Journal of Animal and Veterinary Advances 8 (12): 2750-2755, 2009
ISSN: 1680-5593

Relationships Between Littoral Sediment and Water Characteristics in Eutrophic Macrophyte-Dominated Lake

[1]Serap Pulatsu, [2]Zahide Kocabas, [1]Akasya Topcu and [2]Yeliz Kasko
[1]Department of Aquaculture and Fisheries, Faculty of Agriculture,
Ankara University, 06110, Ankara, Turkey
[2]Department of Animal Sciences, Faculty of Agriculture, Biometry-Genetics Unit,
Ankara University, 06110, Ankara, Turkey

Abstract: The primary purpose of this study is to examine, whether or not it is possible to predict sediment characteristics namely total inorganic phosphorus (LSTINP), organic phosphorus (LSTORP) and total iron (LSTFe) from overlying water characteristics, namely total filterable orthophosphate (OVTFO) and total iron (OVTFe) and Pore Water characteristics, namely Total Filterable Orthophosphate (PWTFO) and total iron (PWTFe) in an eutrophic lake where there is no phosphorus release. The calculated determination coefficients, especially 0.588 for autumn 2004 and 0.767 for spring 2005, confirmed that the littoral sediment iron was correlated to overlying water phosphorus and iron. The results also confirmed that an adequate amount of variation in sediment characteristics can be explained by the pore water characteristics owing to the fact that they were statistically significant ($p<0.01$), except for LSTFe in the spring 2005. The results proved that the measured total filterable phosphorus and total iron concentration of the pore water have a more predictive value for phosphorus concentrations in the littoral sediment of Lake Mogan. In this study, it was also demonstrated that multiple regression equations constructed for one year could not be utilized to predict littoral sediment characteristics effectively in another year.

Key words: Littoral sediment, overlying water, pore water, multiple regression analysis, eutrophication, Mogan Lake

INTRODUCTION

Due to the importance of phosphorus in lake sediment, especially in eutrophication, this topic has been a focal point in many limnological studies; sediments may significantly affect the lake's nutrient level as a phosphorus sink or source (Bostrom *et al*., 1988). The physical and chemical properties of the sediment are important for the exchange of phosphate between the sediment and overlying water. Sediment pore water phosphorus levels are a good indicator for determining the nutrient state of lakes. Phosphorus concentrations in the sediment pore water may be affected by physical, chemical and biological events and may vary according to season, sediment depth and macrophyte concentrations (Carignan, 1985). In aquatic systems, while organic phosphorus in the sediment is usually in undissolved form, inorganic phosphorus returns to the water by way of Total Filterable Orthophosphate (TFO) in the sediment pore water under the effect of chemical factors.

The relationship between the sediment's physical (water content, loss on ignition, bulk density and grain size) and chemical (elemental composition, organic carbon compounds and minerals) parameters in lakes has been investigated in several different studies (Bostan *et al*., 2000; Hakanson and Jansson, 2002). In addition, field and laboratory studies have been undertaken in lakes with phosphorus release from the sediment to determine the relationship between phosphorus concentrations in the sediment, the overlying water and the sediment pore water (Eckert *et al*., 2003; Sinke *et al*., 1990; Shomar *et al*., 2005).

Lake Mogan, under environmental protection status as Gölbaþi Specially Protected Area (Turkey) has gone through a long period of eutrophication and there is extreme pressure on the drainage systems of the lake. In recent years, structurally dynamic and generalized logistic models have been developed for the lake (Tan and Beklioglu, 2005; Zhang *et al*., 2003a, b).

In Lake Mogan, it was found that the main reasons for the very low P release were the absence of anaerobic

Corresponding Author: Serap Pulatsu, Department of Aquaculture and Fisheries, Faculty of Agriculture, Ankara University, 06110, Ankara, Turkey

conditions between September 2004 and May 2006, that macrophytes were the source of oxygen for the sediment and the binding of inorganic phosphorus in high iron content of sediment to iron and aluminium (Pulatsu *et al*., 2008; Topcu and Pulatsu, 2008).

This study aims at investigating to which extent the Littoral Sediment characteristics, namely Total Inorganic Phosphorus (LSTINP), Organic Phosphorus (LSTORP) and Total Iron (LSTFe) are related to overlying water characteristics, namely total filterable orthophosphate (OVTFO) and total iron (OVTFe) and pore water characteristics, namely total filterable orthophosphate (PWTFO) and total iron (PWTFe) by using multiple regression analysis in a macrophyte-dominated clear-water state, Lake Mogan. This study also investigates whether there is significant difference in the formed regression models between seasons and years.

MATERIALS AND METHODS

Study area: Eutrophic Mogan Lake (39°47'N, 32°47'E), is an important recreational area for metropolitan Ankara, Turkey and is situated 20 km south of the city. The outflow of the lake empties downstream into Lake Eymir through a wetland on the north side of the lake. The lake has a surface area of 7.2 km^2, a mean depth of 2.8 m, a lake volume of 13.72×10^6 m^3 and a theoretical water residence of an average 1.35 times per year. Total phosphorus load and loading value were calculated as 10 941 kg $year^{-1}$ and 1.52 g $m/^2$/year for Mogan, respectively (Fakioglu and Pulatsu, 2005; Topcu and Pulatsu, 2008).

Sediment, overlying water, pore water sampling and laboratory analyses: Sediment samples were collected at a monthly interval of September, October and November in 2004 and 2005 and March, April and May in 2005 and 2006 using plexiglass tubes (5 cm inner diameter, 20 cm sediment depth) at the littoral zone (NW part of the lake) at 70 cm which during the summer time primarily had growth of *Chara vulgaris* and *Phragmites australis* and cattails (*Typha domingensis Pers.*) and two species of rush (*Juncus* sp.) cover selected station. The special emphasis of the study was on the upper 5 cm of sediment. Total phosphorus of dried sediments (105°C, 24 h) were analysed spectrophotometrically after digestion in a mixture of oxidizing acids. Sediment inorganic phosphorus fractionations were determined according to Hieltjes and Lijklema (2005). Organic bound phosphorus (org≈P) was calculated as the difference between total phosphorus and the sum of the inorganic fractions. Total iron concentration was measured using Atomic Adsorption/ Flame Emission Spectroscopy (APHA, 1995).

Sediment pore water was obtained by vacum filtration of sediment samples and sediment overlying water was gained by siphoning from the water 10 cm above the sediment. The supernatants of pore water and overlying water were analyzed for Total Filterable Phosphorus (TFP), Total Filterable Orthophosphate (TFO) and TFe were analysed by using the phenantroline method according to APHA (1995) in duplicate.

Statistical analyses: Correlation coefficient is the measure of relationship between two variables. To investigate the relationship between sediment and water characteristics independent variables, correlation coefficients among them were calculated. After that to obtain more information on the relationship between sediment and water characteristics, multiple regression analysis was applied. Regression analysis also provides information on variation in dependent variables explained by independent variables (Draper and Smith, 1998; Neter *et al*., 1989).

The difference between the regression equations formed for different seasons and years was tested by calculating the F-value as follows:

$$F = \frac{\dfrac{SS_t - SS_p}{(m+1)(k-1)}}{\dfrac{SS_p}{DF_p}}$$

Where,

- m = The number of independent variables in the model
- k = The number of groups
- SS_p = The pooled residual sum of squares
- DF_p = The pooled degrees of freedom of residual sum of squares
- SS_t = The total residual sum of squares. F-value shows F-distribution with (m+1)(k-1)
- DF_p = Degrees of freedom (Zar, 1999). All analyses were performed by using MINITAB 15.1 statistical package

RESULTS AND DISCUSSION

In this study, the data collected on LSTINP, LSTORP, LSTFe, OVTFO, OVTFe, PWTFO and PWTFe from the Lake Mogan during the intervals of September, October and November in 2004 and 2005 and March, April and May in 2005 and 2006 were used. The mean and standard error of mean of sediment and water characteristics for autumn in 2004 and 2005 and spring 2005 and 2006 are given in Table 1.

Regarding the measurements taken in autumn, there was a sharp increase in LSTINP, LSTORP, LSTFE and

Table 1: Mean and standard error of mean of sediment ($\mu g\ g^{-1}DW$) and water ($mg\ m^{-3}$) characteristics for autumn and spring (N = 4)

Variables	Autumn-2004	Autumn-2005	Spring-2005	Spring-2006
LSTINP	389.8±34.6	601.3±13.1	361.5±11.7	555.7±23.0
LSTORP	160.0±27.3	718.9±15.2	159.0±23.5	282.9±19.3
LSTFe	17533±248	32125±888	28925±160	30900±666
PWTFO	63.49±4.57	53.16±4.35	66.15±2.07	32.54±4.01
PWTFe	671.45±9.85	712.0±16.1	462.9±23.4	269.3±36.6
OVTFO	46.14±4.56	37.429±0.444	31.83±1.50	51.323±0.511
OVTFe	488.67±9.87	200.2±28.7	203.75±6.74	315.9±28.6

Table 2: Correlation coefficients between sediment and water characteristics for autumn

	Autumn 2004			Autumn 2005		
Variables	LSTINP	LSTORP	LSTFe	LSTINP	LSTORP	LSTFe
PWTFO	-0.856**	0.508	-0.121	-0.320	0.781**	0.868**
PWTFe	-0.762**	0.348	-0.302	0.919**	-0.754**	-0.666*
OVTFO	-0.592*	0.129	-0.480	-0.187	0.272	0.284
OVTFe	0.290	0.185	0.708**	-0.301	-0.425	-0.634*

Table 3: Correlation coefficients between sediment characteristics for spring

	Spring 2005			Spring 2006		
Variables	LSTINP	LSTORP	LSTFe	LSTINP	LSTORP	LSTFe
PWTFO	-0.734**	0.470	0.260	-0.166	-0.509	0.315
PWTFe	-0.864**	0.653*	0.100	-0.909**	-0.896**	0.944**
OVTFO	-0.054	-0.246	0.582*	0.210	0.442	-0.342
OVTFe	0.017	-0.344	0.820**	-0.453	-0.039	0.298

*p<0.05, **p<0.01

PWTFe in 2005 in comparison with those taken in 2004. When the means of sediment and water characteristics were calculated for spring, the results showed that there was a tendency to increase in 2006, except for PWTFO and PWTFe.

To investigate the relationship between sediment and water characteristics, correlation coefficients were calculated for autumn 2004-2005 and spring 2005-2006 and are presented in Table 2 and 3, respectively.

As shown in Table 2, LSTINP displayed a statistically significant relationship between pore water characteristics and OVTFO in autumn-2004. Moreover, there was a statistically significant relationship between LSTFe and OVTFe in autumn-2004. However, regarding the measurements taken in autumn-2005, sediments characteristics generally exhibited statistically significant relationship with pore water characteristics.

When, the correlation coefficients calculated for spring-measurements were inspected (Table 3), the results displayed that the sediment characteristics were inclined to be strongly related to the pore water characteristics. There was only statistically significant correlation between LSTFe and overlying water characteristics in spring 2005.

The results of multiple regression analysis for the relationship between sediment and overlying water characteristics for autumn 2004 and 2005 and spring 2005 and 2006 are given in Table 4.

The results of regression analysis indicated that LSTINP can adequately explained by overlying water characteristics in autumn 2004 and spring 2006.

Similar results were obtained for LSTFe measured in autumn 2004 and spring 2005 (Table 4). Except these results, there was no evidence of a statistically significant regression equation that could be used to predict sediment characteristics by using the overlying water characteristics.

The results of multiple regression analysis for the relationship between sediment and pore water characteristics for autumn 2004 and 2005 and spring 2005 and 2006 are given in Table 5.

The calculated determination coefficients confirmed that an adequate amount of variation in sediment characteristics can be explained by the pore water characteristics owing to the fact that they were statistically significant (p<0.01), except for LSTFe in spring 2005 (Table 5).

The phosphorus of sediment and water in Wadi Gaza Wetland (Israel) was determined by Shomar *et al.* (2005) and they reported that total phosphorus concentrations in sediment followed an opposite trend to phosphorus in water; phosphorus in sediment was high in winter and low in summer. The findings of this study obtained for LSTINP were in accordance with Shomar *et al.* (2005). This could occur because in Lake Mogan, the sediment inorganic phosphorus is used by macrophytes as a nutrient in spring, or because macrophytes are dead in autumn. There were most likely parallel variations in the TFO concentration of the overlying water, causing the low correlation between sediment inorganic phosphorus and overlying water characteristics and the insignificance of regression models in predicting sediment characteristics by using overlying water characteristics.

The phosphorus chemistry in aquatic systems is generally controlled by the interaction with iron. Sediment with high iron content gives an opportunity to overlying water to act as a sink for phosphorus; hence phosphorus release from sediment is hindered (Kisand, 2005; Nyguyen *et al.*, 1997). According to Heidenreich and Kleeberg (2003) determinations the sediment phosphorus release in Spremberg Lake (Germany), a low phosphorus release from sediment (14-20 $\mu g/m^2/day$) resulted from the high content of overlying water iron concentration (mean value: 4 mg L^{-1}) was reported. In this study, the high sediment iron content and the high ratio of total iron to total phosphorus (mean TFe/TP varied between approximately 24 and 55) were the reason for the very low sediment phosphorus release. The calculated determination coefficients, especially 0.588 for autumn 2004 and 0.767 for spring 2005, confirmed that the littoral sediment iron was correlated with overlying water phosphorus and iron (Table 4).

Table 4: The results of multiple regression analysis for the relationship between sediment and overlying water characteristics

Season-year	Regression equation	R^2	$F_{(2,9)}$
Autumn 2004	LSTINP = 2602 - 11.1 OVTFO - 3.48 OVTFe	0.577	6.14*
	LSTORP = - 1938 + 7.57 OVTFO + 3.58 OVTFe	0.404	3.05
	LSTFe = 675 + 33.4 OVTFO + 31.3 OVTFe	0.588	6.41*
Autumn 2005	LSTINP = 866 - 6.30 OVTFO - 0.145 OVTFe	0.136	0.71
	LSTORP = 455 + 8.2 OVTFO - 0.215 OVTFe	0.238	1.40
	LSTFe = 18394 + 469 OVTFO - 19.0 OVTFe	0.457	3.78
Spring 2005	LSTINP = 335 - 2.48 OVTFO + 0.52 OVTFe	0.022	0.10
	LSTORP = 438 + 4.2 OVTFO - 2.02 OVTFe	0.134	0.69
	LSTFe = 24391 - 70.6 OVTFO + 33.3 OVTFe	0.767	14.79**
Spring 2006	LSTINP = - 784 + 30.2 OVTFO - 0.665 OVTFe	0.516	4.81*
	LSTORP = - 932 + 25.4 OVTFO - 0.280 OVTFe	0.315	2.06
	LSTFe = 75115 - 963 OVTFO + 16.6 OVTFe	0.465	3.91

$p<0.01^*$, $p<0.05^{**}$

Table 5: The results of multiple regression analysis for the relationship between sediment and pore water characteristics and comparison of regression equations

Season-year	Regression equation	R^2	$F_{(2,9)}$	Comparison of regression equations- $F_{(2,18)}$
Autumn-2004	LSTINP = -1762 – 16.5 PWTFO + 4.76 PWTFe	0.830	21.95**	42.85**
Autumn-2005	LSTINP = -44.4 + 0.714 PWTFO + 0.854 PWTFe	0.885	34.79**	
Autumn-2004	LSTORP = 4111 + 19.2 PWTFO - 7.70 PWTFe	0.665	8.92**	742.40**
Autumn-2005	LSTORP = 939 + 1.85 PWTFO - 0.447 PWTFe	0.769	14.98**	
Autumn-2004	LSTFe = 65629 + 179 PWTFO - 88.6 PWTFe	0.664	8.88**	336.00**
Autumn-2005	LSTFe = 35501 + 146 PWTFO - 15.7 PWTFe	0.812	19.42**	
Spring-2005	LSTINP = 354 + 7.78 PWTFO - 1.10 PWTFe	0.882	33.63**	45.20**
Spring-2006	LSTINP = 667 + 2.44 PWTFO - 0.709 PWTFe	0.958	102.84**	
Spring-2005	LSTORP = 528 – 25.2 PWTFO + 2.81 PWTFe	0.779	15.85**	25.08**
Spring-2006	LSTORP = 414 - 0.266 PWTFO - 0.456 PWTFe	0.805	18.53**	
Spring-2005	LSTFe = 23900 + 177 PWTFO - 14.4 PWTFe	0.386	2.82	99.88**
Spring-2006	LSTFe = 26975 - 40.9 PWTFO + 19.5 PWTFe	0.934	63.85**	

It was reported that total filtrable orthophosphate concentrations in the overlying water are affected by various factors such as pH, redox potential (Eh) and microbial activities and also show seasonal variation (Clavero *et al*., 1999; Eckert *et al*., 2003; Maassen *et al*., 2003). Since, phosphate exchange between water and sediment is a complex process, the relationship between littoral sediment phosphorus and iron concentrations were almost statistically insignificant in the macrophyte-dominated clear-water state Lake Mogan.

The concentration of iron in sediment pore water is used as an indication of the binding of iron to phosphorus in aerobic waters. The results also prove that the measured total filterable phosphorus and total iron concentration of the pore water have a predictive value for phosphorus concentrations in the littoral sediment of Lake Mogan (Table 5).

According to Maassen *et al*. (2003), concerning P release rates there was no significant correlation between the TP contents in the sediment and the TFO concentrations in the pore water in a highly eutrophic reservoir. However, in this study, phosphorus release was quantitatively very low and all the regression equations formed were statistically significant, except for LSTFe in spring 2005, which means that it is worthwhile attempting to predict sediment characteristics using pore water characteristics as shown in Table 5.

Although, Shaw and Prepas (1990) reported that phosphorus in bottom sediment and pore water TFO were not correlated in seven meso-eutrophic to eutrophic Alberta lakes, in this study it was found that the correlation between sediment and pore water TFO was statistically significant. This can be because there was almost no phosphorus release in Lake Mogan.

Sediment phosphorus release is prevented when TFe/TFO is greater than 1.8 in the pore water according to Shaw and Prepas (1990) determinations. In Lake Mogan, the TFe/TFO ratio for pore water in autumn 2004 and 2005 was calculated as 10.57 and 13.39, respectively. This ratio for pore water was 6.99 for spring 2005 and 8.28 for spring 2006. There was an increase in this ratio calculated for autumn 2005 in comparison with that for 2004. Similarly, the calculated ratio for spring 2006 was higher than that for spring 2005 (Table 1).

The changes in the ratio of TFe/TFO from year to year also had an effect on the regression models formed to predict the sediment characteristics for each year. As shown in Table 5, the F-values which were calculated to determine whether the regression equations are significantly different from each other confirmed that there were statistically significant differences in the regression equations formed between years.

CONCLUSION

Inconsistencies in the sign of regression coefficients for sediment characteristics between two years were also observed, which means that the directions of the relationship between sediment and pore water characteristics changed from year to year and also season to season. However, the findings of this study indicated that even though there were seasonal and annual discrepancies, the properties of the pore water characteristics could be more beneficial in predicting sediment characteristics than those of overlying water both in autumn and spring. In this study, it was also investigated whether it was possible to apply the formed regression equation for 1 year to another year to foresee the sediment characteristics. But, the results showed that multiple regression equations constructed for one year could not be utilized to effectively predict littoral sediment characteristics in another year.

REFERENCES

American Public Health Association (APHA), 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edn. John D., Ducas Co., USA.

Bostan, V., J. Dominic, M. Bostina and M. Pardos, 2000. Forms of particulate phosphorus in suspension and in bottom sediment in the Danube Delta. Lakes and Reservoirs Res. Manage., 5: 105-110. http://www.wiley.com/bw/journal.asp.ref=1320-5331.

Bostrom, B., J.M. Andersen, S. Fleischer and M. Jansson, 1988. Exchange of phosphorus across the sediment-water interface. Hydrobiologia, 170: 229-244. http://www.springerlink.com/content/100271.

Carignan, R., 1985. Nutrient dynamics in a littoral sediment colonized by the submersed macrophyte *Myriophyllum spicatum*. Can. J. Fish. Aquat. Sci., 42: 1303-1311. http://pubs.nrc-cnrc.gc.ca/rp-ps/journalDetail.jspjcode=cjfas&lang=eng.

Clavero, V., J.J. Izquierdo, J.A. Fernveez and F.X. Niell, 1999. Influence of bacterial density on the exchange of phosphate between sediment and overlying water. Hydrobiologia, 392: 55-63. http://www.springerlink.com/content/100271.

Draper, N.R. and H. Smith, 1998. Applied Regression Analysis. 3rd Edn. John Willey and Sons, Inc., New York.

Eckert, W., J. Didenko, E. Uri and D. Eldar, 2003. Spatial and temporal variability of particulate phosphorus fractions in seston and sediments of Lake Kinneret under changing loading scenario. Hydrobiologia, 494: 223-229. http://www.springerlink.com/content/100271.

Fakioglu, O. and S. Pulatsu, 2005. Determination of external phosphorus loading in Mogan Lake (Ankara) following some restoration measures (in Turkish). Yuzuncu Yil Universitesi Ziraat Fakultesi Tarim Bilimleri Dergisi. J. Agric. Sci., 15 (1): 63-69. http://tarimbilimleri.agri.ankara.edu.tr.

Hakanson, L. and M. Jansson, 2002. Principles of Lake Sedimentology. The Blackburn Press. Caldwell, New Jersey, USA.

Heidenreich, M. and A. Kleeberg, 2003. Phosphorus-binding in iron-rich sediments of a shallow reservoir:spatial characterization based on sonar data. Hydrobiologia, 506-509: 147-153. http://www.springerlink.com/content/100271.

Hieltjes, A.H.M. and L. Lijklema, 2005. Fractionation of inorganic phosphates in calcareous sediments. J. Environ. Qual., 9 (3): 405-407. http://jeq.scijournals.org.

Kisand, A., 2005. Distribution of sediment phosphorus fractions in hypertrophic strongly stratified Lake Verevi. Hydrobiologia, 547: 33-39. http://www.springerlink.com/content/100271.

Maassen, S., I. Roske and D. Uhlmann, 2003. Chemical and microbial composition of sediments in reservoirs with different trophic state. Internat. Rev. Hydrobiol, 88 (5): 508-518. http://www.springerlink.com/content/100271.

Neter, J., W. Wasserman and M.H. Kutner, 1989. Applied linear regression models. Richard D. Irwin, Inc. Boston, USA.

Nyguyen, L.M., J.G. Cooke and G.B. McBride, 1997. Phosphorus retention and characteristics of sewage-Impacted Wetland Sediments. Water, Air and Soil Pollut., 100: 163-179. www.springerlink.com/link.asp.id=100344.

Pulatsu, S., A. Topcu, M. Kirkagac and G. Köksal, 2008. Sediment Phosphorus Characteristics in the Clearwater State of Lake Mogan, Turkey. Lakes and Reservoirs: Res. Manage., 13: 197-205. http://www3.interscience.wiley.com/journal/117979475/tocCRETRY=1&SRETRY=0.

Shaw, J.F.H. and E.E. Prepas, 1990. Relationships between phosphorus in shallow sediments and in the trophogenic zone of seven Alberta Lakes. Wat. Res., 24 (5): 551-556. www.elsevier.com/locate/watres.

Shomar, B.H., G. Muler and A. Yahya, 2005. Seasonal variations of chemical composition of water and bottom sediments in the Wetland of Wadi Gaza, Gaza Strip. Wetlands Ecol. Manage., 13: 419-431. www.springerlink.com/link.aspid=103012.

Sinke, A.J.C., A.A. Cornelese, P. Keizer, O.F.R. Van Tongeren and T.E. Cappenberg, 1990. Minerilization, pore water chemistry and phosphorus release from peaty sediments in the eutrophic Loosdrecht Lakes, The Netherlands. Freshwater Biol., 23: 587-599. http://www.wiley.com/bw/journal.aspref=0046-5070.

Tan, C.O. and M. Beklioglu, 2005. Catastrophic-like shifts in shallow Turkish lakes: A modelling approach. Ecological Modelling, 183: 425-434. www.elsevier.com/locate/ecolmodel.

Topcu, A. and S. Pulatsu, 2008. Phosphorus Fractions in Sediment Profiles of the Eutrophic Lake Mogan, Turkey. Fresenius Environ. Bull., 17 (2): 164-172. http://www.psp-parlar.de/feb_auswahl.asp.

Zar, J.H., 1999. Biostatistical Analysis. 4th Edn. Prentice-Hall Inc., New Jersey, USA, pp: xii + 663.

Zhang, J., S.E. Jorgensen, C.O. Tan and M.A. Beklioglu, 2003a. A structurally dynamic modelling-Lake Mogan, Turkey as a case study. Ecological Modelling, 164: 103-120. www.elsevier.com/locate/ecolmodel.

Zhang, J., S.E. Jorgensen, M. Beklioglu and Ö. Ince, 2003b. Hysteresis in vegetation shift-Lake Mogan prognoses. Ecological Modelling, 164: 227-238. www.elsevier.com/locate/ecolmodel.