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Evolution of Eutrophication depending on Environmental Conditions: A Case Study in a Reservoir.

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Abstract:
In the last years, the phenomenon of eutrophication is affecting many river ecosystems. Besides being an environmental problem, it can also be a problem for human health. This study aims to explore how environmental parameters affect the concentration of green algae and cyanobacteria throughout the period from 2010 to 2013 in A Baxe reservoir (NW Spain). Factors such as temperature, rainfall and solar radiation influenced in the presence of the algae, as well as in its concentration. Being limiting factors in the cyanobacterial blooms. The highest value of chlorophyll occurs during the summer, with higher temperatures, coinciding with the dry season and with a light cycle of 15/9 light/dark cycle. We conclude that predictive models can be designed using the weather forecast that are currently available well in advance, with the result that water managers can know when it will be probable that a bloom take place as an early warning system, therefore they will have a protocol of action.

Keywords: Freshwater ecosystems, cyanobacteria blooms, temperature, dry season.

1. Introduction

Anthropogenic activities have caused strong alterations in the structure and function of their environment. Human population growth has placed ever-increasing demands on both aquatic and terrestrial ecosystems (Smith et al., 1999), we are affecting biodiversity and contributing to climate change with land use changes and urbanization (Sliva and Dudley and Li et al., 2009). Human activities have also had profound impacts upon the global biogeochemical cycles of carbon (C), nitrogen (N), and phosphorus (P) (Vitousek et al., 1997; Abell et al., 2010; Vitousek et al., 2010; Lewis et al., 2011; Paerl et al., 2011; Schlesinger, 2013 and Khan et al., 2014) adding nutrients to the aquatic system. Eutrophication is a consequence of the above. Specifically, it is the process by which water bodies are made more eutrophic through an increase in their nutrient supply (Smith et al., 1999). Although this term is most commonly applied to freshwater lakes and reservoirs, it can also be applied to flowing waters, estuaries, and coastal marine waters (Edmondson, 1995).

Ever increasing nutrient loads from excessive watershed development result in accelerated eutrophication problems in many man-made and natural reservoirs. It is not

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easy to predict the behaviour of nutrient-enriched water bodies because of the complex physical, chemical, and biological processed involved (Van Griensven et al., 2006). In this sense, the Water Framework Directive of the European Union (European Commission, 2000) urges the Member States to incorporate of monitor programming the water quality, resulting in many cases useful tools for water quality management in the impounding reservoirs.

The increase of these nutrients allows algae population to improve their growth and development, especially when weather conditions are favourable such as temperature (Xue et al., 2005) and solar radiation (Liu et al., 2011). All this leads to algal blooms, affecting the some alterations in the physical-chemical conditions (Alvarez Cobelas & Arauzo, 1994; Lee et al., 2012).

Cyanobacteria are one of the largest and most important groups of prokaryotic autotrophs with oxygenic photosynthesis in aquatic system (Pernthaler, 2005). As the most common toxic cyanobacterium in eutrophic freshwater, Mycrocystis aeroginosa can form harmful algal blooms (Humbert et al., 2013), causing animal poisoning and present risks to human health (Falconer, 2001 and Oberholster et al., 2004). The ecological effects of a bloom in the aquatic environment during the blooms, some of them are: (1) the reduction of transparency (Andersson et al., 1978 and Yasmasaki 1993). Limitations on light resources, reducing the photic zone which produce some effects, especially in benthic populations. (2) pH increase (Seitzinger, 1991 and Brussaard et al., 1996), depending on the value may appear toxic effects on fish populations. (3) Reduction of CO2 (Huisman et al., 2011): Alteration of phytoplankton competitive iterations (Koch et al., 2014). (4) Toxin (Wilhelm et al., 2011; O'Neil et al., 2012 and Hallegraeff, 2014), with the excretion of allelopathic agents which can cause neurological effects (Ferrante et al., 2013 and Glivert, 2013) in aquatic organisms, including vertebrates. (5) Increasing the population of algae and primary production. Causes an impact on zooplankton (Koch et al., 2014) by reducing the efficiency of the transfer of matter and energy in the food chain. On the other hand, with the collapse of blooms, other effects can be: drastic reduction of dissolved oxygen and an increase in the concentrations of ammonia (Dai et al., 2012). Other effects are the inability to supply drinking water for the population during the blooms (Rolland et al., 2013), the increase of the cost of treatment of water purification, as well as the damage that blooms can cause in the installation of drinking water treatment.

The objectives of the present study were to analyze the water quality of the A Baxe reservoir, and determining their influence on the proliferation of the cyanobacterium *Microcystis* spp., taking into account weather factors that may influence such as air temperature, solar radiation and rainfall.

2. Material and Methods

a. Study Area

The Umia River is situated in the southwest of Galicia, It has a total length of 70 km and its basin includes 440.4 km2, its flow is 16.2 m3/s, and it flows into the Atlantic watershed of Galicia. The climate in the area is oceanic: the average annual rainfall is 1,500 mm and the average temperature is 14.8°C (Carballeira et al., 1983 and Martínez

and Pérez, 2000). Consequently, the period of highest flow is from December to May, and minimum occurs in August (Xunta de Galicia, 2005; Hilty et al., 2006).
Natural vegetation in the riversides is Atlantic deciduous forest with oak (Quercus robur), black alder (Alnus glutinosa), willow (Salix atrocinerea), hazel tree (Corylus avellana), elder (Sambucus nigra) and ash (Fraxinus sp.).
According to Directive 2006/44/EC (European Commission, 2006), the Umia stream supports or becomes capable of supporting fish belonging to species such as salmon (Salmo salar), trout (Salmo trutta), or other species in other areas of Europe. It has been classified as salmonid waters (Ministerio de Medio Ambiente, 2004) On the other hand, the stretch of the river has been classified as CEDEX type 21: Cantabric Atlantic siliceous rivers (Augas de Galicia, 2010).
The Umia River Basin has a high rate of population dispersion. There are 184 villages: 70% have 50 inhabitants and only 2 villages have more than 500 inhabitants (Instituto Galego de Estadística, 2010). The Umia River supplies more than 100,000 inhabitants.

b. Data collection and statistical analyses

Data on water quality of the reservoir during the periods of 2008 and 2010 (August) were analysed. This data was based on weekly analyses made by Augas de Galicia (Regional Environmental Agency of Galicia, Spain). In order to quantify the phenomenon blooms in reservoir A Baxe we used the series of data of *Mycrocistis* spp. and chlorophyll from Augas of Galicia (Augas de Galicia, 2011). We identified it as the dominant genus of cyanobacteria during blooms that periodically occur. Data were measured in two different stations, near the dam of the reservoir and at the end of it.
To address the roles of water quality parameters and limiting factors in algal growth in different seasons, temporal trends between the following measurements were analyzed: pH, air temperature (ºC), total nitrogen (mg/L), total phosphorus (mg/L), chlorophyll-a (μg/L) and *Microcystis spp*. (cel/mL).
Meteorological data (air temperature, rainfall and solar radiation) were taken from Xunta de Galicia (2008), specifically from the weather station of Caldas de Reis, located in the study area, with similar altitude conditions.
Spatial distributions of correlations between Chl-a, *Microcystis* spp. and water quality were analyzed for the dry (from May to September) and cold (from October to April) seasons using Microsoft Excel 2007. Correlations between parameters for each monitoring station in the reservoir were calculated using multivariate statistical analyses. In this case, the statistical analyses were carried out using SPSS Statistics v19 software.

3. Results and Conclusions

Analysis of annual average values of the main water quality parameters total nitrogen (TN), total phosphorus (TP), Chl-a and algae concentration from 2008 to 2010 showed that the water quality of the A Baxe reservoir has deteriorated, but some differences among the parameters. TN and TP presented very similar temporal patterns. Both stations did not show high average values of phosphorus (between 0.3 mg/l and 0.35 mg/l), rarely high values were obtained (7 mg/l), especially during the years 2008 and 2009. However, the degree of eutrophication in the A Baxe reservoir considering

total phosphorus would be Hipereutrofia (> 100 mg/m³ TP). According to the reference standard, the Real Decreto 927/1988 (del Estado, 1988) establishes the following reference values: 0.2 to 0.4 mg/l for Salmonidae and Cyprinidae freshwater.
The TN is used as standard for the study of the relationship N/P, the main indicator studied with the concentration of TP, chlorophyll a and Cyanobacteria. There were some values which exceed the normal values of TN (2 mg), the maximum concentration detected was 10 mg/l.
Temperature values presents a seasonal variation (Figure 1) and the pH values were generally highest in the dry season, the coefficient of correlation between temperature and pH values are 0.79 (p<0.01), There is a strong positive correlation. Temperature is a factor that influences the N_{Total} and P_{Total} ($r_N = 0.57$ and $r_P = 0.75$).

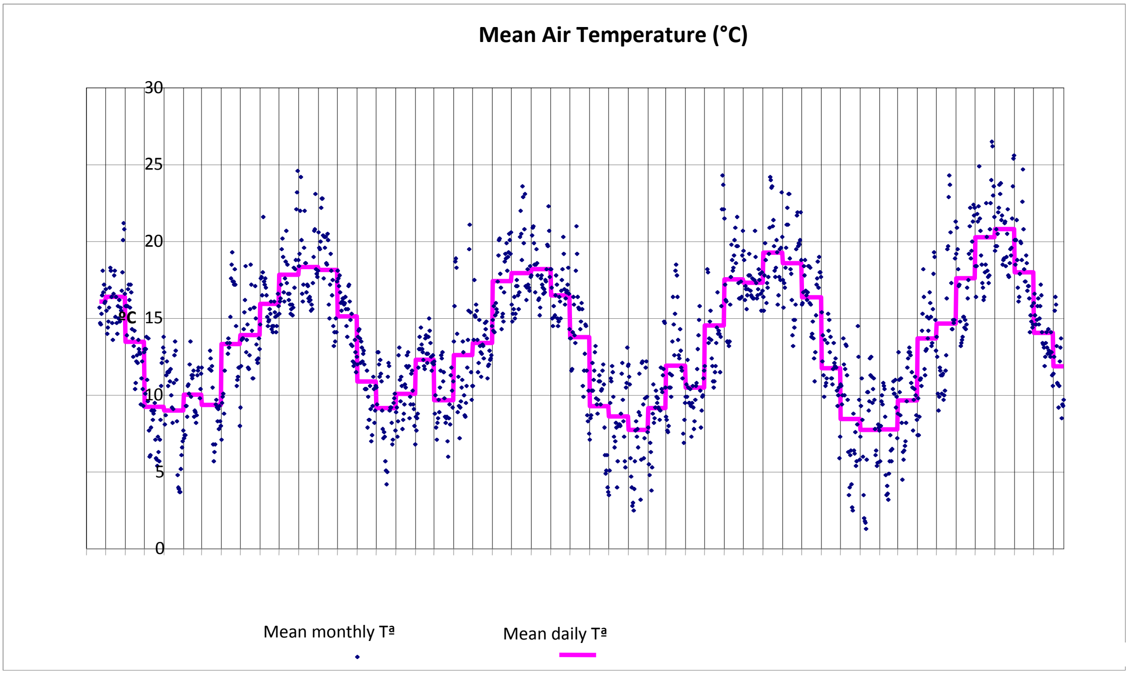

Figure 1 *Temporal evolution of the air temperature in the weather station of Caldas de Reis from 2008 to 2010. Source: own elaboration based on data from Xunta de Galicia (2008).*

If we consider the values of the average monthly air temperature, we can see that the highest values occurred in the months of the dry season (Figure 2), especially from June to September (inclusive).
In order to emphasize that the 2009 was the year that had the lowest value of *Microcystis spp.*, along with having the highest cumulative value of solar radiation this year. Therefore, it can be concluded that the most important factor is not the total value of solar radiation, by contrast it determines how it is distributed throughout the year (Figure 3). Thus the year 2010, which had the highest values of *Microcystis spp.*(Figure 4), had a steep and constant slope from early spring through August.

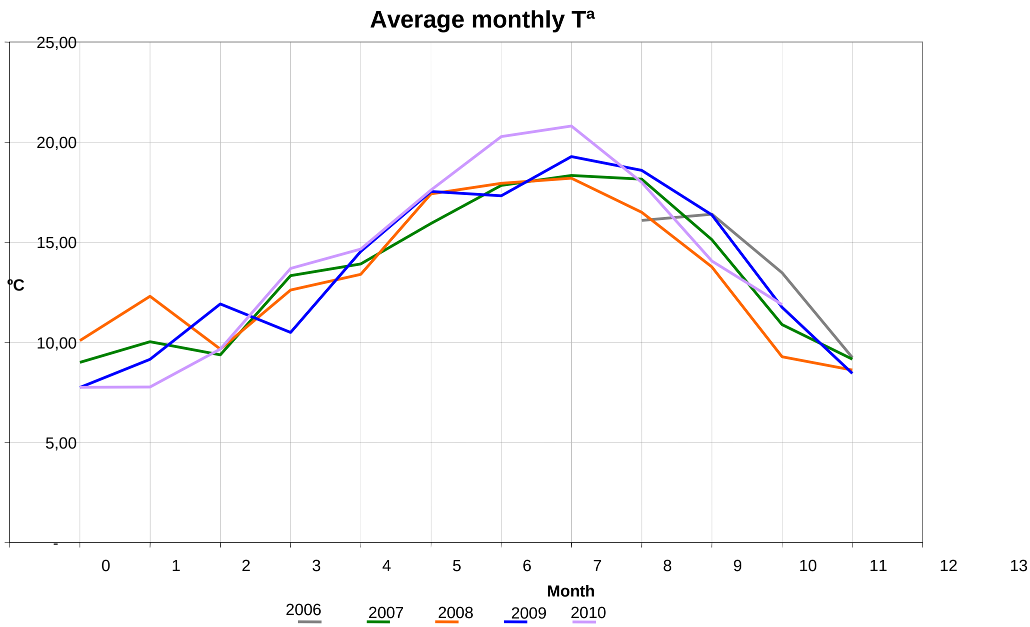

Figure 2 *Average monthly air temperature during the years 2006-2010 in the weather station of Caldas de Reis from 2008 to 2010. Source: own elaboration based on data from Xunta de Galicia (2008).*

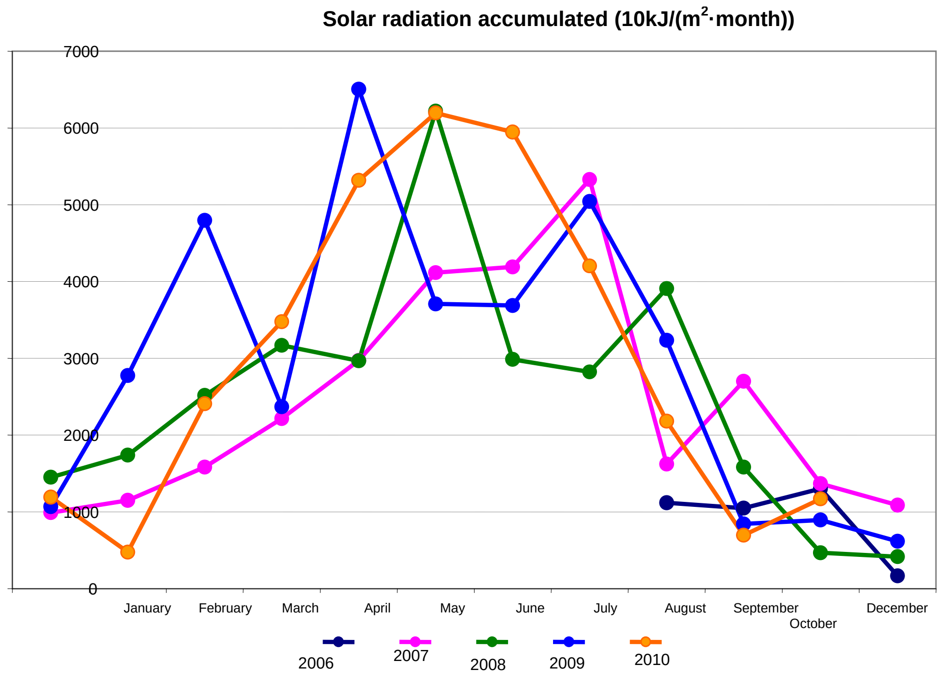

Figure 3 *Temporal evolution of the solar radiation accumulated monthly in the weather station of Caldas de Reis from 2008 to 2010. Source: own elaboration based on data from Xunta de Galicia (2008).*

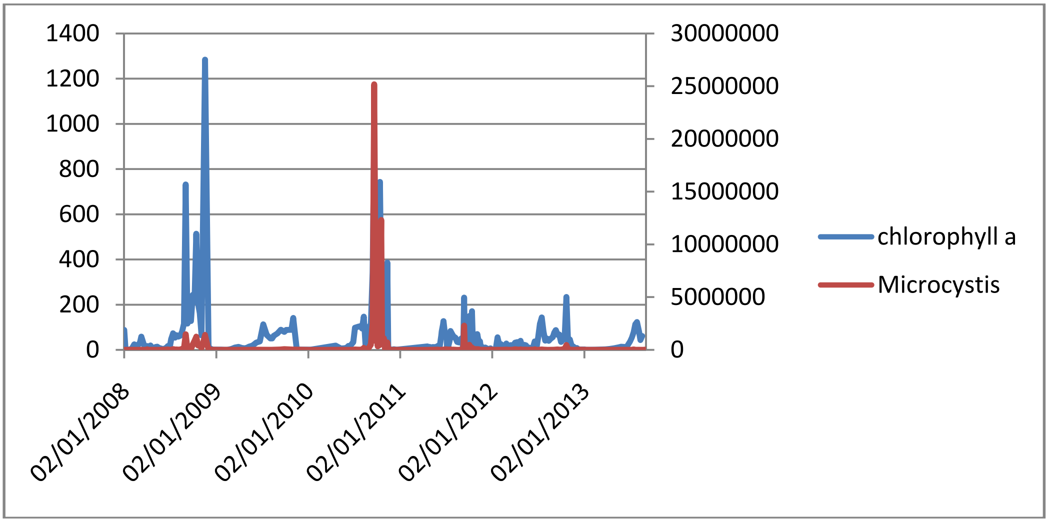

Figure 4 *Temporal evolution of cyanobacteria and chlorophyll values in the reservoir of A Baxe (2008-2013).*

Temperature and solar radiation are not the only factors that influence the process of eutrophication. Rain plays an important role (Jones and Poplawski, 1998) because the renewal of water in the reservoir relies on it. The minimum precipitation records coincide with higher cyanobacteria values (Table 1). If we make a comparison, 2010 registered the lowest rainfall, while 2009 had the highest ones in the same period (between April to September). Therefore, we can deduce that, with high precipitation, less probabilities that cyanobacterial blooms occurs, especially during this interval of the year. As shown in Figure 1, the highest value of chlorophyll occurs during the summer, as the values of *Microcystis spp.*

Table 1 Maximum and minimum values of annual precipitation between 2007-2010 (L/m2/month)

Year	Maximum	Month	Minimum	Month
2007	300,20	February	3,70	October
2008	253,20	January	24,10	June
2009	337,40	December	19,10	September
2010	277,40	October	8,20	August

In our study we conclude that cyanobacterial blooms occur earlier and last longer with the increase of temperature and radiation (Zhang et al., 2012), therefore, in the eutrophication process there is a great influence of environmental parameters.

References

Abell, J. M., Özkundakci, D., & Hamilton, D. P. (2010). Nitrogen and phosphorus limitation of phytoplankton growth in New Zealand lakes: implications for eutrophication control. Ecosystems, 13(7), 966-977.

Alvarez Cobelas, M., & Arauzo, M. (1994). Phytoplankton responses of varying time scales in a eutrophic reservoir. Ergebnisse der Limnologie, 40, 69-69.

Andersson, G., Berggren, H., Cronberg, G., & Gelin, C. (1978). Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. Hydrobiologia, 59(1), 9-15.

Augas de Galicia. (2011). Plan Integral de Actuación sobre a Microcystis sp. no Encoro de Caldas de Reis no Río Umia. (PLAN UMIA)

Augas de Galicia and Consellería de Medio Ambiente, Territorio e Infraestructuras, (2010). Hydrological Plan—River Basin of Galicia-Costa. Chapter 2. Overview of the River Basin (in Spanish); Aguas de Galicia: Santiago de Compostela, Spain, Available online: http://www.planhidroloxicogc.com /web/documentacion (accessed on 16 December 2013).

Brussaard, C. P. D., Gast, G. J., Van Duyl, F. C., & Riegman, R. (1996). Impact of phytoplankton bloom magnitude on a pelagic microbial food web. Marine ecology progress series. Oldendorf, 14(1), 211-221.

Burkholder, J. M., & Glibert, P. M. (2001). Eutrophication and oligotrophication.Encyclopedia of biodiversity, 2, 649-670.

Carballeira, A., Devesa, C., Retuerto, R., Santillán, E., Ucieda F. (1983). Bioclimatología de Galicia. Fundación Pedro Barrie de la Maza, Vigo.

Dai, G. Z., Shang, J. L., & Qiu, B. S. (2012). Ammonia may play an important role in the succession of cyanobacterial blooms and the distribution of common algal species in shallow freshwater lakes. Global Change Biology, 18(5), 1571-1581.

del Estado, B. O. (1988). Real Decreto 927/1988, de 29 de julio, por el que se aprueba el Reglamento de la Administración Pública del Agua y de la Planificación Hidrológica, en desarrollo de los títulos II y III de la Ley de Aguas.

Edmondson, W.T. (1995). Eutrophication. Encyclopedia of Environmental Biology, vol. 1. Academic Press, New York, pp.697–703.

European Commission. (2006). Directive 2006/44/EC of the European Parliament and of the Council of 6 September 2006 on the Quality of Fresh Waters Needing Protection or Improvement in Order to Support Fish Life; Official Journal of the European Communities: Brussel, Belgium

European Commission. (2000). Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy; Official Journal of the European Communities: Brussel, Belgium

Falconer, I. R. (2001). Toxic cyanobacterial bloom problems in Australian waters: risks and impacts on human health. Phycologia, 40(3), 228-233.

Ferrante, M., Conti, G. O., Fiore, M., Rapisarda, V., & Ledda, C. (2013). HARMFUL ALGAL BLOOMS IN THE MEDITERRANEAN SEA: EFFECTS ON HUMAN HEALTH. Capsula Eburnea, 8.

Glibert, P. M. (2013). Harmful Algal Blooms in Asia: an insidious and escalating water pollution phenomenon with effects on ecological and human health.ASIANetwork Exchange, 21(1).

Hallegraeff, G. M. (2014). Harmful Algae and their Toxins: Progress, Paradoxes and Paradigm Shifts. Toxins and Biologically Active Compounds from Microalgae, 1, 1.

Hilty, J. A., Lidicker, W. Z., Merenlender, A. M. (2006). Corridor ecology the science and practice of linking landscapes for biodiversity conservation. E-Libro. Island Press, Washington, DC.

Huisman, J., Paerl, H., Joehnk, K., van de Waal, D., Visser, P., Verspagen, J., ... & Stefels, J. (2011). Harmful cyanobacteria: Favored by global warming but suppressed by rising CO2?.

Humbert, J. F., Barbe, V., Latifi, A., Gugger, M., Calteau, A., Coursin, T., .. & De Marsac, N. T. (2013). A Tribute to Disorder in the Genome of the Bloom-Forming Freshwater Cyanobacterium Microcystis aeruginosa. PloS one, 8(8), e70747.

Instituto Galego de Estadística. (2010). Figures about Galicia: Population, Population Centers and Density (in Spanish); Instituto Galego de Estadística: Santiago de Compostela, Spain, Available online: http://www.ige.eu/igebdt/ selector.jsp?COD=4705&paxina=001&c=0501 (accessed on 13 January 2014).

Khan, F. A., Naushin, F., Rehman, F., Masoodi, A., Irfan, M., Hashmi, F., & Ansari, A. A. (2014). Eutrophication: Global Scenario and Local Threat to Dynamics of Aquatic Ecosystems. In Eutrophication: Causes, Consequences and Control (pp. 17-27). Springer Netherlands.

Koch, F., Burson, A., Tang, Y. Z., Collier, J. L., Fisher, N. S., Sañudo-Wilhelmy, S., & Gobler, C. J. (2014). Alteration of plankton communities and biogeochemical cycles by harmful< i> Cochlodinium polykrikoides</i>(Dinophyceae) blooms. Harmful Algae, 33, 41-54.

Lee, S., Lee, S., Kim, S. H., Park, H., Park, S., & Yum, K. (2012). Examination of Critical Factors Related to Summer Chlorophyll a Concentration in the Sueo Dam Reservoir, Republic of Korea. Environmental engineering science, 29(6), 502-510.

Lewis Jr, W. M., Wurtsbaugh, W. A., & Paerl, H. W. (2011). Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. Environmental science & technology, 45(24), 10300-10305.

Li, S., Gu, S., Tan, X., Zhang, Q., 2009. Water quality in the upper Han River basin, China: The impacts of land use/land cover in riparian buffer zone. Journal of Hazardous Materials, 165(1–3), 317-324.

Liu, X., Lu, X., & Chen, Y. (2011). The effects of temperature and nutrient ratios on< i> Microcystis</i> blooms in Lake Taihu, China: An 11-year investigation.Harmful Algae, 10(3), 337-343.

Martínez Cortizas, A., Pérez Alberti, A. (2000). Atlas Climático de Galicia. Xunta de Galicia, Consellería de Medio Ambiente, Santiago de Compostela.

Ministerio de Medio Ambiente. (2004). Manual of the Directive 78/659/CEE on the Quality of Fresh Waters Needing Protection or Improvement to Be Suitable for the Life of Fish (in Spanish); Ministerio de Medio Ambiente: Madrid, Spain, 2004. Available online: http://www.magrama.gob.es/es/agua/publicaciones/02_manual_directiva_78_659_cee_tcm7-28958.pdf (accessed on 19 January 2014).

Oberholster, P. J., Botha, A. M., & Grobbelaar, J. U. (2004). Microcystis aeruginosa: source of toxic microcystins in drinking water. African Journal of Biotechnology, 3(3).

O'Neil, J. M., Davis, T. W., Burford, M. A., & Gobler, C. J. (2012). The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. Harmful Algae, 14, 313-334.

Paerl, H. W., Xu, H., McCarthy, M. J., Zhu, G., Qin, B., Li, Y., & Gardner, W. S. (2011). Controlling harmful cyanobacterial blooms in a hyper-eutrophic lake (Lake Taihu, China): the need for a dual nutrient (N & P) management strategy.Water Research, 45(5), 1973-1983.

Pernthaler, J. (2005). Predation on prokaryotes in the water column and its ecological implications. Nature Reviews Microbiology, 3(7), 537-546.

Rolland, D. C., Bourget, S., Warren, A., Laurion, I., & Vincent, W. F. (2013). Extreme variability of cyanobacterial blooms in an urban drinking water supply. Journal of plankton research, 35(4), 744-758.

Schlesinger, W. H., & Bernhardt, E. S. (2013). Biogeochemistry: an analysis of global change. Academic press.

Seitzinger, S. P. (1991). The effect of pH on the release of phosphorus from Potomac Estuary sediments: Implications for blue-green algal blooms.Estuarine, Coastal and Shelf Science, 33(4), 409-418.

Sliva, L., Dudley Williams, D. (2001). Buffer Zone versus Whole Catchment Approaches to Studying Land Use Impact on River Water Quality. Water Research, 35(14), 3462-3472.

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems.Environmental pollution, 100(1), 179-196.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., & Srinivasan, R. (2006). A global sensitivity analysis tool for the parameters of multi-variable catchment models. Journal of hydrology, 324(1), 10-23.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. Science, 277(5325), 494-499.

Vitousek, P. M., Porder, S., Houlton, B. Z., & Chadwick, O. A. (2010). Terrestrial phosphorus limitation: mechanisms, implications, and nitrogen-phosphorus interactions. Ecological Applications, 20(1), 5-15.

Wilhelm, S. W., Farnsley, S. E., LeCleir, G. R., Layton, A. C., Satchwell, M. F., DeBruyn, J. M., ... & Paerl, H. W. (2011). The relationships between nutrients, cyanobacterial toxins and the microbial community in Taihu (Lake Tai), China. Harmful Algae, 10(2), 207-215.

Xue, L., Zhang, Y., Zhang, T., An, L., & Wang, X. (2005). Effects of enhanced ultraviolet-B radiation on algae and cyanobacteria. Critical reviews in microbiology, 31(2), 79-89.

Xunta de Galicia, 2005. Plan Galego de Ordenación dos Recursos Piscícolas e Ecosistemas Acuáticos Continentais. Xunta de Galicia.

Xunta de Galicia. (2008). CINAM-MeteoGalicia [Available online: http://www2.meteogalicia.es/galego/observacion/estacions/estacions.asp# (accessed on 06 January 2014)].

Yamasaki, S. (1993). Probable effects of algal bloom on the growth ofPhragmites australis (Cav.) Trin. ex Steud. Journal of plant research, 106(2), 113-120.