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Modeling the effects of climatic and land use changes on phytoplankton and water quality of the largest Turkish freshwater lake: Lake Beyşehir

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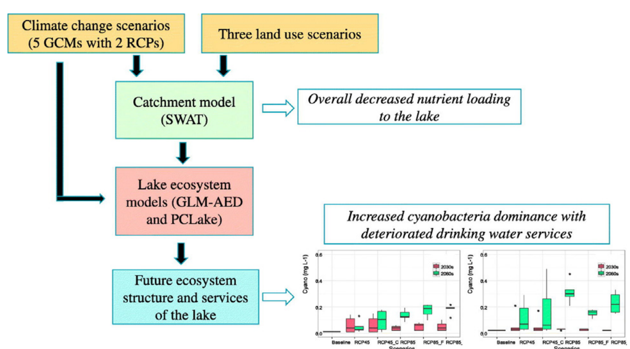
HIGHLIGHTS

- We investigated the effect of climate change and land use on ecosystem structure and services.
- We linked process based model (SWAT) outputs to lake ecosystem models.
- Scenarios had major impacts on hydraulic and nutrient loading.
- Increased temperatures and decreased nutrient loading favoured cyanobacteria.
- Cyanobacteria dominance and decreased water level may deteriorate drinking and irrigation services.

GRAPHICAL ABSTRACT



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SUMMARY

Climate change and intense land use practices are the main threats to ecosystem structure and services of Mediterranean lakes. Therefore, it is essential to predict the future changes and develop mitigation measures to combat such pressures. In this study, Lake Beyşehir, the largest freshwater lake in the Mediterranean basin, was selected to study the impacts of climate change and various land use scenarios on the ecosystem dynamics of Mediterranean freshwater ecosystems and the services that they provide. For this purpose, we linked catchment model outputs to the two different processed-based lake models: PCLake and GLM-AED, and tested the scenarios of five General Circulation Models, two Representation Concentration Pathways and three different land use scenarios, which enable us to consider the various sources of uncertainty. Climate change and land use scenarios generally predicted strong future decreases in hydraulic and nutrient loads from the catchment to the lake. These changes in loads translated into alterations in water level as well as minor changes in chlorophyll *a* (Chl-*a*) concentrations. We also observed an increased abundance of cyanobacteria in both lake models. Total phosphorus, temperature and hydraulic loading were found to be the most important variables determining cyanobacteria biomass. As the future scenarios revealed only minor changes in Chl-*a* due to the significant decrease in nutrient loads, our results highlight that reduced nutrient loading in a warming world may play a crucial role in offsetting the effects of temperature on phytoplankton growth. However, our results also showed increased abundance of cyanobacteria in the future may threaten ecosystem integrity and may limit drinking

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water ecosystem services. In addition, extended periods of decreased hydraulic loads from the catchment and increased evaporation may lead to water level reductions and may diminish the ecosystem services of the lake as a water supply for irrigation and drinking water.

1. Introduction

Climate change is expected to affect lake ecosystem dynamics by altering the quantity and quality of water, possibly resulting in extensive ecological and economic loss (Erol and Randhir, 2012). According to climate projections, the Mediterranean region is one of the most sensitive areas in the world, and a significant reduction in precipitation and an increase in temperature is anticipated for the future (Erol and Randhir, 2012; Christensen et al., 2013). A 3–4 °C increase in air temperatures and a 15–20% decrease in annual precipitation by the end of the century were expected in southern part of Turkey according to projections generated by the Turkish State Meteorological Office (Demir et al., 2013). It is also expected that the demand for freshwater for irrigated crop farming in the Mediterranean region will increase with climate change, which – together with the climate change – may exacerbate the water stress. Reduced water availability may create a significant conflict between sectorial demands (e.g. irrigation and drinking water) and ecosystem needs for maintaining ecosystem structure and functions in freshwaters (Bucak et al., 2017).

The predicted climate change in the Mediterranean is not only expected to decrease water availability (Calbó, 2010), it may also have significant impacts on lake ecosystem structure and function (Beklioglu et al., 2007; Jeppesen et al., 2015). In the semi-arid Mediterranean region, reduced runoff in the catchments may decrease the external nutrient loading to the lakes. However, internal nutrient loading and a reduction of the water volume due to higher evaporation may trigger a nutrient increase (Özen et al., 2010; Coppens et al., 2016; Beklioğlu et al., 2017). Increased temperature and prolonged hydraulic retention time may change the species composition of the phytoplankton and the duration of their blooms, likely resulting in earlier spring blooms (Reynolds et al., 1993; Carvalho et al., 2008; Paerl and Huisman, 2008) and longer duration of autumn blooms. Also, a longer retention time gives an advantage to cyanobacteria over green algae and diatoms (Visser et al., 2015), and prolonged cyanobacteria bloom compromise key ecosystem services such as water supply for drinking or irrigation (Paerl et al., 2011). Additionally, the trophic structure and community composition of the freshwater organisms can be affected by climate warming as evidenced from studies covering large latitudinal and temperature gradients (Jeppesen et al., 2010, 2015).

Management of land and water use is essential to mitigate and adapt to the impacts of climate change. In the Mediterranean region, water availability, demonstrating high seasonal variability, determines the socioeconomic structure (García-Ruiz et al., 2011). An intensive irrigation demand during the least water available season (Morán-Tejeda et al., 2014) poses a risk to freshwater ecosystems and may lead to significant water level reductions, especially in shallow lakes with a high surface area/depth ratio. This, in turn, may result in a degradation of ecosystem structure, function, and services. Moreover, intensive farming can increase nutrient and sediment loads to freshwaters (Foley et al., 2005; Jeppesen et al., 2009, 2015). Enhanced nutrient enrichment is one of the major causes of eutrophication through its direct effects on Chl-*a* concentrations – an indicator of phytoplankton levels – and its indirect effects on oxygen depletion in the water bodies (Jeppesen et al., 2009). All these elements can result in degradation of water quality as well as of a wide range of ecosystem services (Gordon et al., 2010).

Models enable to conduct "virtual experiments" (Meyer et al., 2009), and they are efficient tools for examining ecological questions (Elliott et al., 2000). Over the years, an increasing number of studies have used ecological lake models for management purposes such as combatting eutrophication (Arhonditsis and Brett, 2005a, 2005b), developing mitigation strategies (such as external load reduction and biomanipulation) and predicting the impacts of climate change on lake ecosystems (Trolle et al., 2015; Rolighed et al., 2016). All these extensive research works have triggered the development of ecological lake models advancing from simple regressions to process-based complex dynamic models (Janssen et al., 2015).

Studies focusing on the impacts of climate change are at the core of the lake modeling research due to the necessity of understanding the ecological consequences of climate change and developing adaptation strategies to combat its outcomes. So far, most of the lake modeling studies have been built on single process-based models. However, recently, ensemble modeling, which is commonly employed in climate studies, has been introduced in lake modeling studies as well. For the first time, Trolle et al. (2014) applied ensemble modeling to predict Chl-*a* concentrations by ensembling three different lake ecosystem models for a single lake. This approach not only has a value in understanding the structural uncertainty in model simulations but also provides a possibility to compare different ecological processes schemes (Janssen et al., 2015), allowing development of better prediction powers. In the current study, the future ecological structure of the largest freshwater lake in the Mediterranean basin as well as Turkey, Lake Beyşehir, was simulated by linking catchment model outputs (SWAT) with two different processed based lake models: PCLake and GLM-AED. Our first aim was to perform simulations to understand how climate change and land use practices affect ecosystem structure and function through the lake's capacity to provide services, which are mainly drinking and irrigation water supply. We also aimed to unravel the uncertainties arising from the model selection, climate models and scenarios and to determine the effects of these on the future predictions by using two different lake models, five different climate models and two Representation Concentration Pathways (RCPs).

2. Materials and methods

2.1. Study site

Lake Beyşehir (Fig. 1), the largest freshwater lake in Turkey as well as in the Mediterranean basin, has a surface area of approximately 650 km^2 and mean and max depth of 5–6 and 8–9 m, respectively. The lake is located within the borders of two national parks, Beyşehir and Kızıldağ, the former being the second largest national park in Turkey with a surface area of 86,855 ha, covering 4/5 of Lake Beyşehir (General Directorate of Nature Conservation and National Parks, www.milliparklar.gov.tr). The catchment is situated in a semi-dry Mediterranean climate having an average temperature of 11 °C and an annual total precipitation of 490 mm during 1960–2012. In this period, precipitation values fluctuated between 317 and 716 mm (Beyşehir meteorology station, www.mgm.gov.tr), and the lowest annual average temperature was recorded in 1992 (8.5 °C) the highest in 2010 (13.1 °C).

Lake Beyşehir is located in a tectonic depression area in a northwest-southeast direction in the western Taurus system (Yarar et al., 2009). The lake basin has existed since the Middle Miocene (15.97–11.6 million years ago (Oguzkurt, 2001). Lake Beyşehir is primarily fed by waters from the Sultan and Anamas Mountains and springs from Mesozoic calcareous cracks, precipitation and snow melts. Water from