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Original Article

Can the PAMOLARE 1-layer model predict eutrophication in hypertrophic lakes? A Case study: the Zaribar Lake, Iran

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Abstract: Eutrophication is known as the most common problem in water bodies, caused by high concentrations of different nutrients leading to unbalanced growth of aquatic plants, among other symptoms. Hence, the possibility of eutrophication prediction can be beneficial to the sustainable management of these natural resources and create an opportunity to control their trophic conditions over time. A software package applied for generating these predictions is PAMOLARE with its different models (layers). The 1-Layer model of this method was selected to investigate the trophic condition of hypertrophic Zaribar lake. Prior to 2012, water samples were collected from six stations over a seven-year period. During the last year of this period, sediment samples were also collected. The concentrations of N and P were measured in the samples. The initial results showed that the Zaribar Lake is a hypertrophic water body. Applying the PAMOLARE 1-Layer model showed that this model was not powerful enough to predict the trophic changes in this hypertrophic water body and suggested that other models should be examined and modified for use in these ecosystems. Alternatively, it is necessary to improve the software for the prediction of eutrophication in hypertrophic water bodies.

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Introduction

Water bodies such as lakes and wetlands provide facilities and services for the human beings, as a result of their high levels of production and their rich and unique biodiversity (Herath, 2004; Punt et al., 2010). In more than half of these ecosystems, the quality of these ecosystem services has been reduced due to environmental degradation (Zedler and Kercher, 2005). Human activities have doubled the annual rate of nitrogen fixation and caused an increase of 75% in phosphorus accumulation in lakes and wetlands (Vitousek et al., 1997; Bennett et al., 2001). Due to the acceleration of this trend in past decades, the water resources have faced a severe environmental problem, i.e. eutrophication (Mitsch and Jorgensen, 2003). Among the numerous factors causing eutrophication in the water resources, the accumulation of nutrients such as nitrogen and phosphorus is the most important factor. The response of these water bodies to the accumulation of nutrients results in a decrease in light penetration into the water column, increase in water temperature, and changes in biological, chemical and physical processes (Zha et al., 2010).

Eutrophication is characterized by rapid reproduction of phytoplankton and other microorganisms and decreased water quality, both of which are harmful to the ecological conditions of lakes and wetlands and affect their natural functions (OECD, 1982). Kautsky (1998) used salinity to investigate eutrophication and environmental pollution in lakes and wetlands. He found that there was an inverse relationship between salinity and the concentration of organic matter in these water

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resources. To investigate eutrophication in coastal areas, Dale (2009) studied dinoflagellates populations in surface sediments. He found that climate change affects the eutrophication trend.

Reducing the various forms of nitrogen and phosphorus compounds is the most effective way of restoring eutrophic water bodies, which have been affected by agricultural pollutants (Ardo'n et al., 2010; Duff et al., 2009; Bruland and Richardson, 2005). Total nitrogen and phosphorus concentration in the water column have been reported to be the best indicators of eutrophication trends and prediction (Bobbink et al. 1998; Gunnarsson and Rydin, 2000; Gunnarsson et al., 2004; Koshikawa et al., 2005; Tsujian et al., 2010). Kokfelt et al. (2010) showed that in a lake in northern Sudan concentrations of carbon and nitrogen increased during several years. In a similar study, Larsen and Hervey (2010) found interactions between plant growth, hydrology and sediment transport. Hydrologic and biogeochemical conditions, plant and animal community status and the concentrations of nutrients were found to be a proper base for identification of trophic level of wetlands (Richardson, 2010). The nutrient loadings have considerable effects on plant growth and consequently on eutrophication trends (Tsujian et al., 2010). Other studies showed that the concentrations of nitrogen and phosphorus in sediments are appropriate indicators of eutrophication (Olander and Vitousek, 2000; Vicente et al., 2010; Wang et al., 2010).

Due to the critical role of eutrophication in the limnology of lakes and wetlands, an evaluation of trophic status is the first step in their conservation (Vicente et al., 2010). Therefore various models have been introduced for the management of eutrophic wetlands, which are based on the physical, chemical and biological properties of lakes and wetlands. PAMOLARE was first introduced at the "3rd international workshop on regional approaches for the development and management of reservoirs in the La Plata basin," in 2001. This methodology was produced at Kyoto University at the request of UNEP-IETC (the United Nations Environment Programme - International Environmental Technology Centre) and IUCN (the International Union for Conservation of Nature) (Jørgensen et al., 2003). This methodology has been used and improved for management and control of eutrophication in eutrophic lakes and water resources (Gurkan et al., 2006). Structurally dynamic modeling has also been applied to explore the biological patterns related to system responses to forcing functions, such as changes in nutrient loads (Jørgensen and de Bernardi, 1998; Zhang et al., 2003). The PAMOLARE model has been successfully applied in 18 case studies for parameter estimation, calibration, validation and generation of prognoses (Zhang, 2004). This type of model may be important for qualitatively predicting the outcomes of lake management strategies by generating prognoses although examining more case studies is required to support the possible generalizations relating to their use for such a purpose (Jørgensen and de Bernardi, 1998). It includes a watershed model, which works together with a simple lake model or a structurally dynamic lake model with a medium to high degree of complexity in order to generate outputs based on different restoration measures (Jorgensen et al., 2003). Hence, it is easy to apply the results from the watershed model to assess nutrient loadings (the most crucial forcing functions) using the lake model (Jørgensen, 2010). Testing PAMOLARE using different lakes and water reservoirs has calibrated and validated the models to give better results (Jørgensen, 2008). PAMOLARE has been used in a study in Iran for the Anzali wetland (Ramin, 2004). In this study, the trophic levels of the Zaribar Lake were identified, then, PAMOLARE was used to predict the concentrations of nutrients and other chemical and biological responses in the Lake to validate its use for assessing the various management alternatives. Based on previous studies the concentrations of nitrogen and phosphorus were used for the trophic level identification (Vollenweider and Kerekes, 1980; Carlson and Simpson, 1996 and Robert, 1996).

Material and Methods

Study area: The Zaribar lake is located on the west side of the Zagros mountain, extending from 35º31'30" to 35º37'06"E latitude and from 46º03'52" to 46º10'47"N longitude at an elevation of 1278 m above sea level (Fig. 1). It has a total area of 720 ha. This ecosystem consists of a unique plant and animal diversity, which in recent years resulted in a considerable increase in the numbers of tourists. However, the wastewater discharges from adjacent populated areas, chemical fertilizers and pesticides from farmlands, improper disposal of solid waste and the pressures caused by the increasing numbers of tourists are devastating its ecological and environmental quality (Asarab Consultanting Co., 2007).

Determination of tropic level: Six sampling sites were selected based on their spatial distribution in the wetland (Fig. 1) and water samples were collected in PVC bottles during a seven-year period (2004-2010) during different seasons. One of the sites was located in the entrance of the lake. In 2010, sediment grab samples were collected from three randomly selected sites, stored in plastic bags and transported to the laboratory. These samples were dried and fixed at ambient temperatures prior to analysis.

A Pallin Test photometer (Model 8000) was used for the measurement of nitrogen and phosphorus concentrations in the water column. The water samples were analyzed for nitrite, nitrate, ammonium, and phosphate. Total phosphorus concentrations were measured based on Murphy and Riley (1962) using spectrophotometer (Cintra 40). Kjeldahl nitrogen and total nitrogen concentrations were measured using the ascorbic acid method of Inorg et al. (2005).

A Kolmogorov-Smirnov test was used to investigate the normality of the distribution of total nitrogen and phosphorus in water column and a one way ANOVA test was applied to examine a significance difference between total nitrogen and phosphorus concentrations among sampling sites. The results were compared to existing standards (Table 1; Vollenweider and Kerekes, 1980; Carlson and Simpson, 1996; Robert, 1996).

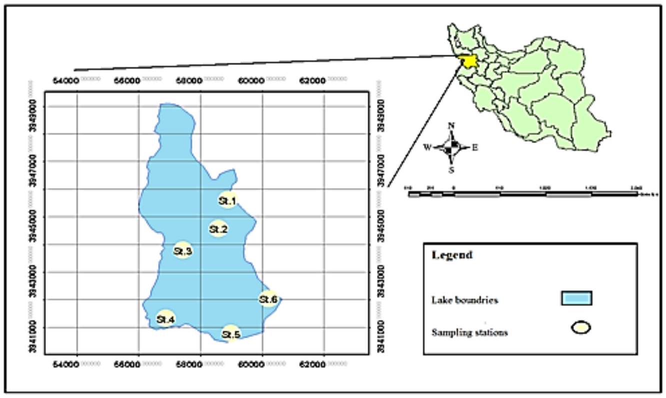

Figure 1. The study area and sampling stations.

Using the 1-layer model for the prediction of trophic levels in Zaribar Lake over the next 20 years: PAMOLARE contains four different eutrophication models; a Vollenweider plot, a 1-layer model with four state variables and the possibility of simulating nutrient concentrations both in the water column and in the sediment (Vollenweider, 1975); a two-layer model with 21 state variables, and a structurally dynamic model with 15 state variables using energy as the function for describing structural changes (Zhang, 2004). The 1-layer model of PAMOLARE is the verified version of Vollenweider model and forecasts nitrogen and phosphorus concentrations in sediments and the water column. The empirical part of the model consists of simple regressions between input data and physico-chemical properties based on responses observed in similar water bodies. For executing the 1-layer model in PAMOLARE software, information on wetland morphology and the concentrations of nitrogen and phosphorus are required. This model is developed as an ecological model that could account for structural changes in the water body affecting the prediction of trophic level. Some of the required information is measured directly or estimated using other factors. The average length, width and depth and nutrient concentrations are measured in the field or in collected samples. Other required factors, including a wide range of trophic indicators which have direct or indirect effects on the trophic level of water bodies, are calculated.

Calculating the required input data: Some of the required information is measured directly or estimated using other factors. Calculated factors are (Jørgensen et al., 2003):

1. Water flow speed: $S=\sqrt{g.Dm}$, Where g=32.3 (Foot/S2), Dm = depth (Foot).
2. Nitrogen and phosphorus loadings: Loading (g×m2×year) = percentage of element (concentration) × (annual volume of water inlet/ wetland area).
3. Sediment bound nitrogen or phosphorus: Bound = Load – Release, or 15-25% × Loading from sediment.
4. Denitrification rate: Denit = N load – (0.34 × Wres) – (0.16× Z ×0.17), Where Denit= rate of denitrification, Z= depth and Wres= Resting time (Water residence time).

All calculated data were put into the software and all PAMOLARE indicators were predicted. The estimated results (outputs) were compared with field observations.

Results

The average concentrations of NO2, NO3-, NH3- and PO3-2 at different times and sites are presented in Table 2. The comparison between total nitrogen and total phosphorus concentrations at the sampling sites is presented in figure 2.

The Kolmogorov Smirnov test showed that the resultant data have a normal distribution (*P*>0.05). No significant difference was found among the five sampling sites in total nitrogen concentrations (df = 5, F = 1.101, P = 0.362) and total phosphorus concentrations (df = 5, F = 0.521, P = 0.761).

The results of the chemical analysis of the sediment samples were processed using the 1-Layer model. All required information required for this method are shown in tables 3, 4 and 5. The results of the simulation are presented in table 6 and figures 3, 4, 5 and 6.

Comparison of the calculated results with those measured in the Zaribar Lake showed that there was no compatibility between the PAMOLARE predictions and those observed in the Zaribar Lake.

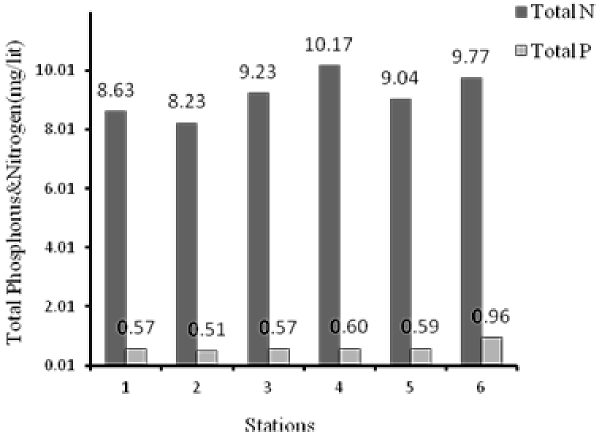

Figure 2. The comparison between total phosphorus and nitrogen concentrations.

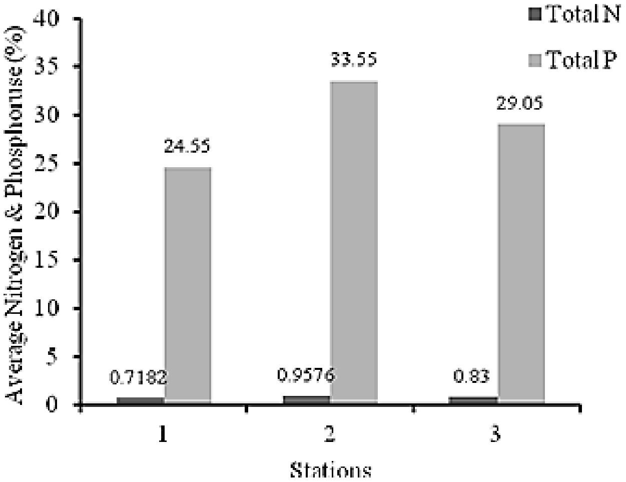

Figure 3. The comparison between total phosphorus and nitrogen concentrations in sediment.

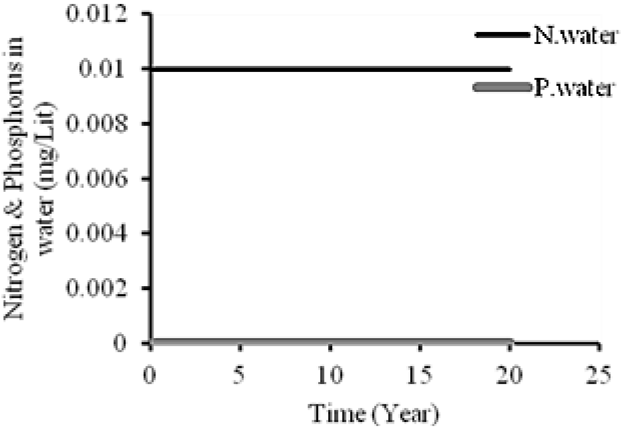

Figure 4. The predicted trend of nutrient changes in water.

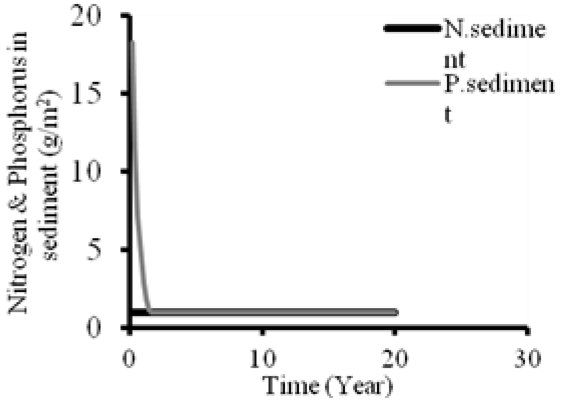

Figure 5. The predicted trend of nutrient changes in sediment.

Discussion

Lakes are valuable water resources, which are under pressures of increasing populations and the consequent increases in the different type of pollutants. Pollutants, especially nutrients such as phosphorus, cause the eutrophication of these water bodies. Therefore, the identification of their trophic status and prediction of eutrophication trends in these natural resources are necessary for selecting the best management and engineering methods for their conservation or restoration.

In this study, no difference was found between the concentrations of nutrients at the different sampling sites (the sites were distributed evenly in the lake). All sites showed similar concentrations of nutrients in their water columns. This might be because of the geomorphology of the lake and the existence of springs on its bottom. The geomorphological and hydrological conditions, especially the high sedimentation rates, might have accelerated the eutrophication of the lake, as previously reported by Zha et al. (2010). Kokfelt et al. (2010) showed that the nutrient cycles in water resources are affected by the rate of sedimentation, similar to what was found in this study. Nutrient compounds attach to sediments and can create more stability in lakes but cause future pollution if the nutrients are released back into the water column. Hence, there could be a direct relationship between sedimentation rate, the presence of the nutrients and the eutrophication level.

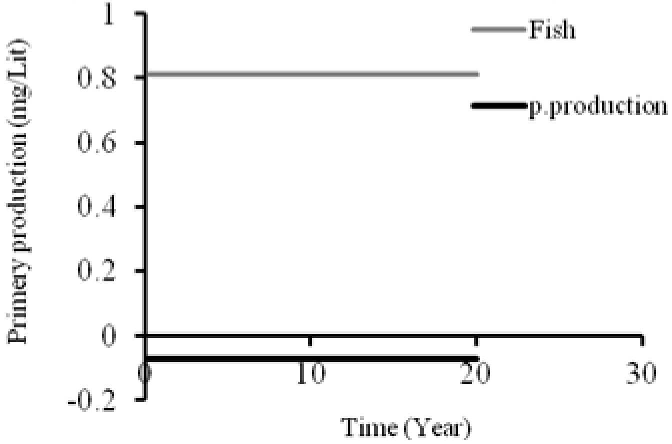

Figure 6. The predicted trend of changes in primary production and fish production (Biomass).

The effects of hydrobiological factors on plant vegetation in lakes were previously reported (Larsen

Table 1. The classification of trophic levels using different standards.

Reference	Parameter	Oligotroph	Mesotroph	Euotroph	Hypertroph
Robert (1996)	Chlorophyll (mg/lit)	-0.002	0.002-0.006	+0.006	
Carlson (1996)	TP (mg/lit)	-0.008	0.008-0.0267	+0.0267	96-384
Vollenweider and Kerekes (1980)	TN(mg/lit)	-0.661	0.661-0.753	0. 753	

Table 2. The average concentrations of nutrients in different sampling stations.

		1	2	3	4	5	6	Mean	SD
Nutrients (mg/lit)	NO_2^{-2}	0.0012	0.0023	0.0048	0.0042	0.0058	0.0057	0.004	0.00187
	NO_3^-	8.44	7.97	9.01	9.69	8.82	9.48	8.90	0.64147
	NH_3	0.18	0.25	0.21	0.47	0.22	0.28	0.23	0.10338
	TN	8.63	8.23	9.23	10.17	9.04	9.77	9.18	0.71492
	TP	0.57	0.51	0.57	0.60	0.59	0.96	0.63	0.163254

Table 3. The concentrations of total phosphorus and nitrogen in the sediment samples.

Stations		1	2	3	Mean	SD
Average of	TP	24.55	33.55	29.05	29.05	4.5
Nutrients	TN	0.7182	0.9576	0.830	0.8352	0.11

Table 4. Other factors required for PAMOLARE 1-Layer model.

Reduction of nutrient outflow due to thermocline (a)	Sedimentation constant (m/year)	Water residence time (year)	Length (m)	Water speed (foot/s)	Depth (m)	Initial factors
1	0.0077	0.0000267	5000	19.50	3.6	Amount

Table 5. Phosphorus and Nitrogen required data for 1-LAYER model.

Nutrient	Initial value in water (mg/lit)	Initial value in (gr/m^3) sediment	Loading value $(gr/m^2/year)$	Sediment release value (gr/m2/year)	Fraction bound in sediment (year)	Stabilized amount (year)
Phosp	0.63	29.05	2.58	2.064	7.26	0
Nitrog	9.18	0.83	7.37	2.26	1.47	0

Table 6: The results of software (PAMOLARE) simulation for a 20-year period.

Time period (0.02yr)	Nitrogen of water (mg/lit/)	Nitrogen of sediment (g/m^2)	Phosphorus of water (mg/lit/)	Phosphorus of sediment (g/m^2)	Limiting nutrient	Chlorophyll (mg/lit/)A	Secchi depth (m)	Zooplankton (mg/lit)	Fish(mg/lit/)	Average primary (mg/lit/) production	Average maximum (mg/lit/)	Average fish yield
0.2	0.01	1.00	0.00	18.27	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
0.4	0.01	1.00	0.00	11.49	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
0.7	0.01	1.00	0.00	7.23	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
0.9	0.01	1.00	0.00	4.55	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
1.1	0.01	1.00	0.00	2.86	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
1.3	0.01	1.00	0.00	1.80	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
1.5	0.01	1.00	0.00	1.13	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
1.8	0.01	1.00	0.00	1.00	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
2.0	0.01	1.00	0.00	1.00	p	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
..	0.01	1.00	0.00	1.00	P	0.00	18.34	0.04	0.81	-0.07	-0.06	0.01
20	…	…	…	…	…	…	…	…	…	…	…	…

and Harvey, 2010; Richardson, 2010). In the Zaribar Lake the hydrologic conditions and the high rates of sedimentation cause development of reed communities in different parts of the wetland. High concentrations of total phosphorus and nitrogen in the lake were found to be the main causes of eutrophication in this ecosystem, which is similar to what has been found in other studies (Ardo'n et al., 2010; Duff et al., 2009; Bruland and Richardson, 2005). The concentration of nitrogen in Zaribar Lake is more significant than that of phosphorus, so it support greatly the dense vegetation cover which traps additional nutrients and this reciprocal relationship propels this lake to hypertrophic levels. Among all chemical and hydrobiological factors investigated in this research, the concentrations of total phosphorus and total nitrogen in water column were found to be the best indicators of the trophic level of the wetland, which supports previous research in other areas (Tsujian et al., 2010;

Koshikawa et al., 2005; Gunnarsson et al., 2004; Gunnarsson and Rydin, 2000; Bobbink et al., 1998). This indicates that those pollutants which have the highest loading rates have the main effect on increasing trophic level in the Zaribar Lake, transforming it to an ecosystem of low value to humans.

The application of the 1-Layer model to this lake was unsuccessful in predicting of the trend changes in nutrient concentrations, fish and biomass production and primary production. This is in contrast to what Ramin (2004) found in the Anzali wetland. In the case of Zaribar Lake, these factors do not appear to reflect the real changes, especially related to our observations in recent years. Therefore, the application of this model to hypertrophic lakes is inappropriate. To apply in hypertrophic conditions, the software needs to be improved to be able to simulate the trophic changes in lakes with higher trophic levels. Gurkan et al. (2006) also reported the inability of PAMOLARE software in modeling and simulation of lakes with special or critical conditions. PAMOLARE failed to generate prognoses of the effects of various pollutants and did not predict the changes in some trophic indicators such as fish and biomass production, primary production and nutrient concentrations in our hypertrophic lakes. Therefore, this model has limited utility for the management of hypertrophic lakes.

In conclusion, the present study supports the idea of using observed total nitrogen and total phosphorus concentrations in the water column as the best method for the identification of the trophic levels of hypertrophic water resources. It is necessary to improve and develop PAMOLARE and its software to predict the eutrophication factors in wetlands at high trophic levels. This necessity was highlighted as the purpose of the software is to be used as a management tool for the prediction of the effectiveness of restoration plans and programs. The Zaribar Lake, as a hypertrophic wetland being impaired by pollutants from different sources, requires a range of environmental and engineering methods for its restoration. However the effectiveness of these methods cannot be simulated or predicted using the existing software. Therefore, it is strongly suggested that PAMOLARE, as widely available software, be further developed and improved for better simulation and modeling of extreme conditions.

References

Ardo'n M., Morse J.L., Doyle M.W., Bernhardt E.S. (2010). The water quality consequences of restoring wetland hydrology to a large agricultural watershed in the southeastern coastal plain. Ecosystems, 13: 1060-1078.

Asarab Consulting Company (2007). Environmental and limnological studies for the conservation of ecological balance in the Zaribar Lake, Marivan. Asarab.

Bennett E.M., Carpenter S.R., Caraco N.F. (2001). Human impact on erodible phosphorus and eutrophication: a global perspective. Ecosystems Bioscience, 51: 227-234.

Bobbink R., Hornung M., Roelofs J.G.M. (1998). The effects of air-borne nitrogen pollutants on species diversity in natural and semi natural European vegetation. Ecosystems Ecology, 86: 717-738.

Bruland G.L., Richardson C.J. (2005). Spatial variability of soil properties in created, restored, and paired natural wetlands ecosystems. Soil Science Society of America Journal, 69: 273-284.

Carlson R.E., Simpson J. (1996). A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society, 96 p.

Dale B. (2009). Eutrophication signals in the sedimentary record of dinoflagellate cysts in coastal waters. Sea Research, 61: 103-113.

Duff J.H., Carpenter K.D., Snyder D.T., Lee K.K., Avanzino R.J., Triska F.J. (2009). Phosphorus and nitrogen legacy in a restoration wetland, Upper Klamath Lake, Oregon. Wetlands, 29: 735-746.

Gunnarsson U., Granberg G., Nilsson M. (2004). Growth, production and interspecific competition in Sphagnum: effects of temperature, nitrogen and sulphur treatments on boreal mire. New Phytologist, 163: 349-359.

Gunnarsson U., Rydin H. (2000). Nitrogen fertilization reduces Sphagnum production in bog communities. New Phytologist, 147: 527-537.

Gurkan Z., Zhang J., Jorgensen S.E. (2006).

Development of structurally dynamic model for forecasting the effects of restoration of lake Fure, Denmark. Ecological Modeling, 197: 89-102.

Herath G. (2004). Incorporating community objectives in improved wetland management: the use of the analytic hierarchy process, Environmental Management, 70: 263-273.

Inorg H., Janssen D.R., Koopmann R. (2005). Determination of Kjeldahl nitrogen in soil, biowaste and sewage sludge, CEN/BT/Task Force, 151, European Standard.

Jørgensen S.E. (1976). Eutrophication model for a lake. Ecological Modeling, 2: 147-165.

Jørgensen S.E. (2010). A review of recent developments in lake modeling. Ecological Modeling, 221: 689–692.

Jørgensen S.E. (2008). Modeling the Eutriphication, Proceeding of Taal 2007: The 12th World Lake Conference. pp: 799-811.

Jørgensen S.E., Tsuno Hidaka T., Mahler H., Santiago V. (2003). PAMOLARE training package, planning and management of lakes and reservoirs: models for eutrophication management.

Jørgensen S.E., de Bernardi R. (1998). The use of structural dynamic models to explain successes and failures of biomanipulation. Hydrobiologia, 359: 1–12.

Kautsky L. (1998). Monitoring eutrophication and pollution in estuarine environments-focusing on the use of benthic communities, Pure and Applied Chemistry, 70: 2313-2318.

Kerekes J. (1977). The index of lake basin permanence. Internationale Revue der gesamten Hydrobiologie und Hydrographie, 62: 291-293.

Kokfelt U., Reuss N., Struyf E., Sonesson M., Rundgren M., Skog G., Rosen P., Hammarlund D. (2010). Wetland development, permafrost history and nutrient cycling inferred from late Holocene peat and lake sediment records in subarctic Sweden. Journal of Paleolimnology, 44: 327-342.

Koshikawa M.K., Fujita N., Sugiyama M., Hori T. (2005). Distributions of pH and chemical components in Mizorogaike, a pond with a floating-mat bog. Limnology 6: 27-37.

Larsen L.G., Hervey J.W. (2010). How vegetation and sediment transport feedbacks drive landscape change in the everglades and wetlands worldwide. The American Naturalist, 176:66-79.

Mitsch W.J., Jørgensen S.E. (2003). Ecological Engineering and Ecosystem restoration. John Wiley and Sons, New York, 412pp.

Murphy J., Riley J.P. (1962). A modified single solution method for determination of phosphate in natural waters. Analytical Chemical Acta, 26: 31-36.

OECD (1982). Eutrophication of waters: monitoring, assessment and control. Final Report, OECD Cooperative Programme on Monitoring of Inland Waters (Eutrophication Control, Environment Directorate), OECD, Paris.

Olander L.P., Vitousek P.M. (2000). Regulation of soil phosphatase and chitinase activity by N and P availability. Biogeochemistry, 49: 175-191.

Punt M.J., Weikard H.P., Groeneveld R.A., Van Ierland E.C., Stel J.H. (2010). Planning marine protected areas: a multiple use game. Natural Resource Modeling, 23: 610-646

Ramin M. (2004). Management and planning of eutrophic wetlands using PAMOLARE software (Case study: Anzali wetland), M.Sc. Thesis, Department of Environment, University of Tehran, Iran.

Richardson C. (2010). The everglades: North America's subtropical wetland. Wetlands Ecology Management, 18: 517-542.

Robert D.D. (1996). Ohio water resource inventory. State of Ohio environmental protection agency. Sea Research, 61: 103-113.

Tilman G.D. (1997). Human alteration of the global nitrogen cycle: sources and consequences, Ecological Application 7: 737-50.

Tsujian R., Fujita N., Katayama M., Kawasz D., Matsui K., Seo A., Shimamura T., TakaemonY., Tsujimura N., Yumoto T., Ushimaru A. (2010). Restoration of floating mat bog vegetation after eutrophication damages by improving water quality in a small pond. Limnology, 11: 289-297.

Vicente I.D., Guerreroc F., Pizarroab L.C. (2010). Chemical composition of wetland sediments as an integrator of trophic state. Aquatic Ecosystem Health and Management, 13: 99 -103.

Vitousek P.M., Aber, J.D., Howarth R.W., Likens G.E., Matson P.A., Schindler D.W., Schlesinger W.H., Wang L., Yin C., Wang W., Shan B. (2010). Phosphatase Activity along Soil C and P Gradients in a Reed-Dominated Wetland of North China. Wetlands 30: 649-655.

Vollenweider, R.A. 1975. Input-output models with special reference to the phosphorus loading concept in limnology. Swiss Journal of Hydrology, 37: 53-84.

Vollenweider, R.A., Kerekes J.J. (1980). Synthesis Report, cooperative program on monitoring of inland waters (eutrophication Control). Report prepared on behalf of Technical Bureau, Water Management Sector Group, Organization for Economic Cooperation and Development (OECD), Paris. 290 P.

Zhang J., Jørgensen S.E., Beklioglu M., Ince O. (2003b). Hysteresis in vegetation shift-Lake Mogan prognoses. Ecological Engineering, 164: 227-238.

Zhang J. (2004). A structurally dynamic approach to ecological and environmental models. Ph.D. Thesis, the Danish university of pharmaceutical sciences, Denmark.

Zha C.Y., Sun U.L., Yin H.L.B. (2010). Eutrophication of lake waters in china: cost, causes, and control. Environmental Management, 45: 662-668.

Zedler J.B., Kercher S. (2005). Wetland resources: status, trends, ecosystem services, and restorability. Annual Review Environmental Resource, 30: 39-74.