and improving the water quality of the lake. The list of species given as a result of the study is a priority report about the phytoplankton composition of this reservoir and will be useful as a resource for further research.

This study showed that the ANN modelling and clustering technique approach were utilized successfully and is appropriate for evaluating phytoplankton composition of the Doğancı Dam Reservoir. Because limnological studies and classical modeling efforts for reservoirs are laborious, expensive and time consuming, this approach will, hopefully, be adopted by water authorities as a decision support tool to reduce future monitoring efforts.

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