THE IMPACTS OF CLIMATE CHANGE AND LAND USE ON THE ECOSYSTEM STRUCTURE AND SERVICES OF LAKE BEYŞEHİR

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ABSTRACT

THE IMPACTS OF CLIMATE CHANGE AND LAND USE ON THE ECOSYSTEM STRUCTURE AND SERVICES OF LAKE BEYŞEHİR

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In this thesis, the main aim was to predict the impacts of climatic and land use changes on the ecosystem structure of Lake Beyşehir with the perspective of ecosystem services. Modeling results revealed the sensitivity of ecological and hydrological dynamics of Lake Beyşehir to climatic changes. Climate change scenarios led to reductions in total inflow rates and water levels, and the results showed that significant reductions in water abstraction are needed to maintain the lake in the future. The outcomes of the current study also indicated an important role of projected land use change on nutrient loading from the catchment, though with minor effects on surface runoff. Although lake models differed in their predictions for future nutrient concentrations and Chlorophyll-*a*, they both indicated a significant increase in cyanobacteria biomass in the future which may result in degradation of the lake water quality.

Analysis of long-term ecosystem services revealed that the lakes' services varied through time with a declining trend in provisional services (e.g., water level, fisheries), however, increased climate regulation services were recorded throughout the century. The water level was found to be important in affecting supporting services of the lake (e.g., biodiversity). Future projections also indicated that irrigation water service of the lake may decrease in the future considering climate change projections. Furthermore, increased cyanobacteria contribution may also affect the drinking water quality of the lake and may limit the drinking water use for certain periods with cyanobacteria bloom.

All in all, the results highlighted that warmer and drier climate may decrease water availability and trigger cyanobacteria bloom that may lead to loss of ecosystem values and services of Lake Beyşehir if necessary adaptation measures are not undertaken.

Keywords: Water level, lake modeling, SWAT, GLM-AED, PCLake

ÖZ

İKLİM DEĞİŞİKLİĞİ VE ARAZİ KULLANIMININ BEYŞEHİR GÖLÜ EKOSİSTEM YAPISI VE HİZMETLERİ ÜZERİNDEKİ ETKİLERİ

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Bu tez çalışmasının ana amacı, iklim değişikliği ve arazi kullanımının Beyşehir Gölü ekosistem yapısında meydana getirebileceği değişiklikleri, ekosistem servisleri perspektifiyle değerlendirip, tahminlemektir. Modelleme sonuçları, Beyşehir Gölü'nün ekolojik ve hidrolojik dinamiklerinin iklim değişikliğine karşı hassas olabileceğini ortaya koymuştur. İklim değişikliği senaryoları, havzadaki toplam akışta ve göl su seviyelerinde düşüşe sebep olmuş; ve gelecekte gölün korunması için su çekiminin önemli miktarda azaltılması gerektiğini göstermiştir. Mevcut araştırmanın sonuçları, aynı zamanda, arazi kullanımındaki değişimin havzadaki toplam yüzey akışındaki etkilerinin az olmasına karşın, besin tuzu yüklemesinde önemli bir etkisi olduğunu göstermiştir. Göl modelleri gelecek besin tuzu derişimleri ve Klorofil *a*'ya ilişkin tahminlerinde farklılık gösterse de, gelecekte göl suyu kalitesinin bozulmasına neden olabilecek siyanobakter oranında önemli bir artış olduğunu göstermişlerdir.

Uzun dönemli ekosistem hizmetlerinin analizi, göl hizmetlerinin doğrudan hizmetlerde (örneğin sulama suyu sağlama, balıkçılık) son yıllarda azalan bir eğilim gösterdiğini; bununla birlikte, iklim düzenleme hizmetlerinde (karbon tutma hizmeti) artış olduğunu ortaya koymuştur. Aynı zamanda göl su seviyesinin destek hizmetlerini (biyoçeşitlilik) etkilediği tespit edilmiştir. Senaryo sonuçları ise, iklim değişikliği projeksiyonlarını göz önüne alındığında, göle ait sulama suyu hizmetinin gelecekte azalabileceğini göstermiştir. Ayrıca, artan siyanobakterlerin gölün içme suyu kalitesini de etkileyebileceği ve belli periyotlarda gölün içme suyu kullanımının sınırlanabilme ihtimali ortaya konmuştur.

Bütün sonuçlar değerlendirildiğinde, daha sıcak ve kurak iklimin, su miktarını azaltabileceği ve siyanobakter aşırı büyümesine yol açabileceği gösterilmiştir. Adaptasyon önlemleri alınmadığı takdirde, bu durum Beyşehir Gölü ekosistemi değer ve hizmetlerinin kaybına yol açabilir.

Anahtar Kelimeler: Su seviyesi, göl modellemesi, SWAT, PCLake, GLM-AED

Oğuz'a

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INTRODUCTION

Freshwaters have a vital role for all living organisms (Bailey et al., 2004; Naiman et al., 1995) and they provide numerous ecosystem services (Janssen et al., 2015), which are defined as direct or indirect benefits that people obtain from ecosystems (Millenium Ecosystem Assessment, 2005). These services include provisional services like providing water for drinking, irrigation, hydropower and industrial purposes; and providing food products (e.g fish, rice, etc.). Freshwaters also have important regulatory and supporting services which include water purification, flood protection, climate regulation and providing habitats for organisms. They are also valued for cultural values, supplying recreational, aesthetic, educational services (Grizzetti et al., 2015).

Freshwaters cover very small part (0.01%) of the world water resources (Dudgeon et al., 2006; Wetzel, 2001). However, they are exposed to the heavy stress related to anthropogenic activities (Table 1.1), such as extensive usage of freshwater for agriculture, industry; nutrient enrichment through agriculture, untreated sewage effluent discharges, hydro-morphological alterations, and invasive species introductions, which deteriorate ecosystem integrity and functioning of freshwaters (Moss, 2010a). Thus, they are one of the most degraded ecosystems in the world (Dudgeon et al., 2006; WWF Living planet 2016).

Table 1.1 Main pressures on freshwater ecosystems (taken from Grizzetti et al., 2015).

Water quantity	Water quality
Hydrological alterations	***Diffuse and nutrient pollution***
Dams	Nutrients
Water abstractions	Chemicals
Groundwater abstractions	Metals
Climate pattern	Pathogens
Change in runoff	Litter
	Salinization, sediments, turbidity
	Brownification
Habitat	**Biological communities**
Hydromorphological alterations	Alien species
Channel bed degradation	Overfishing
Physical alterations of channels	
Dams	

Shallow lakes constitute most of the world's lakes in numbers (Moss, 2010b; Williamson et al., 2009) and they are characterized by fully mixed water column (Moss, 2010a). They are also defined by large littoral zones with dense submerged macrophyte beds due to higher light penetration, and they serve as complex habitats for organisms through their littoral zones, and benthic-pelagic coupling (Scheffer, 1998) enabling increased productivity (Jeppesen, 1998). Notwithstanding the higher complexity and productivity of shallow lakes, they are more sensitive to external disturbances than deep lakes due to noticeable impacts of prevailing meteorological events, higher resuspension in the water column and their lower ratio of surface:volume (Dokulil, 2014; Coops et al., 2003).

Shallow lakes can be found in two alternative stable states: an oligotrophic macrophyte dominated clear-water state or a eutrophic phytoplankton dominated turbid-water state (Scheffer et al., 1993). While enhanced water clarity triggers macrophyte growth through enabling higher light penetration, submerged macrophytes stimulate the variety of mechanisms further enhancing water clarity.

Hence, there is a synergistic interaction between macrophytes and water clarity. Macrophytes can reduce resuspension by stabilizing the sediment through their roots (Barko and James, 1998; James and Barko, 1990). They also serve as complex habitat for many organisms, such as fish, bird and, macroinvertebrate (Meerhoff, 2006; Meerhoff et al., 2007b). Most fish use dense plant beds for spawning and as a refuge. Macrophytes can also act as a refuge for zooplankton against planktivorous fish predation (Meerhoff et al., 2007b). Though there are many factors affecting the transition between these two stable states, climate drivers and nutrient loading are the most prominent ones (Mooij et al., 2009). An increase in nutrient loading and temperature may favor phytoplankton growth and cause a shift to turbid water state that is characterized by high primary productivity, low water clarity and low ecological value (Carpenter et al., 1999).

1.1 Land and water use

Humankind has always had a tendency to change the environment since prehistoric times; by hunting, farming, irrigation, and construction (Goldewijk et al., 2011). However, the intensity of manipulating environment has been increasing since the beginning of 20th century, and this increase resulted in severe environmental crisis due to higher CO_2 concentration in the atmosphere, accelerating global climate change (Houghton et al., 2012). One of the main anthropogenic impacts on the Earth is “land use,” and it is defined as of human activities, arrangements on land, and modification of natural systems (FAO/UNEP, 1999).

Land use has direct/indirect environmental effects since it influences water, nutrient, and energy budgets (Liu et al., 2014; Mao and Cherkauer, 2009). With the substantial changes in land use from the beginning of the 21st century, a prominent increase in surface runoff has been observed worldwide (Piao et al., 2007). It has also been reported that 35% of the observed increase in atmospheric CO_2 has been caused by land use change (Houghton, 2003). Following a 12% increase in the world cropland areas since green revolution for the last 45 years, there has been a

700% increase in the amount of fertilizers used in agriculture (Tilman et al., 2001), and 70% increase in irrigated croplands (Rosegrant et al., 2002). Additionally, augmented water abstraction for agriculture is one of the major threats to the freshwater ecosystems, making them highly vulnerable to the effects of climate change (Erol and Randhir, 2012). Agricultural water use stands for 85% of the global consumptive water use followed by drinking water supply, and industry; all of which cause a decrease in available water resources globally (Gleick, 2003). In semi-arid areas, where yearly evapotranspiration exceeds precipitation, use of water for irrigation can further increase water scarcity and cause water level or volume changes, or even drying up of freshwater systems. It was also shown that irrigated lands might have a salinization problem, which is one of the reasons for the loss of arable lands (Wood et al., 2001).

Land use also affects freshwater ecosystems by deteriorating the water quality. Agriculture is the biggest source of nutrients (N: nitrogen and P: phosphorus) in the waterways (Foley et al., 2005). Intensive farming can increase soil erosion and sediment loadings, which may result in increased nutrient concentrations and chemical leaching to water ecosystems. There are many studies conducted to link the processes occurring in the land and water quality of freshwater lakes (e.g. Norvell et al., 1979; Taranu and Gregory-Eaves, 2008). Nielsen et al., (2012) studied the links between the lakes and land use processes in Denmark and found a strong relationship between land use, nutrients, and chlorophyll *a* (Chl-*a*). In that study, agricultural land use had a positive correlation between total nitrogen (TN) and total phosphorus (TP), and Chl-*a* while forest land cover had a negative correlation with these variables, indicating agricultural non-point sources are the main inputs for the nutrients. Relationships between TP and agricultural land use were even stronger for lakes having rivers in their watershed (55%) compared to lakes without (28%), indicating that rivers mediate a more robust linkage between landscape activity and lake water quality by providing a ‘‘delivery’’ mechanism for excess nutrients in the watershed. Another study from Paul et al., (2012) also demonstrated that trophic state of the lake was negatively correlated with native forest, while it was positively correlated with the pasture and urban area. Thus, all of these studies show the clear link between the catchment and water quality of the freshwaters.

1.2 Climate change and lakes

Anthropogenic carbon emissions following industrial revolution caused an abrupt change in climatic regime, triggering an increase in the global average temperature by 0.85 °C over the last 130 years (1880-2012) (IPCC, 2013). According to Intergovernmental Panel on Climate Change (IPCC) 5^{th} assessment report (IPCC, 2013), many extreme events have been observed since 1950 with decreasing number of cold days and increasing number of warm days in all over the world. Also, increased frequency of heat waves has been observed in Europe, Asia, and Australia, and heavy precipitation events have increased in Europe and North America. On the contrary, in Mediterranean region and West Africa, the frequency of drought events has increased for the last century. It was also reported that 1983-2012 was the warmest period of the Northern Hemisphere for the last 1400 years (with medium confidence).

According to IPCC future projections, climate change is also expected to bring more climatic extremes, such as; droughts, floods, heat waves and hurricanes to different parts of the world. Although it differs among selected storylines, at least 1.5 ^{o}C increase (relative to 1850-1900) is anticipated for all representative concentration pathways (RCPs), except for RCP 2.6. For RCP 6.0 and 8.5, warming may exceed 2 ^{o}C at the end of the century (IPCC, 2013, **Table 1.2**). Precipitation patterns showed considerable variation among regions, and future projections indicate a significant decrease in precipitation with enhanced temperatures (Christensen et al., 2013; Erol and Randhir, 2012) for the Mediterranean region. This will result in an increase in the number of dry days and more frequent heat waves (Christensen et al., 2013; Giannakopoulos et al., 2009).

Table 1.2 Global mean surface temperature change and global mean sea level rise for 2046-2065 and 2081-2100 compared to 1961-1990 period for four different RCPs (taken from IPCC, 2013)

		2046-2065		2081-2100	
	Scenario	Mean	Likely range	Mean	Likely range
Global mean surface temperature change (°C)	RCP2.6	1.0	0.4 - 1.6	1.0	0.3 - 1.7
	RCP4.5	1.4	0.9 - 2.0	1.8	1.1 - 2.6
	RCP6.0	1.3	0.8 - 1.8	2.2	1.4 - 3.1
	RCP8.5	2.0	1.4 - 2.6	3.7	2.6 - 4.8

Climatic changes have profound impacts on lakes and freshwater ecosystems, especially in the Mediterranean region. Milano et al. (2013) demonstrated that majority of catchments in the Mediterranean basin currently experience water stress, and by the 2050s the water stress will be pronounced in areas that are already facing with water insufficiency. Climate change-driven increased evaporation and lower precipitation may lead to lower water levels and enhanced residence time, thereby initiating responses in chemical and biological levels in lake ecosystem dynamics (Beklioglu et al., 2007). Higher temperatures may also affect mixing regime of the lakes with longer stratification periods, possibly resulting in low oxygen levels and increased internal loading (Blenckner et al., 2007). Since expected changes in precipitation showed variation among different regions, chemical and biological responses of the lakes may also differ. While projected higher precipitation in temperate regions may result in an increase in the surface runoff and nutrients transported with them (Andersen et al., 2006; Jeppesen et al., 2009); in arid and semi-arid regions, low precipitation may cause a decrease in the surface runoff and nutrient loading from the catchment. However; decrease in water level with high evaporation in semi-arid regions may also initiate other responses such as salinity and internal loading (Beklioglu and Tan, 2008, Beklioğlu et al., 2017; Coppens et a., 2016; Özen et al., 2012).

Climate-driven physical changes in the lake ecosystem can also initiate responses in nutrient pathways and at the organism level. These processes may trigger a further deterioration of the water quality and weaken the efficiency of the management efforts (Jeppesen et al., 2009, 2007; Trolle et al., 2011b; Williamson et al., 2009) since warming enhances the eutrophication symptoms (Moss, 2009). Kosten et al. (2009) demonstrated that even at low nutrient concentrations, increased temperatures might initiate cyanobacteria bloom and loss of macrophytes due to increased phytoplankton growth (especially cyanobacteria). Furthermore, fish fauna may be affected and can shift to small sized planktivore individuals exerting high predation pressure on zooplankton (Meerhoff et al., 2007a; Tavşanoğlu et al., 2012). Experimental and monitoring studies also showed that refuge effect of macrophytes for zooplankton is not effective in warm lakes, (Meerhoff et al., 2007b) which may favor phytoplankton growth and destabilize clear water conditions. Climate change can also cause a shift in phenology and enhanced colonization success of invasive species (Mooij et al., 2005).

1.3 Hydrology

Hydrology is a major factor determining the chemical and biological dynamics of lake ecosystems; especially in the Mediterranean region, which is distinguished with warm rainy winter and hot dry summers. Water level fluctuations (WLFs) are an inherent feature of the region that have major roles in lake ecosystem dynamics through their effects on nutrient, growth dynamics, primary production, fish spawning, and biodiversity (Beklioğlu et al., 2006; Blindow, 1992; Wallsten, 1989). WLF may also play a role in shifting between clear and turbid water state (Blindow, 1992; Coops et al., 2003; Engel and Nichols, 1994; Gafny and Gasith, 1999; Havens et al., 2004). Low water levels in summer may trigger submerged macrophyte development (Beklioglu et al., 2007, 2006, 2017; Bucak et al., 2012; Coops et al., 2003) through increasing light penetration to the bottom of the lake. However, high water levels can favor phytoplankton, which has the ability to tolerate low light

(Nõges et al., 2003; Beklioğlu et al., 2006). Contrasting studies show that low water levels can increase phytoplankton biomass through increased nutrient concentrations (Chaparro et al., 2011; O'Farrell et al., 2011). Additionally, low water levels during winter can trigger a shift to turbid water state by causing freezing of the sediments, which in turn prevents macrophyte recolonization. Complete desiccation of the littoral area can also cause loss of macrophytes (Beklioglu et al., 2007; Blindow, 1992; Hargeby et al., 1994; Scheffer et al., 1993).

Synergistic effect of temperature and low water level can act together on primary production, by triggering nutrient release from sediment (Haldna et al., 2008) and up-concentrating of nutrients (Özen et al., 2010). For the lakes that have been exposed to nutrient loadings for an extended period, even when there is no loading from the catchment in the dry period, nutrient concentrations can increase by internal loading processes (Coppens et al., 2016; Özen et al., 2010). Also, longer hydraulic residence time may cause salinization (Beklioglu and Tan, 2008; Özen et al., 2010). Salinization may affect zooplankton community composition, shifting to saline tolerant species thereby lowering the grazing pressure on phytoplankton (Brucet et al., 2010; Jensen et al., 2010).

1.4 Eutrophication

Lake eutrophication is the process of increasing primary production in response to the enhanced availability of the limiting factors for photosynthesis such as light, CO_2 and nutrients (Chislock et al., 2013). There are contrasting views about the origin of eutrophication process in lakes. According to Rodhe (1969) and Carpenter (1981), eutrophication occurs naturally for long periods of time when a lake is filled with sediments. However, opposite views state that lakes are originally eutrophic and they are being more oligotrophic through time due to depletion of nutrients over time (Engstrom et al., 2000). Today, eutrophication is mostly perceived as a result of enhanced human activities through both point and nonpoint sources, and it is also regarded as cultural eutrophication (Carpenter et al., 1998).

Eutrophication can also be seen as the deterioration of the water quality of the aquatic ecosystems by enhanced phytoplankton production namely blooms of toxic cyanobacteria. These algal blooms can inhibit light penetration to the water column and further inhibit the growth of the submerged macrophytes (Chislock et al., 2013). Algal blooms in the lake surface can also create anoxic conditions in the water column and initiate death of organisms and massive fish kills (Moss, 2010a). Other than bloom-forming behavior, cyanobacteria can also produce toxins that can be a threat to other organisms and public health (Francis, 1978). Additionally, enhanced photosynthesis rates in the water column can increase the pH and may impair the chemosensory abilities and thus the survival of the organisms (Turner and Chislock, 2014).

With climate warming, it is expected that cyanobacteria get the edge over due to their higher optimum growth temperature and competitive ability under high nutrient concentrations and low light levels (Paerl and Huisman, 2008; Paerl and Paul, 2012). Cyanobacteria is also not preferable by zooplankton as a food source, and that weakens the control of zooplankton over phytoplankton (Tillmanns et al., 2008; Wilson et al., 2006). Eutrophication with climate change can act synergistically on whole trophic cascade, since warm lakes with high nutrients were mostly associated with a large number of planktivore fish, leading to low zooplankton biomass and low grazing pressure on phytoplankton (Meerhoff et al., 2007a).

1.5 Modeling approach

Lake modeling studies evolved from the simple static models to a wide variety of different approaches like complex dynamic models, structurally dynamic models, minimal dynamic models, individual-based models, physiologically structured models and trait-based models (Jorgensen, 2010). Mechanistic modeling approaches, which are commonly used nowadays, considers main ecosystem processes in the lake and requires a basic understanding of physical-chemical and biological interactions (Reckhow and Chapra, 1999). Due to their extensive data requirements, these models were highly criticized in their early development. However, with the improvements in the computational technology, the model complexity progressed after the 1980s. Many different complex dynamic models exist in the literature, and they differ widely in their functional, hydrodynamic and spatial structure, with differences in included compartments, dimensions, and processes (Mooij et al., 2010). Early mechanistic lake models mostly focused on phytoplankton as they were primarily developed for phytoplankton dominated eutrophic lakes wherein macrophyte biomass was low or absent. Through time, other biological components started to be included in models, like macrophytes, zooplankton, and fish (Mooij et al., 2010), especially after the knowledge gained from biomanipulation studies (Søndergaard et al., 2008). With the increase in usage of multi-lake datasets, modifications to original models have been initiated by including other components of the ecosystem as well.

Although lake models give insights about the responses of in-lake variables to external changes, non-point sources transported from the catchment to the water sources should also be considered to model the system better (Ferrier and Jenkins, 2010). In this thesis, PCLake and General Lake Model with Aquatic EcoDynamics Module (GLM-AED) models, which are complex dynamic lake models, were used in combination with catchment scale model SWAT to link the catchment processes to in-lake processes.

1.5.1 SWAT

Soil and Water Assessment Tool (SWAT) model was developed by Agricultural Research Service in the United States, Department of Agriculture (Arnold et al., 1998), and became one of the most used river basin-scale models that have been applied widely throughout the world and; there are also many applications from Turkey as well (Akiner and Akkoyunlu, 2012; Coppens, 2016; Ertürk et al., 2014; Gungor et al., 2016; Güngör and Göncü, 2013; Özcan et al., 2016). SWAT is a physically based continuous model, running on a daily time scale and it is mostly used for predicting the impacts of management scenarios, climate change, and land use change on water sources (Neitsch et al., 2011). The model is based on water balance equations including surface runoff, precipitation (rain and/or snow), evapotranspiration, infiltration and subsurface flows. Nutrient balance equations are also based on factors like external loading, transportation of nutrients with runoff, fertilizers, plant-uptake amount, soil characteristics (Gassman et al., 2007).

Catchment hydrological process starts with the descending of the precipitation to the catchment. It can be intercepted and held by the vegetation or fall onto the soil surface. Depending on the soil water capacity, the water can infiltrate or become surface runoff. While runoff will rapidly enter stream channel, infiltrated water move horizontally as subsurface runoff or may percolate to the groundwater, or be lost as evapotranspiration. SWAT model also considers nutrient cycles and traces the movement of the nitrogen and phosphorus in various forms. In the phosphorus (P) cycle, plant P uptake, fertilizer application, mineralization and decay processes were included (Figure 1.1), while in the Nitrogen (N) cycle plant N uptake, fertilizer application, volatilization of NH_4, nitrification, denitrification, decay and mineralization processes were included (Figure 1.2).

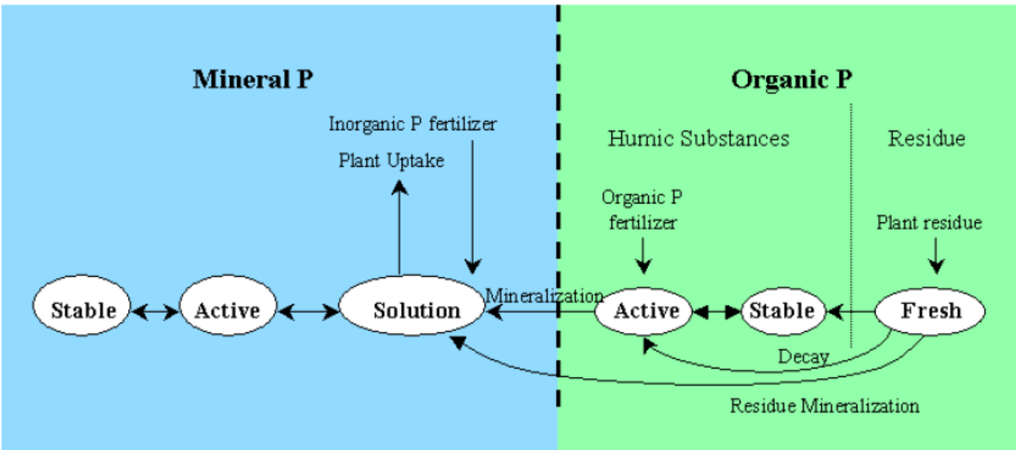

Figure 1.1 Phosphorus cycle in SWAT model (taken from Neitsch et al., 2011)

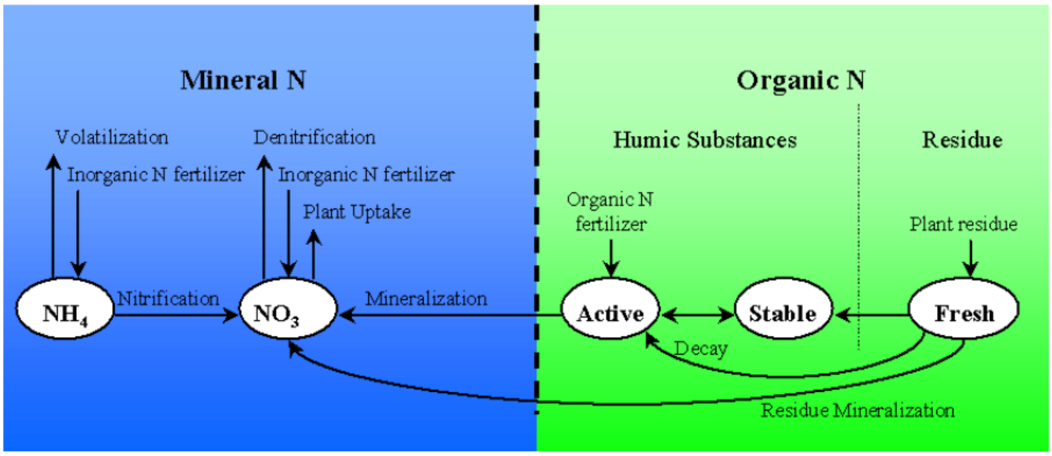

Figure 1.2 Nitrogen cycle in SWAT model (taken from Neitsch et al., 2011)

1.5.2 PCLake

PCLake is a complex dynamic lake model that was developed to simulate nutrient, phytoplankton, macrophyte, food web dynamics for completely mixed shallow lakes (Janse, 2005). PCLake is one of the widely used complex dynamic lake models, and is being used for various purposes, like testing the impacts of management scenarios (Janse et al., 1993; Prokopkin et al., 2010), water level fluctuations (Stonevicius and Taminskas, 2007), fish and sediment removal, and flushing.

The first version of PCLake (PCLoos) was developed for a peat lake in Netherlands (Janse et al., 1992; Van Liere and Janse, 1992) for understanding the mechanisms underlying algal blooms. With the improvements in the field and increased interests, the model has been improved to include many state variables, enabling the modeling of trophic interactions better and switch between alternative stable states. Furthermore, wetland module has also been included to simulate the impacts of halophyte zones for lake restoration (Janse et al., 2001; Sollie et al., 2008).

PCLake is a zero dimensional model in which the lake column is represented as completely mixed water body and top 10 cm of the sediment. It is suitable for shallow lake bodies that are permanently mixed and having no vertical and horizontal variation. Interactions between the water column and sediment top layer are modeled with specific biogeochemical modules including processes like settling, resuspension, mineralization, diffusion, and sorption (Figure 1.3). The nutrient cycles are dynamic, and the mass balance per element is checked after every time step (Janse, 2005). The biological module comprises of three groups as phytoplankton, one zooplankton, one zoobenthos, planktivorous fish (adult and juveniles), piscivorous fish and submerged macrophytes. Phytoplankton biomass is calculated by taking into account the primary production, respiration, mortality, settling, resuspension, grazing and transport processes. All animal groups are modeled as the product of feeding, egestion, respiration, mortality, and predation. Zooplankton is set to feed on phytoplankton and detritus with grazing pressure depending on seston concentration, filtering rate, and food preference parameters. Though having advanced biogeochemical and biological module, it does not have hydrodynamics and thermodynamic module (Janse, 2005). However; with the redesigned PCLake Model: FABM-PCLake, it is also possible to couple PCLake with one-dimensional and three-dimensional hydrodynamic models (Hu et al., 2016). PCLake applications were mostly recorded from temperate regions (Janse et al., 2008; Nielsen et al., 2014; Rolighed et al., 2016); however, the model is being used in other regions as well recently, such as China (Janssen et al., 2014) and the Mediterranean region (Coppens, 2016; Kuzyaka, 2015; Mellios et al., 2015).

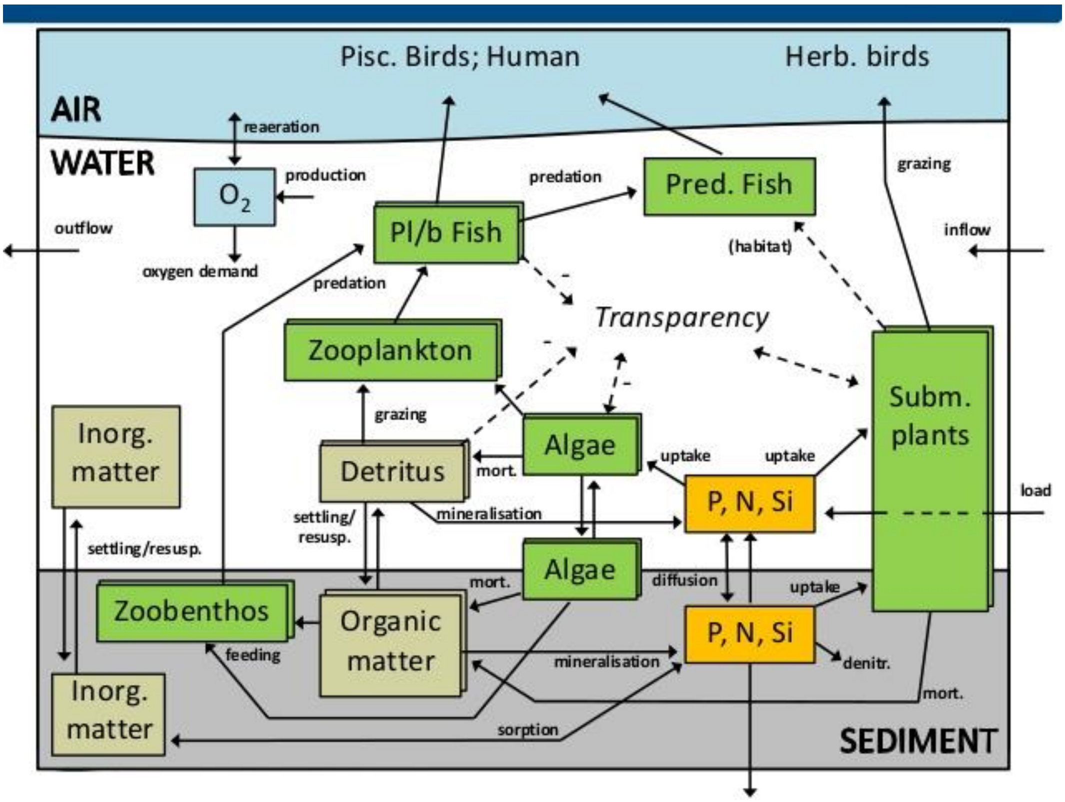

Figure 1.3 Model structure of PCLake. Solid lines represent mass fluxes; dashed lines represents interactions (taken from Jeuken & Janssen, 2014).

1.5.3 General lake model (GLM)

General Lake Model (GLM v2.0.0), a one-dimensional (1D) hydrodynamic model, which considers variation in vertical gradient, is coupled to the Aquatic EcoDynamics module library (AED) through the Framework for Aquatic

Biogeochemical Modeling (FABM) (Hipsey et al., 2014, 2013). GLM computes the temperature, salinity and density gradients in vertical profiles regarding inflow, outflow and meteorological forcings (Figure 1.4). GLM uses Lagrangian layer scheme (Imberger and Patterson, 1981) in which the lake is represented as layers having an equal thickness and the layers expand or contract considering density changes driven by surface heating, mixing and flows. Most of the algorithms related with hydrodynamics in GLM are adopted from widely used lake hydrodynamic model DYRESM (Bruce et al., 2006; Gal et al., 2009; Han et al., 2000; Rinke et al., 2010; Trolle et al., 2011a).

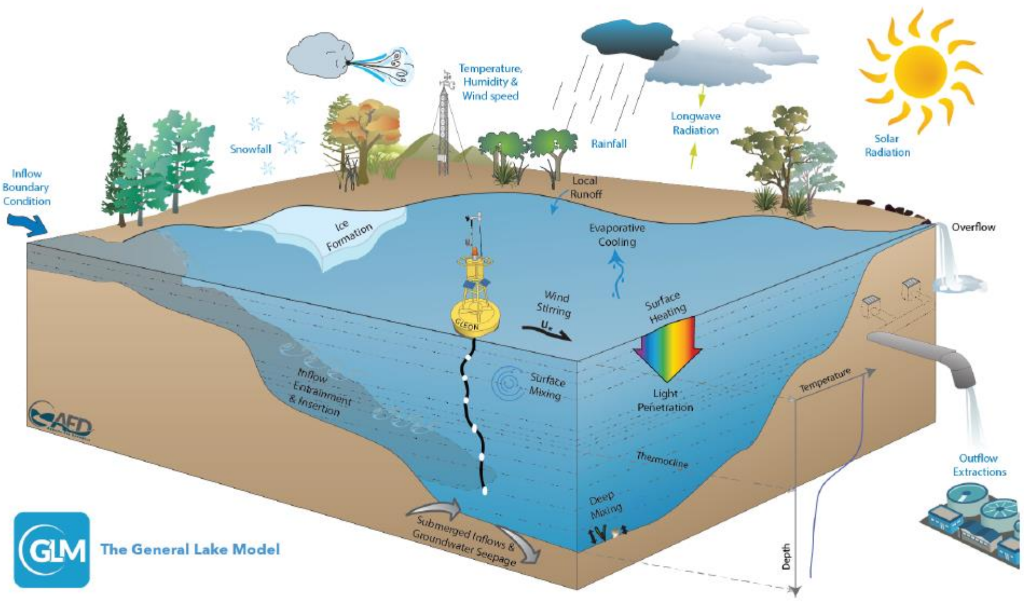

Figure 1.4 Overview of the GLM model (Hipsey et al., 2014). Blue text indicates input information required for setting up the model, while black text indicates key processes simulated.

AED ecological module (Figure 1.5) enables to simulate various chemical processes including inorganic and organic nutrient cycles, oxygen dynamics and biological organisms as functional groups. Initial motivation of AED is developing a flexible aquatic ecosystem module that could be customized easily according to the selected biogeochemical and ecological configurations. While customizing the modules, hierarchical dependencies of the modules should be considered (Hipsey et al., 2013). AED supports the oxygen, silica, phosphorus, nitrogen, organic matter, Chl-*a*, phytoplankton, zooplankton and pathogen modules. In nutrient modules, mineralization, decomposition, sediment fluxes, uptake by phytoplankton and excretion by organisms are simulated. For Nitrogen module, denitrification and nitrification processes are also included. Phytoplankton biomass is calculated considering nutrient uptake, excretion, mortality, respiration, vertical movement, and grazing by zooplankton. In zooplankton module, processes of assimilation from grazing, respiration, excretion, fecal pellet production, mortality and predation by larger organisms are included (Hipsey et al., 2013).

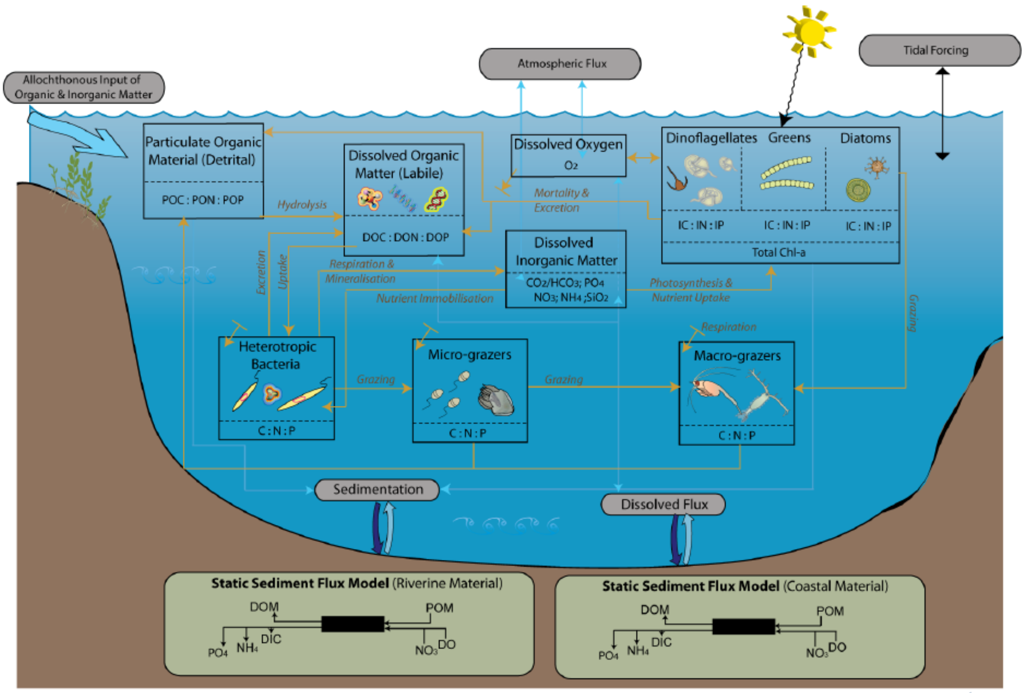

Figure 1.5 Overview of the Aquatic EcoDynamics Library (AED) conceptual model (Hipsey et al., 2013) for nutrient pathways and organisms. Text in black box indicates the simulated variables and gray text indicates the simulated processes.

1.6 Objectives

Lake Beyşehir, the largest lake in Turkey and also in the Mediterranean basin, has been exposed to intense water abstraction for irrigation of the downstream Konya Closed Basin for decades. As climate change projections indicate augmented temperatures and drops in precipitation for the future (IPCC, 2013), the lake may further expose to decreased water levels, which may initiate responses in chemical and biological level, affecting the ecosystem structure and services of the lake. Change in climatic patterns and socioeconomic structure in the future may also alter land use in the catchment and this may influence the lake dynamics as well. Hence, in this thesis, the main aim is to investigate the roles of climate change and land use on lake's hydrology, ecological dynamics, and ecosystem services. The objectives of the thesis are:

- To simulate future water availability in Lake Beyşehir catchment and future water levels in response to climate change and land use and to offer outflow management options by predicting the maximum water abstraction (Chapter 3),
- To simulate the future ecological status of Lake Beyşehir in response to climate change and land use scenarios for assessing the future ecosystem structure (Chapter 4),
- To assess the changes in long term ecosystem services of Lake Beyşehir from past to the future (Chapter 5).

CHAPTER 2

DETAILED STUDY SITE DESCRIPTION

2.1 General characteristics of Lake Beyşehir

Lake Beyşehir, the largest freshwater lake in Turkey as well as in the Mediterranean Basin, is located in southwest Anatolia (within the borders of Konya and Isparta provinces) (Figure 2.1). The lake 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, with the former being the second largest national park in Turkey with a surface area of 86,855 ha, and covering 4/5 of Lake Beyşehir (General Directorate of Nature Conservation and National Parks, 2016). Moreover, part of the catchment was also declared as Grade 1 Natural Site Area. The catchment is situated in a semi-dry Mediterranean climate having an average temperature of 11 ^{o}C and an annual total precipitation of 490 mm, during 1960-2012 (Figure 2.2). Precipitation values fluctuated between 317 to 716 mm (Beyşehir meteorology station, www.mgm.gov.tr), and the lowest annual temperature was recorded in 1992 (8.5 ^{o}C), while the highest annual average temperature was observed in 2010 (13.1 ^{o}C) (Figure 2.2). Evapotranspiration constitutes the major loss of water from the catchment, and precipitation to potential evapotranspiration ratio is 0.55, indicating water limitation in the catchment.

Lake Beyşehir is located in tectonic depression area in a northwest-southeast direction in the Western Taurus system (Yarar et al., 2009). The lake basin exists since Middle Miocene (15.97-11.6 million years ago), and both tectonic and karstic processes are influential in the formation of lake basin (Oguzkurt, 2001). In the basin, the limestones, which are widespread especially in the Mesozoic area, have been intensively karstified under the influence of precipitation and tectonism. Karstification in the western Taurus region extends from 2500-3000 meters above sea level (m.a.s.l.). to 150-200 m.a.s.l. Anamas and Dedegöl Mountains extend to the west of Beyşehir Lake, and Sultan Mountains to the north and east. 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 the lake flows through to Çarşamba stream, to Suğla Plain, then to Konya Plain and Salt Lake.

As a characteristic of Mediterranean climate, there are natural fluctuations in water level with seasonal variations up to 0.5-1 m. However, a long-term general trend of declining water levels has also been observed in recent decades. According to historical water level changes (1905–2012), the mean water level of the lake is 1123.3 m.a.s.l., and the lake was subjected to four distinct low water level periods (1928–1939, 1957–1965 and 1974–1976, 1989–2011) and four distinct high water level (1905–1927, 1940–1956, 1966–1973 and 1977–1988) periods (see Figure 5.2). The longest low water level period was observed after the peak in the mid-1980s (1125 m.a.s.l) and lasted from 1989-2011. Water from the lake and catchment is currently used for both drinking water and agricultural irrigation for Konya Basin (770 km^2) with the canal built in 1914 (Oguzkurt, 2001).

Due to the complex karstic geology and associated hydrology of Lake Beyşehir, there is high uncertainty in the water budget. A study showed that the lake water is connected to Manavgat stream through groundwater system (Acatay, 1966). Ekmekçi, (1993) also demonstrated that leakage from the lake is highly correlated with the water level, and when water level exceeds 1123 m.a.s.l., leakage occurs. The lake does not have a regular thermal stratification pattern due to the prevailing winds (Mercan, 2006). Historical and paleolimnological studies also pointed out that lake water level fluctuation appears to be critical for ecosystem structure of the lake that during low water level periods, expansion of macrophytes was observed

(Beklioğlu et al., 2006). Moreover, low water level periods were characterized by low-light tolerant macrophyte species and dominance of pelagic taxa for diatom and cladoceran (Levi et al., 2016). The trophic status of the lake is within an oligotrophic to mesotrophic range, having low phytoplankton biomass and nutrient concentrations. The lake had several problems in its history such as sewage effluent discharge, exotic fish introduction, and excessive water withdrawal. *Sander lucioperca* was introduced in 1977, and it caused the extinction of the endemic species *Alburnus akili*, and drastic changes in fish community structure (Oguzkurt, 2001). *Carassius gibelio, Tinca tinca* (from the 1990s onwards), and *Atherina boyeri* (in 2002) have also been introduced to the lake (Innal and Erk'akan 2006; Yeğen et al., 2006).

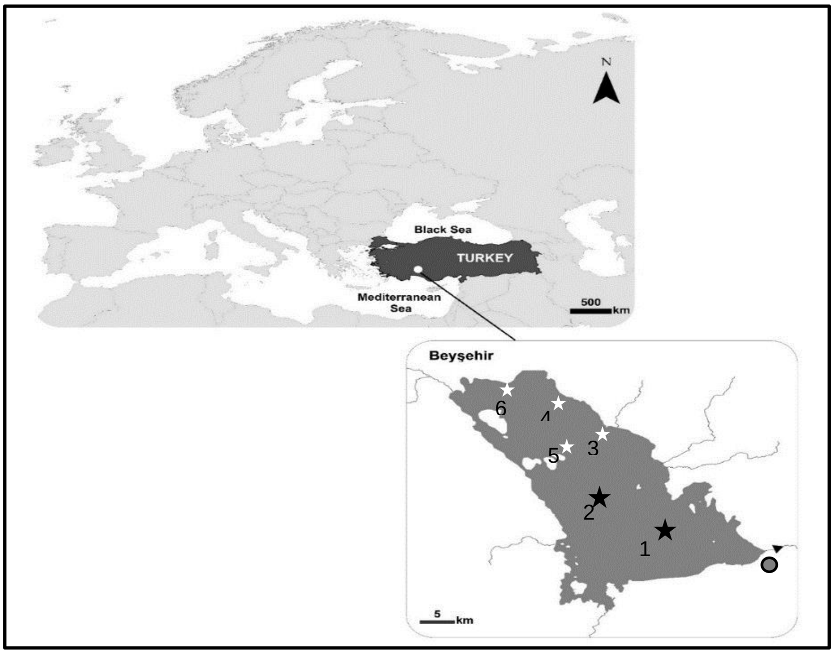

Figure 2.1 Location of the Lake Beyşehir and its catchment. Black stars (1, 2) indicate in-lake sampling stations those were sampled throughout the sampling period of 2010-2012. White stars (3-6) are the additional sampling points that were sampled in September 2010 to test the variation in physico-chemical features on the horizontal plain of the lake. Gray circle indicates the location of Beyşehir meteorology station.

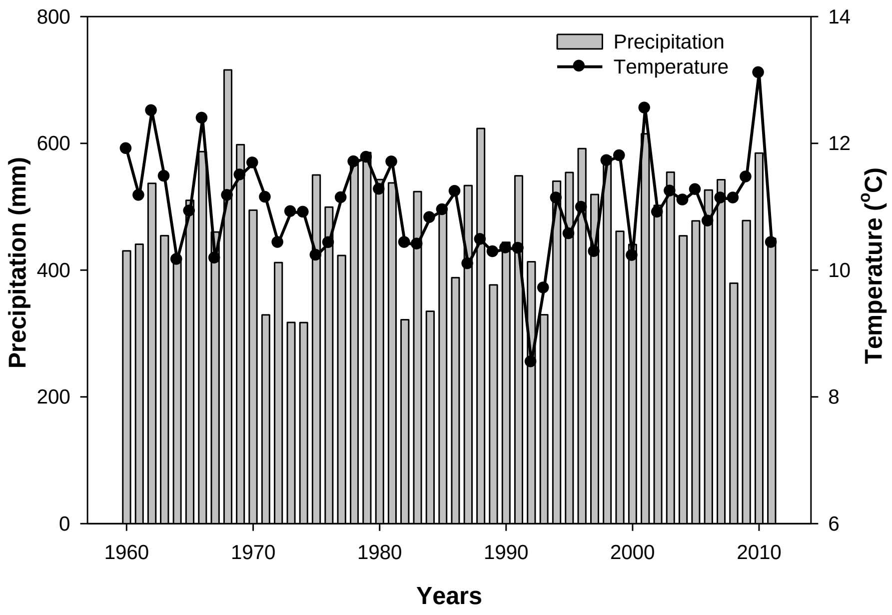

Figure 2.2 Changes in total annual precipitation and the annual average temperature during 1960-2011 recorded in Beyşehir meteorological station. (Data source: Turkish State Meteorological Service, www.mgm.gov.tr).

2.2 Materials and Methods

2.2.1 Water sampling

The monthly monitoring program was conducted within the period of April 2010-March 2012. The data collected during this programme was used for lake model calibrations as well (Chapter 4). Lake Beyşehir, is a large lake but variation in physicochemical and biological variables along horizontal and vertical plains is low (Nas et al., 2010). We also tested homogenous nature of the lake for physicochemical and biological variables by taking samples from 6 different locations of the lake (Figure 2.1) in September 2010, and we did not find any major differences among sampling stations (Table 2.1). Therefore, throughout the field survey, we limited our in-lake observation stations to 2 for reducing the sampling effort. We also tested the difference between these two selected in-lake stations during the monitoring period with paired t-test. The results did not reveal significant difference between these two stations (Table 2.2). Hence, throughout this thesis, average values of these two stations were used. Conductivity, pH, dissolved oxygen concentration, temperature, and salinity were measured *in situ* for both lake & inflows using a YSI 556 MPS multi-probe field meter (YSI Incorporated, OH, USA). Moreover, water samples were retrieved from the inflows directly to sampling bottles, and a KC-Denmark Ruttner sampler was used to take an integrated sample from the water column at the in-lake stations. Samples were stored in cool boxes after collection and kept frozen until analysis. Water depth and Secchi disc depth were also measured at each sampling event from in-lake stations. For phytoplankton, 50 ml of water was taken from integrated water column sample and fixed in 2% Lugol's solution. For zooplankton enumeration, 20 L of water from the integrated water sample was filtered through the 20 µm mesh size net and was preserved in 4% Lugol's solution.

Table 2.1 Chemical and physical variables at six stations sampled in September 2010. Locations of the stations are given in Figure 2.1.

Station ID	Total alkalinity (meq L^{-1})	SRP (µgL^{-1})	TP (µg L^{-1})	Temperature (°C)	Conductivity (µS cm^{-3})	Salinity (‰)	Chl-*a*
1	2.9	6.2	29.5	23.0	391	0.19	5.6
2	3.1	6.0	29.2	22.8	401	0.19	6.5
3	3.0	5.5	28.0	22.7	400	0.19	7.1
4	3.1	5.1	31.0	23.8	402	0.19	7.5
5	2.2	5.8	33.7	23.6	401	0.19	6.4
6	2.7	6.5	29.6	22.7	402	0.19	4.4

Table 2.2 Paired t-test results for the difference between two stations sampled throughout the monitoring period (2010-2012). Locations of the stations are given in Figure 2.1. df: Degrees of freedom.

Variables	t	p	df
TP	-0.44	0.67	18
SRP	-2.14	0.05	18
TN	-1.36	0.19	18
NO_3	-0.213	0.83	18
NH_4	-1.53	0.145	17
Silicate	0.47	0.64	18
Alkalinity	-2.11	0.05	18
Chl-*a*	-1.75	0.1	17

2.2.2 Macrophyte and fish sampling

Macrophyte and fish surveys were performed once a year in September 2010 and 2011. Macrophytes were surveyed along parallel transect lines at 2-3 km intervals around the lake. The sampling points along each transect were located at 1 km intervals. Since the lake has a large surface area, macrophyte sampling was performed only in the littoral zone. Macrophyte coverage, the average height of each plant species, Secchi depth and water depth, were recorded for submerged macrophytes at each point on the transect lines together with GPS coordinates (Canfield et al., 1984). Identification of the species was carried out to species level if possible, in the field (Davis, 1984; Fassett, 1969; Seçmen and Leblebici, 1997; TÜBİVES, 2016).

Since Lake Beyşehir has a large surface area, fish surveys were conducted in three different regions (Figure 2.3). The composition and abundance of fish (Catch per unit effort - CPUE) were determined by overnight fishing. Lundgren gill nets with multiple mesh sizes (5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, and 55 mm, each section being 3 m long and 1.5 m deep) were used. For each region, 7

Lundgren gill nets for littoral, and 14 nets for pelagic were used. Since the depth of the pelagic zone is deeper than 3 m and in order to better represent the fish fauna, pelagic fish sampling was conducted at two zones: 7 nets were set at 0-1.5 m of the pelagic (surface), and 7 nets were set at 2-3.5 m. Pelagic and littoral nets were set parallel to each other and left overnight for an average duration of 12 hours. Fish were identified to species level (Balık and Geldiay, 2002; Kuru, 2004) and weighed for the calculation of biomass per unit effort (BPUE) as catch per net per night.

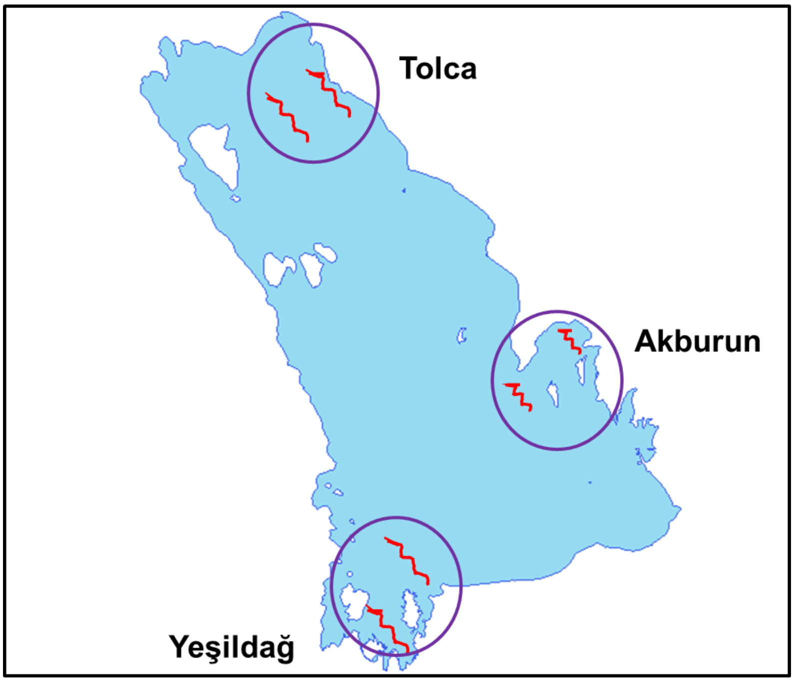

Figure 2.3 Sampling regions in Lake Beyşehir, for the fish surveys. Red curved lines indicate fish sampling areas for each region.

2.2.3 Laboratory analyses

Water samples taken from in-lake stations were analyzed in the laboratory for P and N compounds, alkalinity, and suspended solids (SS). Samples were further analyzed for Chl-*a* and plankton. To determine TP, the acid hydrolysis method were used

(Mackereth et al., 1978). Filtered water was processed using the molybdate reaction to determine the soluble reactive phosphorus (SRP) (Mackereth et al., 1978). Nitrogen analysis including total nitrogen (TN), nitrite–nitrate (NO_2-NO_3) and ammonium (NH_4) was performed using the Scalar Autoanalyzer Method (San++ Automated Wet Chemistry Analyzer, Skalar Analytical, B.V., Breda, The Netherlands).

Phytoplankton identification and countings were conducted according to Utermöhl (1958) technique by Şeyda Erdoğan (METU Limnology Laboratory) using taxonomic reference books of John et al., (2002) and Prescott, (1973). At least 100 individual of the most abundant species were counted in random fields, and at least 10 individuals from each species were measured to calculate the biovolume of each species (mm^3 L^{-1}) (Hillebrand *et al.,* 1999). Phytoplankton biovolume was calculated according to Hillebrand et al. (1999). For zooplankton identifications, Cladocera and Rotifera were identified to the genus level, while Copepoda was identified as Cyclopoid, Calanoid, and nauplii. For calculating zooplankton biomass, the body length of at least 25 individuals of the species was measured if possible, and biomass was estimated using allometric body length-weight relationships (Dumont et al., 1975; McCauley, 1984).

2.2.4 Data treatment and statistical analysis

2.2.4.1 Species composition and metrics

Species richness and diversity indices were calculated for macrophyte, fish, zooplankton and phytoplankton. Richness is defined as the total number of different species represented in each sampling event. Diversity is a measure both considers richness and evenness of the species in an ecosystem. Shannon-Wiener Index (H) were calculated in R programme (R Core Team, 2016) using vegan package (Oksanen et al., 2013). Shannon-Wiener Index (H) is calculated as:

$$H = -\sum_{i}^{s} p_i log_b p_i$$

Where p_i is the proportion of species i, and s is the number of species and b is the base of the logarithm. Natural logarithm (b= e) is used in calculating H.

2.2.4.2 Redundancy analysis

Redundancy Analysis (RDA) was used for elucidating the factors determining phytoplankton composition. Before applying RDA, species data was Hellinger-transformed, and environmental variables (given in Table 2.3) were log transformed. Highly collinear environmental variables were removed based on their high variance inflation factors (VIF), if VIF>8, the environmental variable was discarded (Feld et al., 2016). RDA analysis was initially performed with all environmental variables, chosen by considering the VIF factors. Then, Monte Carlo permutation tests were applied to check the significance of each environmental variable used in RDA. The backward selection procedure was used, and environmental variables that did not explain a significant portion of species variance after Monte Carlo permutations ($p< 0.05$; 999 random permutations) were removed from the analyses. Analyses were performed in R 3.2.5 version (R Core Team, 2016) using the vegan package (Oksanen et al., 2013).

2.2.4.3 Regression tree

Conditional Inference Trees (CIT) was used to determine the relative importance of Secchi depth and water level on total macrophyte coverage. In CIT analysis, data are recursively partitioned into smaller groups considering the maximization of the homogeneity of the two resulting groups. The party (A Laboratory for Recursive Partitioning) R package (Hothorn et al., 2006) was used for the analyses.

2.3 Ecological structure of the lake

2.3.1 General physicochemical characteristics of the lake

During the sampling period, there were inter- and intra-annual variations in water level up to 1.0 m. Secchi depth varied between 0.6-3.1 m (Table 2.3). Even though the lake has a maximum depth of 8-9 m, it was thoroughly mixed during the sampling period, and no thermal stratification was observed (Figure 2.4). The concentrations of the inorganic nitrogen (NH_4 and NO_3) and soluble reactive phosphorus (SRP) were very low (mostly below detection limits of the methods). Furthermore, while TP concentrations did not show a clear seasonality, TN concentrations ranged between 0.1-0.69 mg L^{-1}. Chl-*a* concentration was also low with a median of 3.1 μg L^{-1} (Table 2.3)

Table 2.3 Summary statistics of lake and climatic variables, which were also used as predictor variables in RDA analysis. nd indicates the values below the detection threshold of the methods.

Variables	Unit	Max	Min	Median
Precipitation	mm $month^{-1}$	197	0	43
Wind	m s^{-1}	2.4	1	1.9
Outflow	hm^3 $month^{-1}$	53.5	0	8.9
Water level	m	8.7	7.7	8.13
Water temperature	Celcius	25.3	3.8	14
Oxygen	mg L^{-1}	12.4	6.05	8.4
pH	-	8.74	7.23	8.2
Conductivity	μS m^{-1}	415	358	399
Secchi depth	m	3.1	0.6	1.1
NO_3-N	μg L^{-1}	40	nd	14
NH_4-N	μg L^{-1}	10	nd	0.01
TN	μg L^{-1}	690	100	280
SRP	μg L^{-1}	10	nd	4
TP	μg L^{-1}	47	10	23
Chl-*a*	μg L^{-1}	9.9	0.6	3.1
Salinity	‰	0.2	0.17	0.19
SS	mg L^{-1}	45.8	3.1	8.8

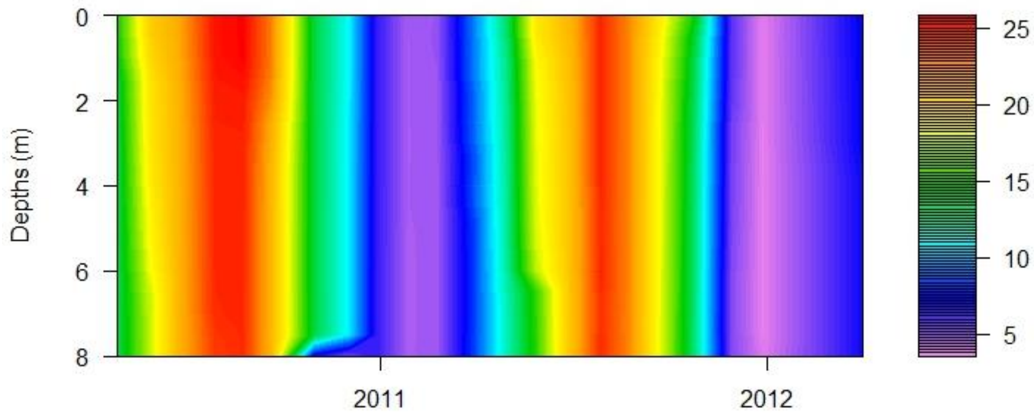

Figure 2.4 Temperature (°C) profile of Lake Beyşehir during the monitoring period of 2010-2012.

2.3.2 Plankton

During the study period, Bacilliarophyta (Diatoms), Cyanobacteria, Chlorophyta and Pyrrophyta (Dinoflagellates) were the main phytoplankton groups (Figure 2.5), and Diatoms dominated the phytoplankton community. Dominant species were *Cyclotella sp., Mougeotia sp., Melosira varians, Ceratium sp.*, and *Dinobryon divergens.* The contribution made by cyanobacteria was 10.4% and 8.6% during growing seasons (April to October) for 2010 and 2011, respectively (Figure 2.5). Full phytoplankton species list for the sampling periods is given in Appendix A, Table A.1. Phytoplankton diversity ranged between 0.9-2.65 and richness ranged between 9-24 (Table 2.4). Zooplankton composition was dominated by Copepoda (Cyclopoid copepod adults and nauplii) and Cladocera species (*Bosmina sp., Daphnia sp. Diphanosoma sp.)* while the contribution of Rotifera was low. Full list of the zooplankton species recorded during the sampling period is given in Appendix A, Table A.2. Zooplankton diversity ranged between 0.42-2.22, while richness ranged between 7-16 (Table 2.4).

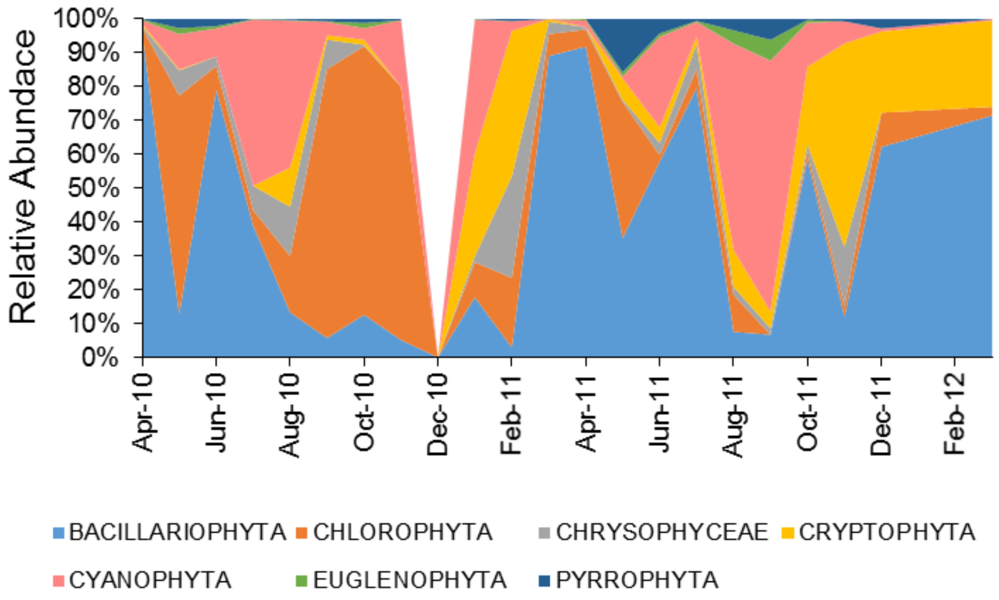

Figure 2.5 Relative abundances of phytoplankton groups during the 2010-2012 sampling period. Phytoplankton sample was not available for December 2010.

Table 2.4 Ranges of Shannon-Wiener diversity and richness for phytoplankton, zooplankton, macrophyte, and fish, calculated for each sampling event. Since macrophyte and fish samplings were performed annually (2 sampling events), no median values were available.

		Min	**Max**	**Median**
Phytoplankton	Diversity	0.9	2.65	1.56
	Richness	9	24	16
Zooplankton	Diversity	0.42	2.22	1.29
	Richness	7	16	10
Macrophyte	Diversity	1.11	1.59	NA
	Richness	7	13	NA
Fish	Diversity	0.58	0.61	NA
	Richness	12	16	NA

In RDA, four dominant phytoplankton groups, which constituted 90% of the biovolume, were included. RDA results showed that the precipitation, concentration of NO_3, wind, and temperature were the significant variable for explaining 44% of the variation in phytoplankton composition (Figure 2.6). The results showed that first axis was strongly related to precipitation and wind while the second axis was related to NO_3 concentration and wind. Bacillariophyta was positively related to precipitation, wind, and NO_3, and negatively related to temperature, whereas cyanobacteria and Pyrrophyta were positively related to temperature and negatively to precipitation and NO_3 concentration. In addition, Chlorophyta was found be negatively related with wind and positively related to NO_3.

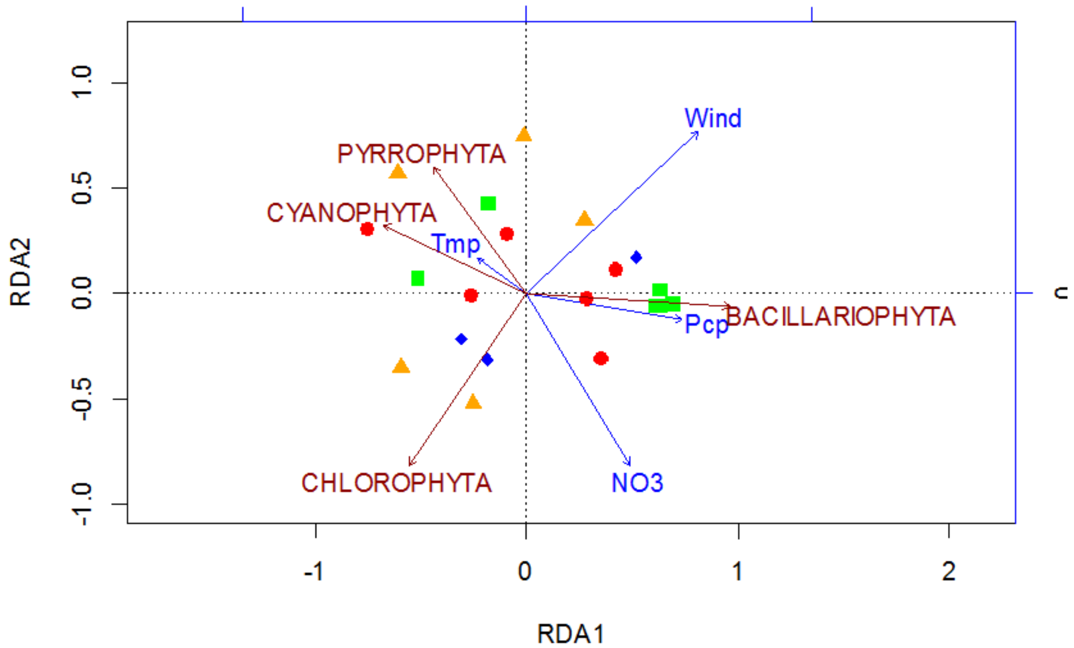

Figure 2.6 RDA results for phytoplankton composition. Orange triangles: autumn, blue diamonds: winter, green squares: spring, red circles: summer. Pcp: Precipitation, Tmp: Temperature.

2.3.3 Macrophyte

Average percent plant coverage was 17% for 2010 and 9% for 2011 (Figure 2.7). *Ceratophyllum sp*. dominated the lake both for 2010 and 2011, and *Myriophyllum spicatum*, *Potamogeton lucens*, *Potamogeton perfoliatus*, and *Najas marina* were the other abundant species recorded throughout the macrophyte surveys. Macrophyte species richness was 13 for 2010, and 7 for 2011and diversity was 1.59 and 1.11 for 2010 and 2011, respectively. List of macrophyte species recorded during the study is given in Appendix A, Table A.3.

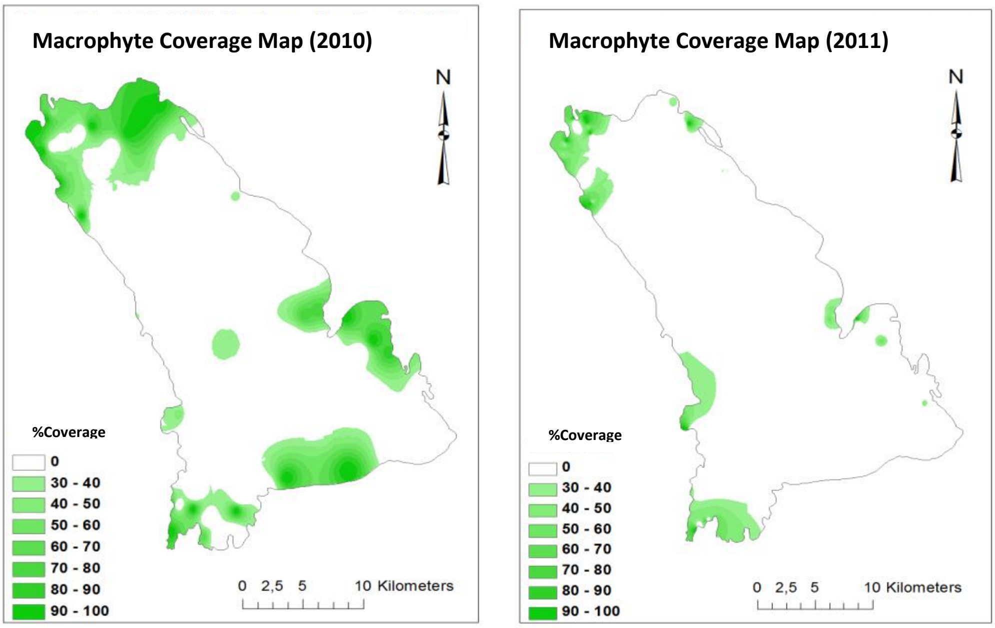

Figure 2.7 Macrophyte coverage of the Lake Beyşehir for a) 2010 and, b) 2011

Conditional inference tree (CIT) results showed that Secchi depth and water level explained 40% of the variance of plant coverage in Lake Beyşehir. The areas having Secchi depth > 103 cm and water depth ≤350 cm had the highest average macrophyte coverage with 71% (Figure 2.8). For the depths greater than 350 cm, the likeliness of having high macrophyte coverage was low with 16% in average.

In addition, for the areas having Secchi depth less than 103 cm, 225 cm of water depth was critical as the stations having the depth of lower than 225 cm had 35% coverage. The lowest plant coverage was observed in areas having Secchi Depth lower than 103 and depth > 290 cm.

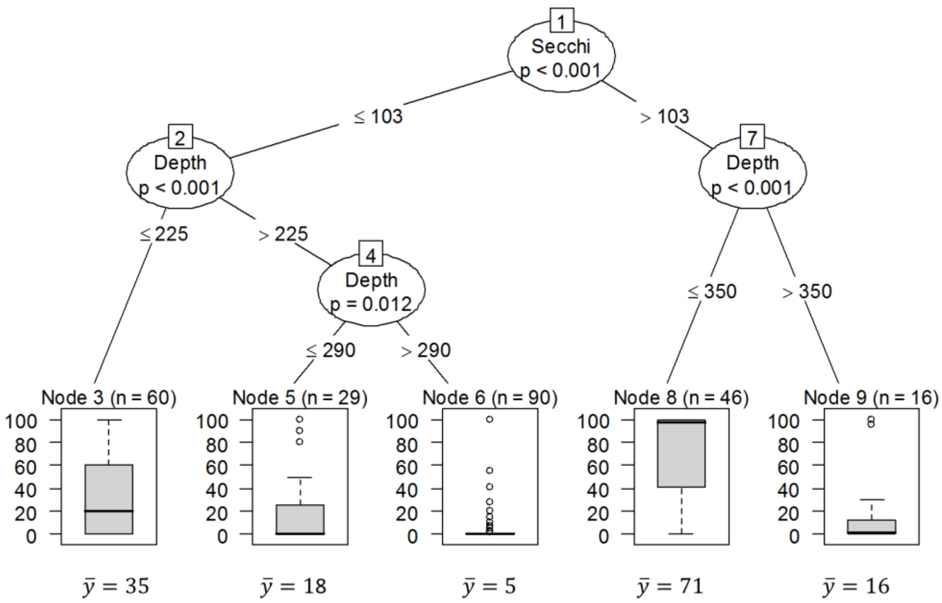

Figure 2.8 Conditional inference trees for macrophyte coverage. $\bar{y}$ indicates mean coverage.

2.3.4 Fish

During the fish surveys conducted in September 2010 and 2011, sixteen fish species (thirteen of them identified to species level and 3 to genus level), from three different fish families (Cyprinidae, Atherinidae, Percidae) were recorded (Table 2.5). The dominant species were *Atherina boyeri*, *Pseudorasbora parva*, *Carassius carassius*, which were introduced species, and *Squalis lepidus* (Figure 2.9). During the sampling, fish species that are endemic to Lake Beyşehir and Central Anatolia such as *Squalis anatolicus, Chondrostoma beysehirense, Pseudophoxinus anatolicus, and Pseudophoxinus caralis* were also recorded. These species are also listed on the IUCN Red List of Threatened Species (IUCN, 2016). Fish diversity ranged between 0.58-0.61, while richness ranged between 12-16.

Table 2.5 Fish species recorded in Lake Beyşehir in September 2010 and 2011. * indicates the fish species that are endemic for Turkey.

Fish species	2010	2011
Carassius carassius	+	+
Pseudorasbora parva	+	+
Atherina boyeri	+	+
Alburnus sp.	+	+
*Pseudophoxinus anatolicus**	+	+
Carassius sp.	+	+
*Chondostroma beysehirense**		+
Cyprinus carpio	+	+
Squalius lepidus	+	+
*Squalius anatolicus**	+	
Sander lucioperca	+	+
Tinca tinca	+	+
Carassius gibelio		+
Squalius cephalus		+
Leuciscus sp.		+
*Pseudophoxinus caralis**		+

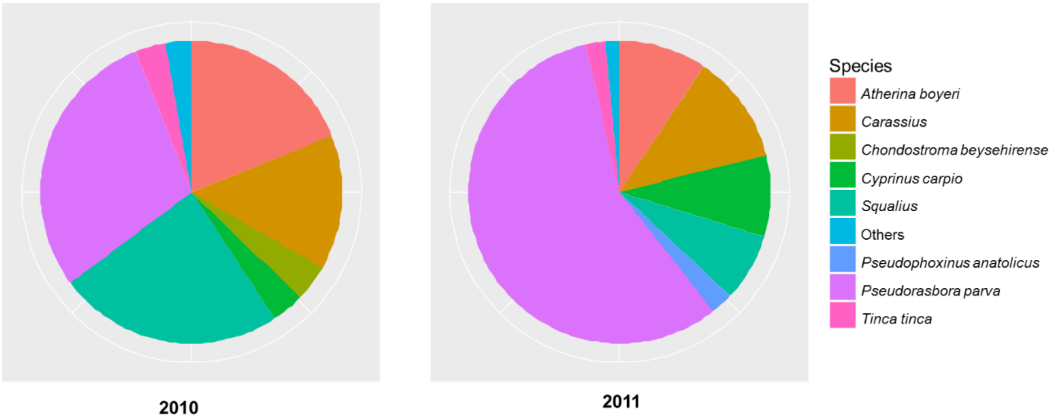

Figure 2.9 Relative abundances of the fish in Lake Beyşehir in September 2010 and 2011. Carassius includes both *Carassius carassius* and *Carassius sp*., Squalius includes *Squalis anatolicus, Squalis lepidus,* and *Squalis cephalus*.

CHAPTER 3

FUTURE WATER AVAILABILITY OF THE LARGEST FRESHWATER MEDITERRANEAN LAKE IS AT GREAT RISK AS EVIDENCED FROM SIMULATIONS WITH THE SWAT MODEL[1]

3.1 Introduction

Global warming is expected to increase the frequency of extreme climatic events such as droughts, floods, and heat waves in Europe (Beniston et al., 2007; Kovats et al., 2014; Lehner et al., 2006). The Mediterranean region already suffers from water scarcity and episodes of droughts due to intensive water use and the natural intrinsic climatic characteristics (Chenini, 2010). Additionally, significant changes in freshwater availability are expected to occur with the ongoing climate change. Climate projections for the Mediterranean region predict a significant decrease in precipitation (Christensen et al., 2013; Erol and Randhir, 2012) and enhanced temperatures, which would result in an increase in the number of dry days and more frequent heat waves (Christensen et al., 2013; Giannakopoulos et al., 2009). Evaporation from water surfaces and evapotranspiration from land surfaces caused by higher temperatures may lead to a further decrease in water availability (Calbó, 2010) and thus reinforce the existing water scarcity problems in the region.

Apart from climate forcing, land use influences the water and energy balance in watersheds through its effects on infiltration, evapotranspiration, and surface runoff

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(Liu et al., 2014; Mao and Cherkauer, 2009). Disruption of natural vegetation (for instance, forests) and an increase in urbanized areas generally trigger an increase insurface runoff (Foley et al., 2005), whereas an extension of agricultural areas often decreases surface runoff (Calder, 2007; Hibbert, 1967). With the substantial changes in land use since 1900, noticeable increase in surface runoff has been observed worldwide (Piao et al., 2007). In addition to the direct effects of land use change, increased water abstraction for agriculture is one of the major threats to the freshwater ecosystems, rendering them highly vulnerable to the effects of climate change (Erol and Randhir, 2012). In Southern Europe, agriculture is the major water-using sector with a total freshwater abstraction share of 80% (EC, 2009). Thus, increased abstraction may lead to significant water level reductions (Beklioğlu et al., 2006; Beklioglu et al., 2007; Stefanidis & Papastergiadou, 2013). This may have a particularly strong effect on shallow lakes due to their high surface area/depth ratio (Coops et al., 2003). The ultimate result may be a complete drying out as exemplified by the drying out of one of the largest freshwater lakes in Turkey, Lake Akşehir (343 km^2), due to a major water diversion of its inflows for the purpose of intensive irrigation of croplands (Bahadır, 2013; Çatal and Dengiz, 2015; Sener et al., 2010). Further threats to the lakes are expected due to climate change-induced reduced water availability in summer, leading to increased irrigation in Southern Europe (Kalogeropoulos and Chalkias, 2013; Kovats et al., 2014). In addition, the projected demographic changes in the Mediterranean region, including increased population growth, summer tourism (Rico-Amoros et al., 2009) and urbanization, are expected to intensify the water usage by expanding the demands for agricultural products.

Water scarcity and frequent drought periods are likely to have high economic costs (Milano et al., 2013). During the last 20 years, droughts have created a significant economic deficit in the Mediterranean catchments (Erol and Randhir, 2012). This emphasizes the need to implement measures that maintain water sources and ensure sustainable water usage in order to meet the future water demands from different sectors (agriculture, human settlement, ecosystem need, energy, etc.) (Kovats et al., 2014). The cost of inaction and/or taking reactive actions would be much higher than those associated with adopting proactive measures (Collet et al., 2015; Palmer et al., 2008).

In this study, Lake Beyşehir, which is the largest freshwater lake in the Mediterranean basin and situated in the Western Taurus karstic region, was chosen to function as a model for Mediterranean lakes subjected to intense water use and climate change. Since the Mediterranean region is one of the most vulnerable regions in the world and its freshwater ecosystems are highly regulated, sustainable water management is crucial to preserve the water bodies and meet the water demand of society. Water scarcity issues are not limited to the Mediterranean basin; other parts of the world with a Mediterranean-type climate, such as south-west Australia (Reisinger et al., 2014), South Africa (Niang et al., 2014), and California (Romero-Lankao et al., 2014), all face similar issues, preventing water demands from being met in a projected future warmer climate. Hence, the aim of this study is to elucidate how multiple stressors – like climate change, land use, and water abstraction – will impact the future water availability and water levels in Mediterranean water bodies. This study not only contributes to the still limited number of climate change impact studies on Turkish and Mediterranean catchments, but it also presents a modeling framework for assisting water managers in planning mitigation strategies in the region. The knowledge gathered may provide insight into the development of sustainable systems for lake and reservoir management, bearing in mind the uncertainties in climatic predictions and how these relate to water availability and lake levels.

The main objectives of this study are: i) to quantify the effects of the projected changes in climate and land use on the water availability in the catchment of the largest Mediterranean lake, Lake Beyşehir, ii) to evaluate the effects of the projected climate and land use scenarios on the lake water level, iii) to offer outflow management options by predicting the maximum outflow (maximum abstraction loss) permitted for maintenance of natural lake water levels as a viable adaptation measure to climate change.

3.2 Material and Methods

3.2.1 Study site

Lake Beyşehir (area: 650 km^2, max. depth: 8-9 m, mean depth: 5-6 m) is located in Isparta and Konya provinces in the southwestern part of Turkey (between 31°17'-31° 44' E, 37° 34'-37° 59' N). The lake has had a Natural Site protection status since 1991 and is surrounded by two National Parks (the Beyşehir and Kızıldağ National Parks, Republic of Turkey, Ministry of Forestry and Water Affairs). The lake is also an "Important Bird Area" (BirdLife International, 2015), an "Important Plant Area" (PlantLife International, 2015), and it hosts the endemic fish species *Chondrostoma beysehirense* Bogutskaya, 1997 and *Pseudophoxinus anatolicus* Hankó, 1925. Until recently, it also functioned as a habitat for the extinct endemic species *Alburnus akili* Battalgil, 1942 (Yeğen et al., 2006).

The catchment area of the lake is 4704 km^2 and includes an upstream area of the Konya Closed Basin (area: 49805 km^2, population size: 2.6 million) (Ayaz, 2010) (Figure 3.1). The lake is the main water source for irrigated crop farming in the Konya Closed Basin. The catchment is situated in the transition zone between the Mediterranean and continental climates (average temperature: 11 ± 0.7 °C, yearly precipitation 490 ± 94 mm, calculated from measurements conducted by the Turkish State Meteorological Service in the Beyşehir district during 1960-2012). The catchment has a highly variable topography and land use characteristics. The elevation ranges between 1027 and 2958 m.a.s.l., with an average elevation of 1370 m. The northern and eastern parts of the catchment are flat and intensively used for crop farming, while the western part of the catchment is dominated by mountains covered with forests and small areas of low-intensity agriculture. Nearly half of the catchment (42.7%) is covered by range-brush, 25.5% by agricultural land, and 13.5% by water (including Lake Beyşehir, the inflows, and wetlands), while forested areas (evergreen and deciduous forests) constitute 11.2% (Figure 3.1).

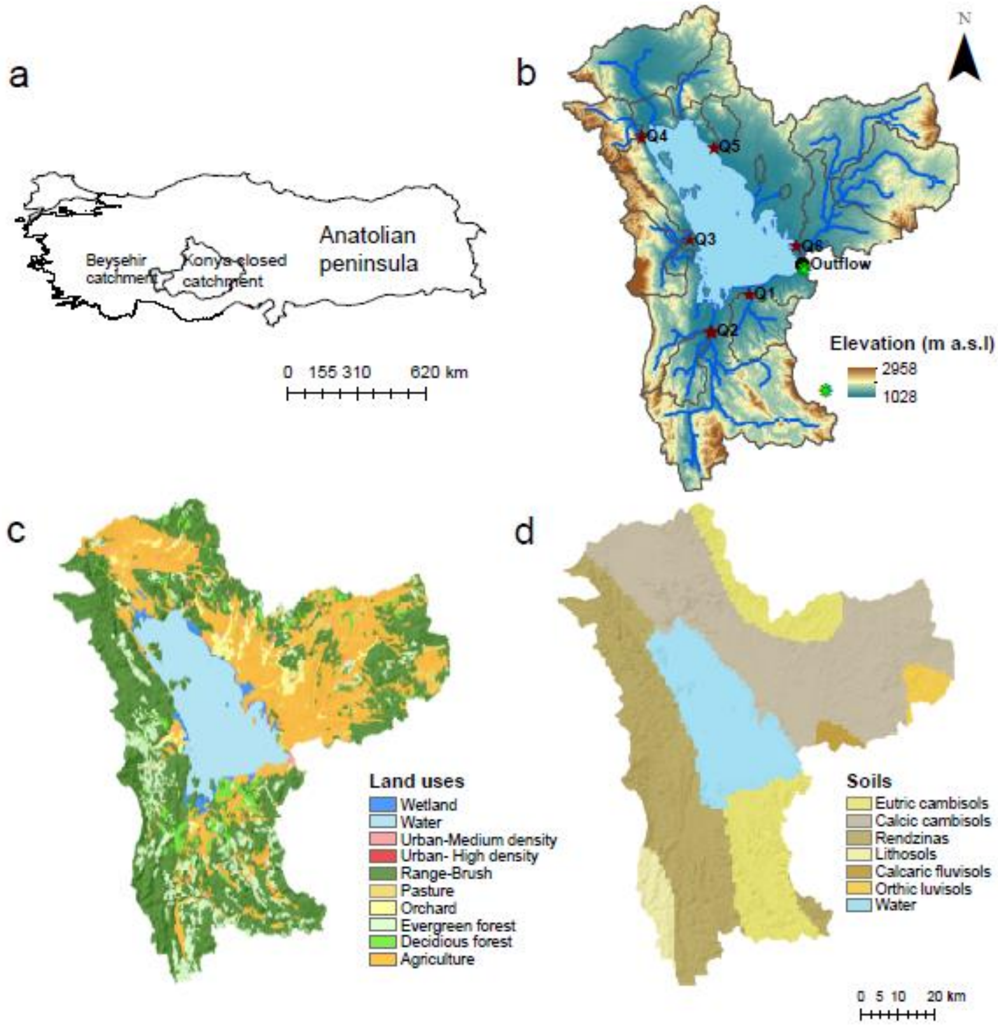

Figure 3.1 Location of the study site and GIS layers used in the SWAT model. (a) Location of the study site; (b) digital elevation map of the Beyşehir catchment. Brown borders show the sub-catchment boundaries. Numbers indicate the inflows (local names of inflows are: Q1: Üstünler, Q2: Soğuksu, Q3: Hizar, Q4: Çeltek, Q5: Tolca-Ozan, Q6: Sarısu) used in the calibration, the black circle shows the outflow, green symbol indicates the meteorology station; (c) distribution of land use categories; (d) soil map.

The Western Taurus region, where the lake is located, is one of the most important karstic areas in Turkey (Hoşafçıoğlu, 2007). The lake is primarily fed by streams from the Sultan and Anamas Mountains on the eastern and western sides, respectively, and by springs from mesozoic limestone sinkholes, groundwater, and direct precipitation (Figure 3.1). The lake has 13 inflows, of which five are permanent and flow throughout the year, while the remaining are intermittent and dry up during summer (Hoşafçıoğlu, 2007). Since the lake water is intensively used for irrigating the downstream area of Konya Closed Basin, a regulator is being used to control the lake's outflow.

According to the data collected by the State Hydraulic Works between 1960 and 2012, the lake's monthly average water input (including precipitation, inflows, and groundwater) is 90.8 ± 72 hm^3, and surface evaporation is 83.4 ± 35 hm^3. Average monthly water abstraction for irrigation of the downstream basin is 23.9 ± 27 hm^3. Lake Beyşehir is also being used as a major drinking water supply for the Beyşehir district; however, the proportion of water used for drinking is of minor importance (annual average of 6 hm^3). Within the framework of an inter-basin water transfer project implemented in 2009, 130 hm^3 water per year is diverted from the Derebucak basin to the lake (DSİ, 2012). The groundwater is also heavily exploited for irrigation in the catchment through the uncontrolled and unregistered wells, creating uncertainty in the estimation of the overall water budget (Mercan, 2006).

3.2.2 Modeling

Modeling of hydrological components in karstic catchments is a challenging task that involves many uncertainties. The structures of karstic aquifers, having a high level of spatial heterogeneity and containing permeable networks of conduits, determine the hydrological behavior of the catchment and complicate the estimation of flow dynamics (Jaquet et al., 2004). In karstic areas, groundwater constitutes the most significant proportion of river flow, and karstic aquifers may form a large number of temporary/ephemeral small streams (Kourgialas et al., 2010). In addition, in regions where the groundwater network is extensive, there may be contributions and/or loss of water from outside the catchment boundaries (Nikolaidis et al., 2013). All these factors may complicate the prediction of flows in karstic catchments using topographical catchment models. Several attempts have recently been made to consider karstic geomorphology in catchment modeling using Soil and Water Assessment Tool (SWAT) (Amin et al., 2016; Kourgialas et al., 2010; Nikolaidis et al., 2013).

In this study, SWAT model was used to elucidate the potential impacts of the future climate changes and the various land use practices on the hydrological balance of the Lake Beyşehir catchment. Using the outputs of the SWAT model (total runoff, potential evapotranspiration), the outflow rate, and precipitation, the Support Vector Regression Model (ε-SVR) (Vapnik, 1995) was run to estimate the water level of the lake in response to future scenarios of both climate and land use changes. Considering the predicted water level values, the maximum outflow (maximum abstraction) volumes to sustain natural lake levels were also calculated for each climate change scenario.

3.2.2.1 SWAT

3.2.2.1.1 Model description

SWAT model (SWAT 2012, Revision 622) (Arnold et al., 1998) is a catchment (river basin) model and it was developed to quantify the impacts of land management practices on surface waters by simulating evapotranspiration, plant growth, infiltration, percolation, runoff and nutrient loads, and erosion (Neitsch et al., 2011). SWAT is a physically based, semi-distributed model, which has been tested (e.g. for agricultural water management purposes) and discussed extensively in literature (Gassman et al., 2007).

Catchment processes in SWAT are modeled in two phases – the land phase, covering the loadings of water, sediment, nutrients, and pesticides from all sub-basins to a main channel, and the water routing phase, covering processes in the main channel to the catchment outlet (Neitsch et al., 2011). In SWAT, the "catchment" is further divided into sub-basins and Hydrologic Response Units (HRUs), of which the latter are unique combinations of land use, soil, and slope.

In the model, the hydrological balance is calculated as:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \qquad (1)$$

where SW_t is the soil water content at time *t* (mm H_2O), R_{day} is the precipitation on day i, Q_{surf} is the surface runoff on day *i* (mm H_2O), E_a is the evapotranspiration on day i, (mm H_2O), w_{seep} is the amount of the seepage to the vadose zone from soil profile on day i (mm H_2O), Q_{gw} is the amount of return flow on day i (mm H_2O), and SW_0 is the initial soil water content.

3.2.2.1.2 Model parameterization and data sources

For parameterization of the SWAT model for the Lake Beyşehir catchment, the following data were used:

- Digital Elevation Model: ASTER (30 m resolution, http://gdex.cr.usgs.gov/gdex/) DEM was smoothed to 90 m resolution and then burned into a river network (based on the known locations of reaches and the lake surface). Delineation of the stream network was conducted with a threshold area of 500 ha. The delineation resulted in 16 sub-basins (Figure 3.1). Three slope intervals (less or equal to 5%, 5-20%, greater than 20%) were defined.
- Land use: Data were obtained from the Corine 2006 database (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-

raster) at 100 m resolution (Figure 3.1). Land use and agricultural management were described by splitting the generic agricultural (AGRL in SWAT nomenclature) areas into four dominant crop management systems (winter wheat: 41%, winter barley: 31%, chick peas: 24%, sugar beet: 4%) based on data obtained from local authorities and the Turkish Statistical Institute (TÜİK, 2013). Agricultural management schedules were generated after consultation with local experts (Appendix B, Table B.1).

- Soil map: Harmonized World Soil Database with 1 km resolution was used (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML) (Figure 3.1). Soil hydrological and physical parameters were initially derived from soil texture data using the Hypres model (Wösten, 2000).

- Climate: Meteorological data on precipitation, minimum and maximum temperature, wind, solar radiation, and relative humidity were compiled from the Turkish State Meteorological Service (www.mgm.gov.tr) between 1960-2012 for the Beyşehir (37° 41' N, 31° 44' E) and Seydişehir (37° 26'N, 31° 51'E) stations located in the south-eastern parts of the catchment (Figure 3.1).

- Hydrological response units (HRUs) were defined by 0%-0%-0% threshold values for land use, soil, slope, and overlay of the maps gave 714 HRUs. The Penman-Monteith method (Monteith, 1964) was used for estimating potential evapotranspiration, and surface runoff was calculated using the U.S. Soil Conservation Service curve number procedure (USDA-Soil Conservation Service, 1972). The elevation range was divided into five elevation bands with an elevation fraction of 0.2 to account for the effects of the wide elevation gradient in the catchment.

- Flow data used for the calibration was compiled from the State Hydraulic Works (DSI). The model was initially set up for the years 1991-2011 and the initial four years of the data were used as a warm-up period to minimize the effects of the uncertainty relating to initial conditions in water balance. The most recent data from the period 2002 to 2011 (comprising the most complete dataset with only few missing values) were used for the calibration, and the data from 1995 to 2001 were used for validation. Long-term flow-gauged measurements were only available for six of the thirteen inflows.

3.2.2.1.3 Model implementation

Following the model setup, the most sensitive parameters were determined using the one-at-a-time method, where one parameter is changed at a time, while the other parameters remain unchanged. Every parameter was adjusted within a ±20% interval, and if a statistically significant change ($p<0.05$) was observed within this interval, the parameter was included in the subsequent calibration process.

The Soil and Water Assessment Tool Calibration and Uncertainty Analysis Program (SWAT-CUP) (Abbaspour, 2013), developed for calibration of the SWAT model, was employed for calibration. Calibration of discharge rates was performed using the Sequential Uncertainty Fitting (SUFI-2) procedure as described by Abbaspour et al., (2007), implemented in SWAT-CUP. During the calibration processes, Nash-Sutcliffe model efficiency coefficient (NS) was used as an objective function. According to the review by Moriasi et al., (2007), in which model evaluation criteria metrics were quantified based on the performance ratings used in the literature, NS coefficients over 0.5 are considered satisfactory for a monthly flow calibration. In this study, calibration was conducted on a daily time step and statistics were calculated on both a daily and a monthly basis. Detailed descriptions of model evaluation criteria used in this study are given in Appendix C.

In order to predict the effects of climate and land use scenarios on total runoff, the calibrated SWAT setup for the Beyşehir catchment was run from 2012 to 2099 for the different scenarios described in 3.2.3. In addition, the monthly averages of total runoff were compared to evaluate the potential shifts in seasonality. Contributions of baseflow, potential evapotranspiration and actual evapotranspiration were also compared. Mann-Whitney U test was employed for the comparisons of baseline and future hydrological variables.

3.2.2.2 Support Vector Regression (ε-SVR)

3.2.2.2.1 Model description

Support Vector Machines (SVMs) is a machine learning technique that can be applied to both classification and regression problems (Vapnik, 1995). Recently, it has been used within different research areas including the prediction of water level changes (Büyükyildiz et al., 2014; Çimen and Kisi, 2009). One advantage of SVM is that it embodies the structural risk minimization (SRM) principle. In ε-SVR, the main aim is to find the function with the maximum possible deviation (ε) from targets in training data (preventing overfitting); however, the errors must always be smaller than ε (Schölkopf et al., 1998). Hence, the SRM principle in SVMs not only enables minimization of the training error, but also minimizes the generalization error, which is the capacity of the model to forecast the unseen test data.

In this study, we used the ε-insensitive loss function which is described as (Raghavendra and Deka, 2014; Vapnik, 1995):

$$L_{\varepsilon}\big(v, g(u)\big) = \begin{cases} 0 & |v - g(u)| \leq \varepsilon \\ |v - g(u)| - \varepsilon & otherwise \end{cases}$$

where $L_\varepsilon\big(v, g(u)\big)$ is the loss function, which is the deviation of the estimated values from the observed values, v is the observed output vector, u is the input vector, and $g(u)$ is the vector of predicted values. The aim is to find the model with the highest error tolerance (ε) while keeping the model as flat as possible via using the ε-sensitive function. The regression problem can be defined as:

$$g(u) = w.u + b$$

where b is the bias term, and w is the vector of regression coefficients. In order to prevent overfitting and enabling flatness of the solution, $||w||^2$ should be minimized, and the regression problem can be expressed in terms of convex optimization problem.

$$min_{w,b,\xi,\xi^*} \quad \frac{1}{2}||w||^2 + C\sum_{i=1}^{n}(\xi_i + \xi_i^*)$$

$$v_i - (w * u_i + b) \leq \varepsilon + \xi_i$$

Subject to $(w.u_i + b) - v_i \leq \varepsilon + \xi_i^*$

$$\xi_i, \xi_i^* \geq 0, \mathrm{i} = 1,2, \dots, \mathrm{n}$$

The terms added here, ξ_i, ξ_i^*, are slack variables and they represent the deviation outside the ε-insensitive zone. Parameter C stands for the degree of penalizing loss for the training error. In order to prevent under-/overfitting, in addition to $||w||^2$, $C\sum_{i=1}^{n}(\xi_i + \xi_i^*)$ should also be minimized. Hence, parameter C and ε influence the model smoothness and complexity. While smaller C and greater ε result in underfitting, the opposite results in overfitting. The above formulation is referred to as linear SVM (Raghavendra and Deka, 2014). Linear SVM can be converted to nonlinear SVM by mapping the original low-dimensional input space into a high-dimensional feature space (Hilbert space) using non-linear functions, which are called kernels. In this study, the radial basis function (RBF) kernel was used:

$$K(x, x') = \exp(-\gamma \|x - x'\|^2)$$

where γ is the width of the RBF kernel and indicates the spread of the independent variables in the training dataset.

3.2.2.2.2 Model application

Given the karstic nature of the Lake Beyşehir catchment, the limited availability of observational data (for inflows and precipitation), and the uncontrolled water abstraction, it is difficult to calculate a simple water budget and to predict future water levels. Although evaporation constitutes a major component of a lake's water budget, predicting the future evaporation from water surface is difficult, since data on the corresponding lake surface areas are needed. Consequently, SWAT outputs of potential evapotranspiration (PET) levels (for the sub-basin including the lake) were used as a surrogate for evaporation from the lake surface. ε-SVR technique was applied using the radial basis kernel function. Precipitation, outflow volume, and SWAT outputs of PET and inflows were used as inputs for the ε-SVR model. The ε-SVR model was trained for the period 1975-1985. Data from the period 1985-1990 were then used as the testing period to validate the model for water level. When applying ε-SVR, optimized values for the error term (ε), configuration factor (C), and gamma parameter (γ) were sought to identify the best match between the observed and simulated values using ORANGE software 2.7 (Demsar et al., 2013). The performance of the ε-SVR was evaluated by using the NS value, mean absolute error (MAE), root mean square error (RMSE), and percent bias (PBIAS) (Appendix C). The cumulative sum of the monthly water level changes was derived to predict the water level, as the ε-SVR model outputs are monthly water level changes.

Water input from Derebucak water transfer project was also considered in the ε-SVR simulations. Between 2009 and 2012, a yearly average of 130 hm^3, approximately 15% of the total inflow, was added to Lake Beyşehir through this water transfer project. Assuming that the lake will also be fed by trans-basin diverted water in the future, future stream inputs (inflow rates derived from SWAT) were multiplied by 1.15 before being provided to the ε-SVR model as an input. Average monthly outflow values were calculated for each month using the data from 1960-2012, and the derived monthly values were used as a fixed monthly water withdrawal rate in the future scenarios. The year 2012 was used as the starting time (time=0, initial water level=8.24 m) for future simulations, and the water level change was simulated from 2012 to 2099.

Since the training data represented a limited water level range (7.37 m - 10.51m), the ε-SVR model is in principle only valid within this range. Therefore, shrinking or expanding the lake area beyond the water level range may lead to over-prediction or under-prediction of the water level. Hence, after calculating the cumulative water level in future scenarios, the calculated water level was corrected using the information on the hypsometric curve of the lake. The corrected water level was calculated via multiplying the water level by the ratio of the area corresponding to the calculated water level and the average area of the lake during the training period.

3.2.2.2.3 Predicting maximum outflow

After running the ε-SVR model for all climate and land use scenarios with default outflow rates, additional runs were performed in order to estimate the maximum outflow volume to obtain an average water level change of ±0.5 m for the whole time period. Maximum outflow volume estimation is needed for maintaining the irrigation of the downstream catchment, preventing the lake from having extreme water level reductions and drying out. The maximum outflow in the simulation was computed by decreasing the default outflow by 5 to 75% (for 1% increments) and running the ε-SVR model for each outflow iteration. This process was applied to each climate scenario. In the outflow iterations, the outflow reduction was not considered as a fixed rate throughout the simulation period; instead, the yearly changes in the water level output of each climate scenario were considered. For this purpose, the water level outputs generated in the different climate change scenarios (from previous runs with default outflow) were split into yearly time periods, and the yearly average water level change was calculated. The yearly averages were divided by the average water level change for the whole time period. This way, it became possible to estimate the magnitude of the yearly water level change relative to the overall average change. Next, different weights of outflow reductions were given to different years according to the magnitude of the water level change.

3.2.3 Scenarios

3.2.3.1 Climate change

Climate change scenarios were based on the data provided by the Turkish Meteorological Service (www.mgm.gov.tr). Two General Circulation Models (GCMs: HadGEM2-ES (HadGEM) and MPI-ESM-MR (MPI)), representing the contemporary climate dynamics of Turkey (Demir et al., 2013), were used with two Representative Concentration Pathways (RCP 4.5 & RCP 8.5). RCP 4.5 assumes that greenhouse gas (GHG) emission will peak around 2040, followed by a decline, while RCP 8.5 assumes that emissions will increase throughout the 21st century. The climate models were dynamically downscaled for the period 2013 to 2099 at a 20 km resolution using the RegCM 4.3.4 Regional Climate Model (Demir et al., 2013). The entire period was simulated in the climate change scenarios.

Bias correction was applied on temperature and precipitation by using the quantile mapping methods described by Piani et al., (2010). The period 1970-2000 was selected as a reference for the baseline simulation and for bias correction of the climatic outputs. Bias correction was conducted using the qmap R package (Gudmundsson, 2014; Gudmundsson et al., 2012) to find the best match between the observed values and simulated time series for the reference time period. RQUANT function (Gudmundsson et al., 2012) was used to estimate the values of quantile-quantile relationships between the observed and simulated climate time series for regularly spaced quantiles using local linear least square regression. Comparison statistics and graphs for observed and bias-corrected temperature and precipitation are given in Appendix D.Transfer functions derived from correction of the baseline period were also used for generating future bias-corrected data. For other meteorological variables (wind speed, relative humidity, solar radiation), the SWAT weather generator was used to generate future daily values based on statistics of the baseline climate.

The future scenarios showed yearly average increases in temperature, with values ranging between 1.5 to 4.0 ^{o}C. In the RCP 8.5 scenarios, the results of both climate models exhibited a noticeable temperature increase compared to the RCP 4.5 scenarios (Appendix B, Table B.2), the increase being higher for the HadGEM model than for the MPI model. Monthly average differences in temperature for the baseline period and the future projections are given in Appendix B, Table B.2.

The MPI model with the RCP 8.5 scenario projected an 82 mm decrease in total annual precipitation, whereas a 35 mm decrease was projected for the RCP 4.5 scenario. In addition, there was a decrease in precipitation for all months except for November and December, in which the level of precipitation increased slightly. For the HadGEM model with the RCP 4.5 scenario, a 10 mm increase in precipitation was projected, being concentrated in winter and spring. The HadGEM model with the RCP 8.5 scenario showed a slight decrease in precipitation (6 mm); however, there was an increase in precipitation in January, May, and June (Appendix B, Table B.3).

3.2.3.2 Combined Land use and Climate Change Scenarios

Four land use scenarios (LU) and two outflow scenarios were generated. First, climate change scenarios were applied without any change in land use. Next, each land use scenario was combined with different climate change scenarios. A simplistic static land use change approach was employed to integrate the land use scenarios, assuming a constant land use change for the whole simulation period. The simulated land use and outflow scenarios are listed as:

- *LU1:* Sugar beet farming has increased in the catchment (TÜİK, 2013) and has high economic value due to a well-functioning local infrastructure for industrial processing of the crop. Presumably, sugar beet farming areas will increase in the future. Therefore, in this scenario, 20% of the total cultivated area of wheat and barley was replaced by sugar beet.

- *LU2:* Climate change may alter the natural vegetation. Increasing temperature and decreasing precipitation may trigger a shift from forest to shrubland (Anderson, 1991). Therefore, in this scenario, 25% of the forest area was converted to shrubland.

- *LU3:* The extent of agricultural areas in Europe is expected to decrease, particularly in Southern Europe, and this situation may result in land abandonment (Brown, 2011). Therefore, in this scenario, 20% of the agricultural land was abandoned followed by a shift to shrubland.

- *LU4:* To contrary to LU3, the extent of agricultural areas may also expected to increase to satisfy the needs of an increasing population (Rico-Amoros et al., 2009). Therefore, in this scenario, a generic increase in agricultural area was assumed and 20% shrubland was converted to agricultural land.

- *Increased outflow scenarios* (*OUT10 and OUT20)*: Outflow from Lake Beyşehir is used for irrigation of a 770 km^2 area in its downstream catchment and is the most important surface water resource for irrigation. Since sugar beet farming has an increasing trend in the downstream catchment, the demand for irrigation water may increase in the future. How an increased water demand for downstream irrigation would affect the water level of the lake was simulated. Hence, generic water demand scenarios, in which the outflow was increased by 10% and 20%, were developed.

3.3 Results

3.3.1 Performance of the models

3.3.1.1 SWAT model

The most sensitive parameters used during the calibration are shown in Appendix B, Table B.4. Snowmelt and groundwater parameters were found to be highly sensitive.

Results of the calibration and validation of the flow rates for the main lake inflows are shown in Figure 3.2. SWAT was able to capture most of the seasonal variation in discharge values. Three of the inflows located close to the meteorological stations in the catchment exhibited NS values higher than 0.5, while NS values were around 0.5 for the remaining inflows. In addition, the Üstünler (Q1) and Hizar (Q3) rivers (Figure 3.1, Figure 3.2), which are located in the western part of the catchment, had lower NS values, and generally lower discharge rates as well. Their contribution to the lake water budget was minor relative to that of the other rivers (Table 3.1).

For the validation period, the performance of the model for the flows were satisfactory, except for the Hizar River. Although the model performance for baseflows was generally good, it did not fully capture a few of the peak flows. Performance statistics (NS coefficient and Bias %) are given in Table 3.1. After the model calibration, groundwater contribution (lateral + groundwater flow) constituted the major part of the total runoff, while the surface runoff comprised about 15-20% of total runoff.

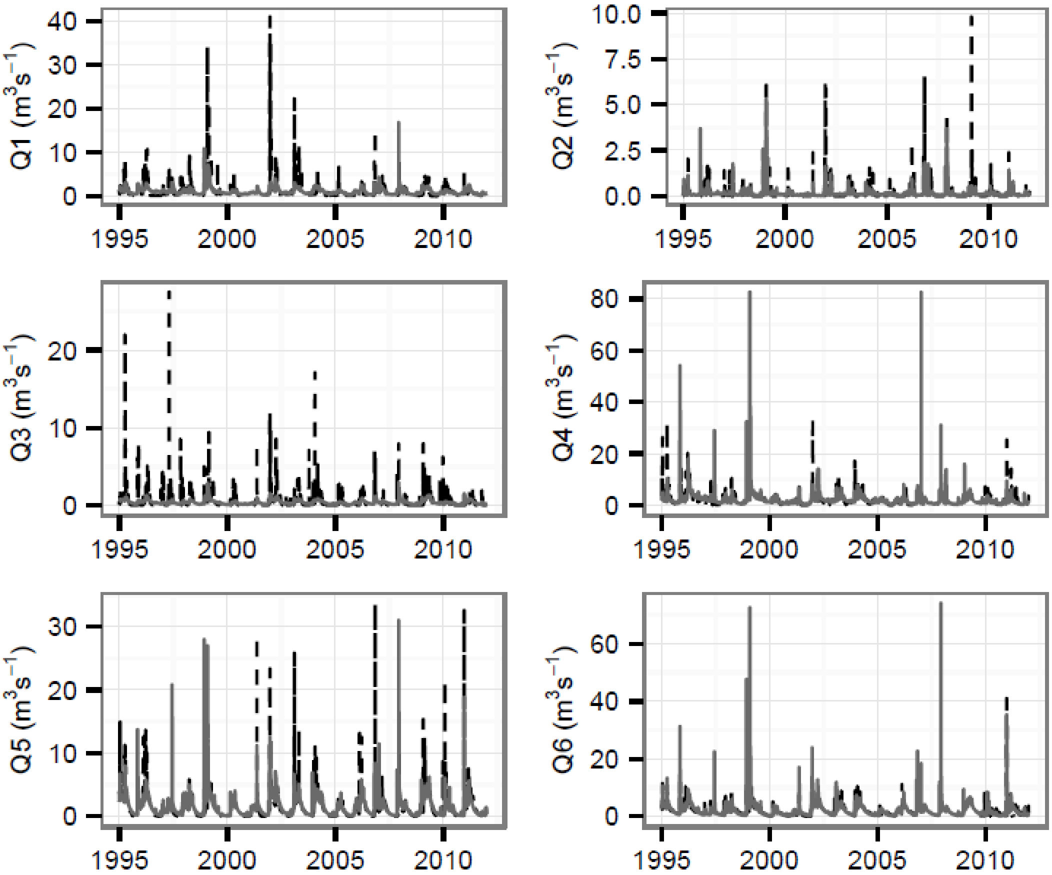

Figure 3.2 Calibration and validation results. Daily simulated (gray, solid lines) and observed (black, dashed lines) flows after calibration of the SWAT model. Q1: Üstünler, Q2: Soğuksu, Q3:Hizar, Q4: Çeltek, Q5: Tolca-Ozan, Q6: Sarısu. X axis indicates dates.

Table 3.1 Daily and monthly performance statistics for the main inflows. Calibration period = 2002-2011; validation period = 1995-2001. Mean values for the simulated and observed periods are in $m^3 s^{-1}$.

	Calibration								Validation							
Station	Monthly			Daily			Observed	Simulated	Monthly			Daily			Observed	Simulated
Name	NS	R^2	PBIAS	NS	PBIAS	R^2	mean	mean	NS	R^2	PBIAS	NS	R^2	PBIAS	mean	mean
Q1	0.4	0.42	-11.7	0.28	-14.4	0.28	0.88	0.99	0.49	0.51	5.6	0.23	0.24	1.7	1.24	1.17
Q2	0.37	0.38	1.3	0.23	-2.2	0.24	0.12	0.12	0.54	0.56	-29.8	0.19	0.32	-36.1	0.1	0.13
Q3	0.48	0.56	8	0.27	4.3	0.25	0.42	0.39	0.25	0.35	26.9	0.1	0.12	27.8	0.54	0.4
Q4	0.51	0.52	2.6	0.44	-1.9	0.44	1.9	1.85	0.57	0.6	12.1	0.02	0.21	0.6	2.43	2.13
Q5	0.73	0.73	-0.9	0.53	-1.8	0.53	1.39	1.41	0.71	0.74	-7.6	0.48	0.49	-9.9	1.44	1.55
Q6	0.76	0.77	-2.4	0.61	8.1	0.63	2.1	2.15	0.65	0.78	-12.9	-0.29	0.48	-18.3	1.93	2.17

3.3.1.2 Modeling the water levels using ε-SVR

The best fit between the modeled and the observed water level change (Figure 3.3) appeared with the parameter combination of C=32, ε=0.05, γ= 0.5 with the radial basis kernel function. Based on the scores in the training and validation data, it can be concluded that the model captured the observed trends. The NS value was 0.86, MAE was 0.055 m, RMSE was 0.06 m, and PBIAS was 0.2% for the training period. In the validation period, the values changed slightly to 0.93, 0.05 m, 0.04 m. and 14%, respectively.

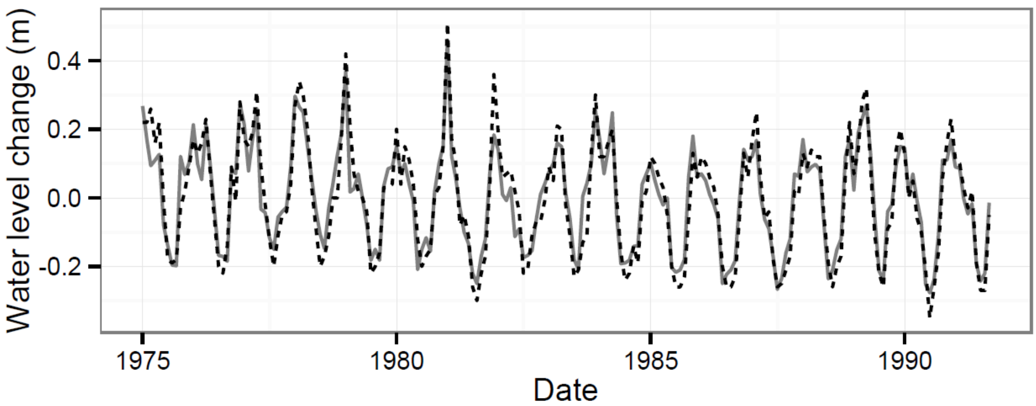

Figure 3.3 Observed and modeled water level changes in the ε-SVR model. Data from 1975 to 1984 were used for the training period and 1985-1990 data were used for the validation period. Solid line indicates modeled water level change, dashed lines indicate observed

3.3.2 Effects of the climate change and land use scenarios on water availability

3.3.2.1 Baseline simulations

Baseline simulations were run for the time period 1971-2000, and an annual average runoff of 89.62 mm was generated for the whole catchment (Table 3.). Baseflow constituted the major input as 44% of the total flow was generated from lateral flow (interflow) and 37.5% from return (groundwater) flow. On the other hand, surface runoff constituted 18.5% of the total flow. Evapotranspiration constituted most of the water loss, the average evapotranspiration and precipitation (including snowfall) being 431 mm and 541 mm, respectively (Table 3.2).

Table 3.2 Catchment water balance for baseline and future periods. Values are rounded to the nearest integer. PCP: Precipitation, ET: Evapotranspiration, PET: Potential Evapotranspiration, 4.5: RCP 4.5 scenario, 8.5: RCP 8.5 scenarios. Units of the variables are in mm.

Climate	Land use	PCP	ET	PET	Surface runoff	Groundwater
Baseline	Baseline	541	431	922	13	57
HadGEM 4.5	Baseline	512	455	1029	13	56
HadGEM 4.5	LU1	512	458	1029	12	56
HadGEM 4.5	LU2	512	456	1028	13	56
HadGEM 4.5	LU3	519	456	1041	13	59
HadGEM 4.5	LU4	503	455	1012	13	52
MPI 4.5	Baseline	465	421	988	12	50
MPI 4.5	LU1	465	425	988	12	50
MPI 4.5	LU2	465	421	987	12	49
MPI 4.5	LU3	471	421	999	12	52
MPI 4.5	LU4	457	421	972	12	46
HadGEM 8.5	Baseline	488	451	1081	13	52
HadGEM 8.5	LU1	488	455	1081	13	52
HadGEM 8.5	LU2	488	452	1081	13	51
HadGEM 8.5	LU3	494	452	1094	13	53
HadGEM 8.5	LU4	480	450	1064	14	48
MPI 8.5	Baseline	409	399	1048	10	42
MPI 8.5	LU1	409	404	1049	10	42
MPI 8.5	LU2	409	399	1049	10	42

3.3.2.2 Effects of the climate change scenarios

The MPI model outputs predicted higher reductions in total flow for the future compared to the HadGEM model for both RCPs (Figure 3.4). The RCP 8.5 scenario with MPI model projected that a significant decrease in runoff of up to 52% will occur at the end of the century (2071-2099) and a 18% decrease by 2070 (Table 3.2, Table 3.3). In the RCP 4.5 scenario, significant changes in flow were predicted, confidence exceeding 95% for the period until the 2040s and after the 2070s. However, for the 2040s period, the predicted 10% decrease was significant with a confidence score of 77% (Table 3.3, Figure 3.4). The MPI model outputs for both climate scenarios projected reduced surface runoff (7-18% for RCP 4.5 and RCP 8.5, respectively) and baseflow (15-28% for RCP 4.5 and RCP 8.5, respectively). Yearly increases in PET were 65 mm for the RCP 4.5 scenario and 125.2 mm for the RCP 8.5 scenario, and the increases were found to be particularly significant after the 2070s and the 2040s for the RCP 4.5 and RCP 8.5 scenarios, respectively (Table 3.3). No change appeared in actual evapotranspiration in the RCP 4.5 scenario, while a 23.2 mm decrease was found in the RCP 8.5 scenario due to reduced water availability (Table 3.2).

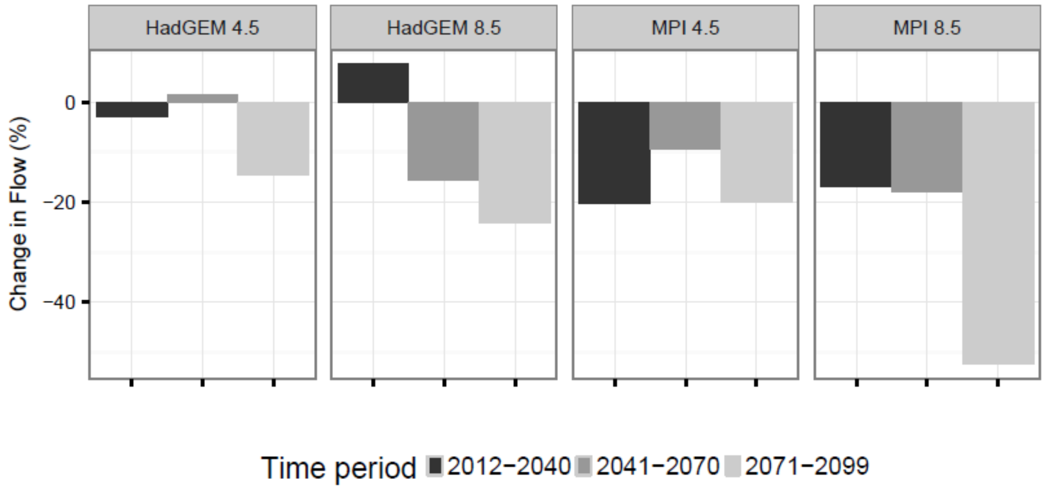

Figure 3.4 Changes in total flow compared with the baseline simulation for 2012-2040, 2041-2070 and 2071-2099 for the MPI and HadGEM climate change models and the RCP 4.5 and RCP 8.5 scenarios.

In the HadGEM model, the RCP 4.5 scenario exhibited slight differences in flow compared to the baseline period until 2070, while a 14% reduction (confidence > 95%) was projected for the period between 2071 and 2099. In the RCP 8.5 scenario, the HadGEM model generated a 7% runoff increase (with 71% confidence) at the beginning of the simulation period (2012-2041), followed by a future reduction of 15% and 24% (with confidence > 95%) in total runoff for the periods 2041-2070 and 2071-2099, respectively (Figure 3.4). Although average total flows were found to decline in general, the climate change projections demonstrated that their seasonality will change as well. Thus, winter flow rates were predicted to increase and spring flows to decrease (Appendix B, Figure B.1). The contribution of surface runoff displayed a slight increase of 2-4% in the HadGEM model outputs, whereas the baseflow contribution decreased between 3 and 11% in the RCP 4.5 and RCP 8.5 scenarios, respectively. An increase in potential evapotranspiration was found in for both scenarios, estimated as 107.2 mm and 159.7 mm, exceeding 67% confidence for all time periods, and increased actual evapotranspiration values of

17.6 mm and 13.5 mm were found in the RCP 4.5 and RCP 8.5 scenarios, respectively (Table 3.2).

Table 3.3 Confidence (%) that the precipitation, PET and runoff differed between future scenarios and baseline period. Confidence values larger than 67% are marked in bold.

	Scenarios	2012-2040	2041-2070	2071-2099
PCP	**HadGEM 4.5**	8	51	30
	MPI 4.5	**90**	9	**83**
	HadGEM 8.5	27	60	**68**
	MPI 8.5	**83**	**88**	**99**
PET	**HadGEM 4.5**	**75**	**90**	**98**
	MPI 4.5	57	63	**88**
	HadGEM 8.5	**78**	**99**	**99**
	MPI 8.5	57	**94**	**99**
Runoff	**HadGEM 4.5**	24	30	**98**
	MPI 4.5	**99**	**77**	**99**
	HadGEM 8.5	**71**	**98**	**99**
	MPI 8.5	**99**	**99**	**99**

3.3.2.3 Effects of the combined land use and climate change scenarios

The results of future simulations projected minor effects of the LU1 and LU2 scenarios on total flow. In contrast, the LU3 scenario demonstrated an increase in total flow compared to the other land use scenarios. Additionally, the LU4 scenario -the opposite of the LU3 scenario-, assuming an increase in agricultural land area, showed the highest total runoff decrease (7 to 14%) for the RCP 4.5 and RCP 8.5 scenarios, respectively, in the HadGEM model (Table 3.2). In the MPI model with the LU4 scenario, a decrease in runoff of 18% and 31% for the RCP 4.5 and RCP 8.5 scenarios, respectively (Table 3.2), were estimated. Slight differences were observed for the LU3 and LU4 scenarios compared to the climate change scenarios without land use change, although the confidence values were low (confidence < 67%) for all the land use scenarios.

3.3.3 Effects of the climate change and land use scenarios on water level

According to the scenario results, changes in precipitation, PET, and runoff in the catchment were predicted to create a notable reduction in the future water levels of Lake Beyşehir. Figure 3.5 shows the results of the cumulative water level change throughout the simulation period.

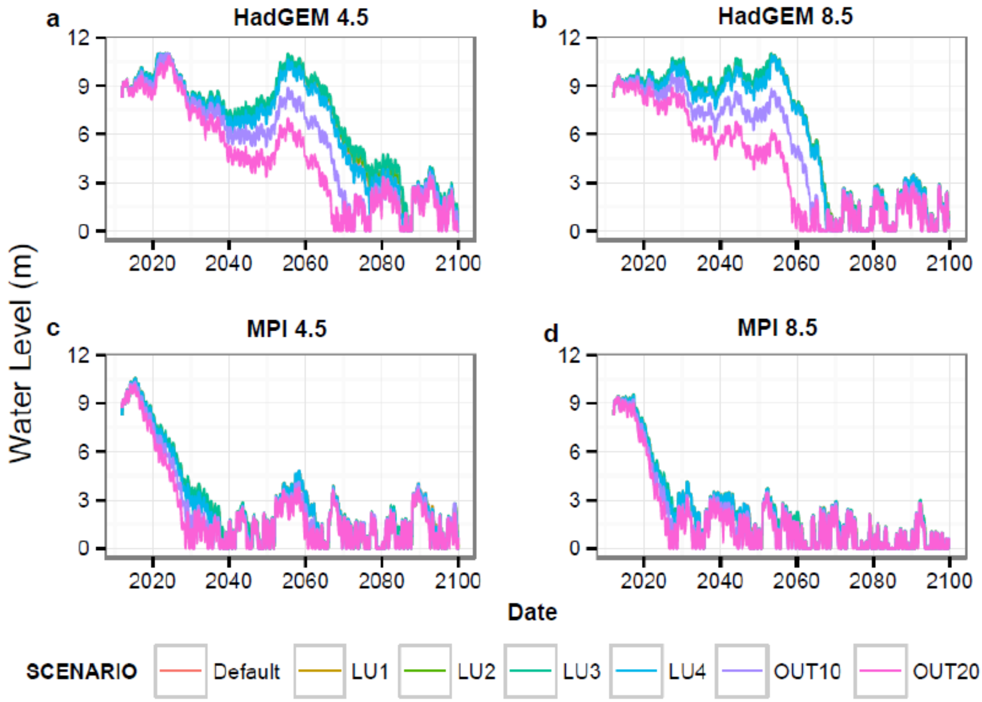

Figure 3.5 The changes in water level in Lake Beyşehir under different climate and land use scenarios during the simulation period for a) HadGEM model, RCP 4.5 scenario, b) HadGEM model, RCP 8.5 scenario, c) MPI model, RCP 4.5 scenario, d) MPI model, RCP 8.5 scena

According to the ε-SVR outputs, the MPI model projected a continuous water level reduction until the 2040s. After that period, the water level was estimated to fluctuate between 0 and 4 m if the current yearly average abstraction continues. According to the HadGEM model outputs, continuous water level decrease was projected to occur after the 2060s. Moreover, according to the HadGEM model with the RCP 8.5 scenario, the lake could dry out after the 2070s, while with RCP 4.5 scenario drying out of the lake might occur in the 2090s (Figure 3.5). After the 2070s, the water level was predicted to fluctuate between 0 and 3 m. No noticable impact on the water level appeared in the land use scenarios (Figure 3.5).

Scenarios with increased water abstraction through the outflow (OUT10, OUT20) in combination with the climate scenarios triggered a more notable water level decrease. The HadGEM model with the RCP 4.5 scenario predicted the first drying out to occur in the 2070s for both the OUT20 and the OUT10 cases. On the other hand, for the RCP 8.5 scenario drying out was predicted to occur in the 2060s in the OUT20 case and in the 2070s in the OUT10 case. For the MPI model with the RCP 4.5 and RCP 8.5 scenarios, the water level fluctuated between 0 and 4 m after the 2035s and the 2030s for OUT10 and OUT20, respectively (Figure 3.5).

3.3.4 Predicting the maximum outflow for sustainable water management

Maximum outflow volume was estimated to achieve an average water level fluctuation of ±0.5 m for the whole time period (Figure 3.6). The volume of the outflow water withdrawal for downstream irrigation should be reduced by, on average, 38% (120 hm^3) in the RCP 4.5 scenario, while a 60% (194 hm^3) reduction was required in the RCP 8.5 scenario. For the last 25 years of the future simulation period in RCP 8.5 scenario, the MPI modeled outflow volume should be set to zero to prevent a continuous water level decrease. For the HadGEM model, the estimated average yearly outflow volume reductions needed to maintain the average water level fluctuation of ±0.5 m were 9% (29 hm^3) and 26% (82 hm^3) for the RCP 4.5 and RCP 8.5 scenarios, respectively (Figure 3.6).

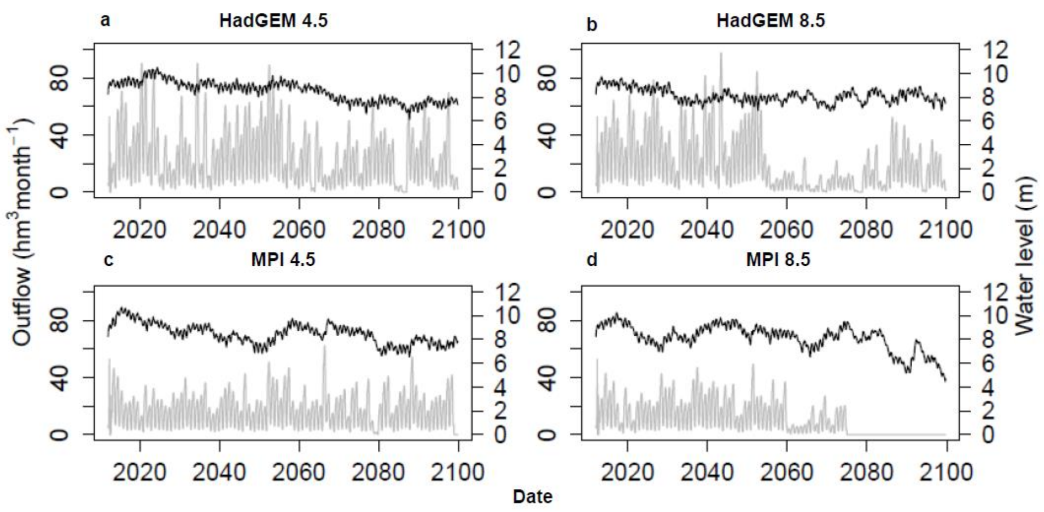

Figure 3.6 Monthly calculated outflow volumes and water level changes for a) HadGEM model, RCP 4.5 scenario, b) HadGEM model, RCP 8.5 scenario, c) MPI model, RCP 4.5 scenario, d) MPI model, RCP 8.5 scenario. Gray lines indicate the outflow and black lines indicate

3.4 Discussion

The key findings of this study were: (1) all climate change scenarios predicted a significant decrease in total runoff, however, the duration of the decrease varied among the models, (2) land use had a minor impact on total runoff compared to climate change scenarios, (3) potential evapotranspiration of the catchment could be used as an input variable for estimation of water levels when direct calculation of lake surface evaporation is unavailable, (4) changes in hydrological processes in the catchment and climate had notable impacts on water levels, since all climate change scenarios projected water level declines, (5) outflow volume reduction is critical to maintain the lake levels.

All the climate change scenarios predicted a significant decrease in the total runoff, which was projected to be more pronounced after the 2070s due to the reduced precipitation and enhanced potential evapotranspiration in the catchment lasting until the end of the century. However, the extent of the decrease varied among the models. The MPI model predicted a greater decrease in the runoff for both RCPs than does the HadGEM model due to a more pronounced reduction of precipitation and a lower water yield (Table 3.2). All flow components (baseflow and surface runoff contribution) exhibited declining trends in all scenarios. An exception is the RCP 8.5 scenario in the HadGEM model where a slight increase in the surface runoff contribution emerged. This was due to a minor increase in winter precipitation and low evapotranspiration, creating saturation of the soil and generation of surface runoff (Molina-Navarro et al., 2014; Morán-Tejeda et al., 2014). Decreased groundwater recharge (Table 3.2) can also be attributed to prolonged dry spells in summer, triggering a fast reduction of soil moisture (Ertürk et al., 2014; Sellami et al., 2016). Seasonal shifts in the hydrographs were associated with earlier snowmelt and reduced snowfall in winter (Arnell and Reynard, 1999; Morán-Tejeda et al., 2014), as well as higher winter temperatures (Appendix B, Table B.2). While an increase in both temperature and potential evapotranspiration were predicted in the future climate change scenarios, the slight decrease in actual evapotranspiration has been exhibited by the MPI model results. Decreased evapotranspiration can be attributed to reduced water availability in the soil, caused by decreased precipitation and augmented temperatures (Ertürk et al., 2014).

The results of many studies conducted in the Mediterranean region (Appendix B, Table B.5) concur with the findings presented here and show that additive effects of hydrologic processes such as precipitation and evaporation might spark a major reduction in total runoff (Cisneros Jiménez et al., 2014). A comprehensive work by Milano et al., (2013) demonstrated that 44 out of 73 catchments in the Mediterranean basin currently experience water stress, and by the 2050s the water stress will have been pronounced in areas already having severe water stress. These basins are mainly located in the Southern and Eastern Mediterranean where the highest demographic growth is predicted, further augmenting the future water demand. Also, other studies undertaken in the Mediterranean region have projected a major climate change-induced reduction in runoff at the end of the century (Ertürk et al., 2014; Molina-Navarro et al., 2014): 50-70% for Southern Turkey (Ertürk et al., 2014) and 22-49% for Spain (Molina-Navarro et al., 2014), the latter involving a 25-34% reduction in Catalan catchments (Pascual et al., 2015).

When interpreting modeling outcomes, it is necessary to consider uncertainties. The two GCMs used in the current study were able to model the trends of contemporary climate data; however, the precipitation and temperature predictions for the future varied widely. Although the direction and seasonality of the changes exhibited similar patterns, the magnitude of the changes differed between the climate models. A study by Maurer, (2007), simulating the Sierra Nevada Mountain hydrology using 11 GCMs, also found marked variations in precipitation predictions among GCMs. Moreover, in the detailed study of Wilby and Harris, (2006), four GCM models, two emission scenarios, two statistical downscaling techniques and two hydrological models have been considered as different sources of uncertainty, leading to the conclusion that the GCMs are the main sources of variation in simulating low flows. Hence, it is suggested to use of several GCMs and emission scenarios in climate impact studies (Eisner et al., 2012). In addition, pronounced variations in GCMs have a direct influence on total runoff, and variations in flow may be highly significant as well. For instance, Thompson et al., (2015) reported 0.8% to 52% reductions in annual runoff in their simulations for the Inner Niger Delta. Similarly, large variations in river discharges emerged in this study, from +7% to -20% by the 2040s, from +1% to -18% by the 2070s, and from -14% to -52% by the end of century due to variations in GCMs and RCPs. Usage of moderate (RCP 4.5) and extreme (RCP 8.5) GHG emission scenarios in this study, may have also amplified the variation of the predicted changes in water yield. In addition, using only temperature and precipitation scenarios in the model may have exaggerated the reduction in water availability since wind speed is an important component of PET calculations (McVicar et al., 2012a) and it shows a global decreasing pattern (McVicar et al., 2012b). In the view of the possible limitations and uncertainties, the results presented here should be interpreted with some caution.

Effects of land use management on total flow were minor in the LU1 and LU2 scenarios compared to the climate change scenarios. However, a slight increase in total flow appeared in the LU3 scenario with reduced agricultural area, due to a consequent decrease in irrigation. In LU4, agricultural expansion reduced the available water for runoff and caused a decrease in total flow with increased percolation and enhanced water consumption for irrigation (Ghaffari et al., 2010). Although the effects of land use scenarios were not significant, decreased runoff with agricultural expansion scenario may indicate an increased water demand for irrigation. This may further reduce the water availability in the Mediterranean region and exacerbate the already existing water stress. Efficient irrigation technologies and improved water distribution networks may compensate for the water stress to some extent but not fully eliminate the risk of climate change-induced water scarcity (Milano et al., 2013).

The minor impacts of land use changes on total flow compared to the effects of climate changes concur with the results from other studies on the Mediterranean climatic region (Molina-Navarro et al., 2014; Serpa et al., 2015). The predicted minor effect of land use may, however, in part be attributed to the selected hydrological model since uncertainty derived from the selection of hydrological models may be as large as that of GCMs (Prudhomme et al., 2014; Wada et al., 2013). Morán-Tejeda et al., (2014) compared the capability of SWAT and Regional Hydro-Ecologic Simulation System (RHESSys) models to simulate the effects of climate and land use changes on the catchment hydrology. They found out that SWAT simulations are more sensitive to climatic inputs, whereas climate and land use changes had similar effects on the total flow in the RHESSys model. Even though the models may yield similar outputs for current conditions, the inherent uncertainty and the nature of the models may create a difference in the magnitude of the projected changes (Butts et al., 2004; Krysanova and Arnold, 2008). When implementing land use changes, a static approach that assumes a constant land use change was used in this paper. Although dynamic approaches might produce more realistic results, there are only a small number of studies that use a dynamic land use model in SWAT (Wagner et al., 2016).

Lake evaporation constitutes a major discharge component of a lakes water budget (Duan and Bastiaanssen, 2015; Gianniou and Antonopoulos, 2007; Rosenberry et al., 2007). However, its calculation in simulations is challenging due to lack of information on how the lake area will change over the years. Thus, in the ε-SVR model, PET outputs of SWAT were used instead of evaporation and the model performed very well. Hence, despite the lack of lake area information, the ε-SVR model was able to simulate water level by using outflow, inflow, precipitation and PET as inputs. It should be borne in mind, however, that the complex karstic geology of the Lake Beyşehir catchment makes it difficult to interpret the uncertainties of the future water level simulations. In addition, the average outflow from the last 50 years was used for the future water level simulations and it was assumed that the outflow rates will be constant in the future. However, water level management is a dynamic process and the ongoing meteorological changes need to be considered in practice.

According to the projected water levels of Lake Beyşehir, this largest freshwater lake in the Mediterranean region may be in danger of drying out if the extensive use of water for irrigation in the areas downstream of the lake continues, considering that the climate is expected to get warmer and drier in future. Both climate models demonstrated severe water level reductions for all RCPs, and the MPI model showed an extended period of water level decrease due to reduced runoff and precipitation (Appendix B, Table B.3). Although the HadGEM model projected only a slight change in precipitation, increased temperatures and potential evapotranspiration triggered a large water loss through evaporation. These changes are likely to lead to a major water level decrease, especially after the 2060s. Additionally, all climate change scenarios projected periodic drying out of the lake and extreme water level fluctuations. Such changes may also have profound ecological consequences and threaten the biota (Coops et al., 2003), especially the endemic fish species (Micklin, 2007). Moreover, increased evaporation with reduced runoff may also cause salinization due to reduced flushing and enhance concentration of nutrients, changing the structure and dynamics of the lake ecosystem (Beklioğlu et al., 2006; Stefanidis & Papastergiadou, 2013; Jeppesen et al., 2015). Implementation of a strict water abstraction regulation policy is therefore required, since the estimations showed that an average reduction of 9-60% (according to different climate models and scenarios) in the outflow volume is necessary to prevent Lake Beyşehir from drying out. In addition, despite the fact that the outflow volume was set to zero for the last 25 years of the simulation period (2075-2099), the estimated water level continued to decrease in the MPI model with the RCP 8.5 scenario. Thus, in the most pessimistic scenario, no water abstraction strategy seems able to prevent the water level drop and the risk of salinization remains high due to the prolonged hydraulic residence time.

Lake management in arid and semi-arid regions is a challenging task as it requires addressing the increased demand for irrigation while simultaneously protecting water to satisfy the needs of the ecosystem. Most studies from the Mediterranean region highlight the reduced water availability and the increased demand for irrigation (Kovats et al., 2014) in the future, and the results on Lake Beyşehir are in line with those findings. In this study, the importance of outflow management is demonstrated by simulating the water level of largest lake of the Mediterranean region and estimating the outflow volumes required to sustain lake levels. The modeling framework proposed in this work can be used to establish time and cost-efficient mitigating measures for sustainable water resource management. Furthermore, this study recommends reducing the amount of water used for irrigation and using emerging agriculture technologies, such as drought-resistant crops and efficient irrigation technologies for overcoming the water scarcity problem.

To further expand the study and its validity, more GCMs with all possible RCPs can be used to reduce the uncertainties of the climate model. A detailed groundwater model for Lake Beyşehir can also be included to elucidate groundwater-surface water interactions and improve the representation of the water balance in the catchment.

3.5 Conclusions

In this study, the future water levels of Lake Beyşehir, the largest freshwater lake in the Mediterranean basin, was estimated using an integrated modeling approach that accounts for the impacts of climate and land use changes. The performance of the ε-SVR model indicated that potential evapotranspiration (PET) can be used as an input variable to simulate water levels when direct calculation of lake area is not possible. The results demonstrated that the water-scarce Mediterranean region may be at risk of losing its freshwater resources since the climate change scenarios projected a 15-52% reduction in total flows by the end of this century. In contrast, land use scenarios was not found to have significant impact on hydrology. However, the results of the agricultural expansion scenario showed that the combination of an increase in agricultural areas and an enhanced irrigation demand may further exacerbate the water stress. In all climate change simulations with the default outflow scenario, reduced inflows, diminished precipitation, and increased PET were shown to cause a severe water level decrease. The reduction in water level was estimated to be even worse in the increased outflow scenarios. Assuming an optimum water level management, a 9-60% reduction in outflow withdrawal was needed to prevent the lake from drying out by the end of this century. Albeit the current study has some limitations due to the choice of GCMs, emission scenarios, downscaling methods and structural uncertainties in the hydrological model, all the climate change projection results point out a decrease in water availability in the already water-limited Mediterranean catchments. Thus, the results presented here indicate the importance of managing outflows to prevent reduction of water resources in the Mediterranean region.

CHAPTER 4

MODELING THE EFFECTS OF CLIMATE CHANGE AND LAND USE ON ECOSYSTEM STRUCTURE OF LAKE BEYŞEHİR

4.1 Introduction

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, increasing number of studies used ecological lake models for management purposes, like 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). All these extensive research triggered the evolution of ecological lake models with the advancements from simple regressions to process-based complex dynamic models (Janssen et al., 2015).

Studies focusing 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 with its outcomes. Climate change is expected to affect lake ecosystem dynamics by altering the quantity and quality of freshwaters, possibly resulting in high ecological and economic loss (Erol and Randhir, 2012). According to the climate projections, Mediterranean climatic regions is one of the most sensitive areas in the world, and significant reduction in precipitation and increase in temperature anticipated for the future (Christensen et al., 2013; Erol and Randhir, 2012). Recent projections generated by the Turkish State Meteorological Office (Demir et al., 2013), demonstrated that the southern part of Turkey may be dramatically affected as climate scenarios anticipated a 3-4 °C increase in air temperatures and a 15-20% decrease in annual precipitation by the end of the century. It is also expected that demand for freshwaters for irrigation in Mediterranean region would increase with climate change, which may exacerbate the water stress together with climate change. However, less water availability may create a significant conflict in Mediterranean region on the usage of freshwater sources as well as ecosystem needs (Bucak et al., 2017).

Climate change is not only expected to decrease water availability in Mediterranean (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 catchments may decrease the external loading to the lakes. However, internal loading and water volume reduction due to higher evaporation may trigger nutrient increase (Beklioğlu et al., 2017; Coppens et al., 2016; Özen et al., 2010). Increased temperature and retention may change species composition of phytoplankton and duration of their blooms, likely resulting in earlier spring bloom (Carvalho et al., 2008; Paerl and Huisman, 2008; Reynolds et al., 1993) and longer duration of autumn bloom. Longer retention time also gives an advantage to cyanobacteria over green algae and diatoms (Visser et al., 2015), and prolonged cyanobacteria bloom limits the ecosystem services such as water supply for drinking or irrigation (Paerl et al., 2011). Trophic structure and community composition of the organisms can also be affected by climate warming as evidenced from studies covering large latitudinal and temperature gradients (Beklioğlu et al. in prep, Jeppesen et al., 2015, 2010).

Land and water use managements are essential to mitigate the impacts of climate change. In Mediterranean region, water availability, which shows high seasonal variability, determines the socio-economic structure (García-Ruiz et al., 2011). Intensive irrigation demand during the least water available season (Morán-Tejeda et al., 2014) pose a risk for freshwater ecosystems and may lead to significant water level reductions especially in shallow lakes, which have a high surface area/depth ratio, this in turn can result in degradation of ecosystem structure and function or services. Also, intensive farming can increase nutrient and sediment loads to freshwaters (Foley et al., 2005; Jeppesen et al., 2015, 2009). Increased nutrient enrichment is one of the major causes of eutrophication through its direct effects on Chl-*a* concentrations –indicator of phytoplankton- and indirect effects on oxygen depletion in the water bodies (Jeppesen et al., 2009). All these can result in degradation of water quality which cause loss of wide range of ecosystem services (Gordon et al., 2010)

Most of the lake modeling studies were built on single process-based models. However, ensemble modeling which is commonly employed in climatic studies is brought into play in lake modeling studies recently. Trolle et al. (2014) applied ensemble modeling for predicting chl-*a* concentration for the first time by ensembling three different lake ecosystem models in a single lake. This approach not only has a value in decreasing the model structural uncertainty in the simulations but also provides a possibility to compare different ecological processes schemes (Janssen et al., 2015) to develop better prediction powers. In the current study, the future ecological structure of the largest freshwater lake in Turkey, Lake Beyşehir, was simulated by linking catchment model outputs (SWAT) with two different processed based lake models: PCLake and GLM-AED. In this study, our first aim is to perform simulations to understand how climate change and land use practices affect the ecosystem structure and its service capacity of the lake, which are mainly drinking and irrigation water supply. We used proxies of TP, and total TN, Chl-*a*, cyanobacteria biomass, and water level for ecosystem structure of the lake. While water level is an indicator of the capacity the lake's water for using irrigation services; levels of nutrient, Chl-*a*, and cyanobacteria can indicate the capacity of lake's water for drinking supply. We also aim to uncover the uncertainties arising from the model selection and determine the effects of model selection on future predictions by using two different lake models and five different climate models,

4.2 Materials and Methods

4.2.1 Model Implementation

In the current study, combined approach of catchment and lake modeling was used for predicting the impacts of climate change and land use on Lake Beyşehir (see Chapter 2 for study site and data collection details). Modeling scheme was summarized in Figure 4.1. Hydraulic and nutrient loads were simulated through SWAT catchment model. Then outputs of SWAT (nutrient and hydraulic loads) and climate model outputs (temperature and precipitation) have been given to lake models in order to predict the future concentrations of TN, TP, Chl-*a*, cyanobacteria, and water level in the lake, indicating future ecosystem structure and services as drinking and irrigation water supply. For drinking water and recreation water standards, we adopted World Health Organization's (WHO) limits for cyanobacteria biomass. According to WHO's limits for cyanobacteria contribution to Chl-*a* concentration should be lower than 10 mg m^{-3}. Low-risk probability is defined as >10 mg m^{-3} and <50 mg m^{-3}, while high-risk probability is defined as > 50 mg m^{-3} (Chorus and Bartram, 1999).

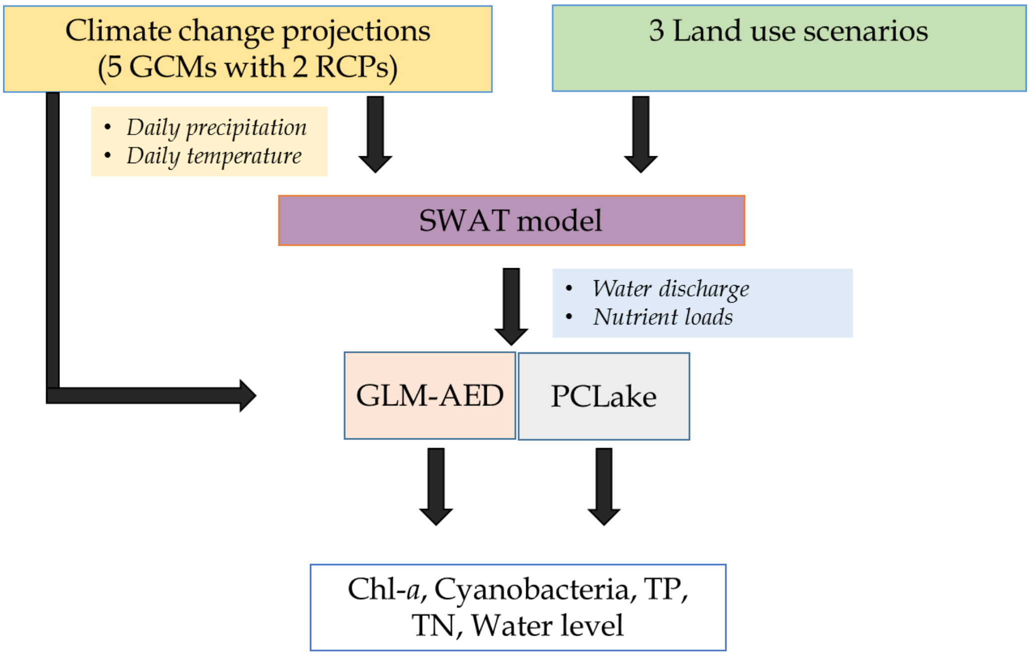

Figure 4.1 Modeling framework used in this study. GCM: General Circulation Model, RCP: Representative Concentrations Pathways, TP: Total Phosphorus, TN: Total Nitrogen, GLM-AED: General Lake Model coupled to Aquatic EcoDynamics Library.

4.2.1.1 SWAT

SWAT model was previously calibrated for hydrological processes of Lake Beyşehir catchment (Bucak et al., 2017). Detailed data requirements and the collected data for Lake Beyşehir SWAT implementation is given in section 3.2. In the current chapter, SWAT model was further calibrated to simulate nutrient processes in the catchment. The SWAT model was set up for 2010-2012 since only 2-year monthly monitoring data for nutrient loadings (P and N) from inflows was available. Nutrient calibration was conducted by SWAT-CUP software using the SUFI2 algorithm (Abbaspour, 2013). Calibration was performed for nitrate and SRP loadings. During calibration, percent bias (PBIAS) was used as an objective function. Most sensitive parameters for nutrient calibration and their fitted values are given in Table 4.1. While assessing model calibration, performance criteria that is developed by Moriasi et al., (2007) was used, in which for nutrient calibration, percent bias (PBIAS) being < ±25 can be regarded as *very good*, < ±40 as *good* and < ±70 as *satisfactory*. It should be noted that these criteria for calibration statistics are for monthly calibration results; while the results given in the current study are for daily calibration.

Table 4.1 Fitted parameter set of the calibrated SWAT-model for Lake Beyşehir catchment

Parameter	**Description**	**Fitted value**
PHOSKD	Phosphorus soil partitioning coefficient	193.7
NPERCO	Nitrogen percolation coefficient	0.953
SDNCO	Denitrification threshold water content	0.98
ADJ_PKR	Peak rate adjustment factor for sediment routing	1.69
CDN	Denitrification exponential rate coefficient	1.98
RSDCO	Residue decomposition coefficient	0.067
SPEXP	Exponent parameter for calculating sediment reentrained in-channel sediment routing	1.39
PRF	Peak rate adjustment factor for sediment routing	0.34
SPCON	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.007921
RCN	Concentration of Nitrate in Precipitation (ppm)	3.75
N_UPDIS	Nitrogen uptake distribution parameter	85
GW_SOLP	Concentration of soluble phosphorus in groundwater contribution to streamflow from subbasin (mg L^{-1})	0.049-0.61
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded	0.205-0.993
HLIFE_NGW	Half-life of Nitrogen in groundwater (days)	6-198.5
USLE_P	USLE equation support practice factor	0.011-0.996

4.2.1.2 Lake models

Two-year monthly monitoring data (2010-2012), collected during this study (detailed information about data compilation is given in Chapter 2), was used to set-up and calibrate the models. In addition, meteorological data was compiled from Turkish State Meteorological Service. The detailed information about the structure of PCLake and GLM-AED models are given in Chapter 1. Forcing data for running the models are presented in Table 4.2.

Since PCLake does not have a thermodynamic component, the daily simulated temperature was derived through GLM-AED model, and it was given as an input to PCLake. PCLake also requires daily evaporation. Thus, evaporation was calculated using Penman equation (Penman, 1948) using radiation, temperature, wind speed, relative humidity and lake area. Monthly nutrient concentrations of the inflows were linearly interpolated to generate the daily data. Residual flows were calculated from the simple water budget equations considering water level, precipitation, inflow, outflow, and area information. Both of the models require the meteorological forcing of precipitation, wind speed, and radiation, though GLM-AED additionaly requires cloud cover, relative humidity and air temperature (Table 4.2).

In addition, models also require values for physical (water depth), chemical (N, P, Silicate, dissolved oxygen concentrations) and biological variables (phytoplankton biomass, phytoplankton composition, zooplankton biomass) from the first day of the simulation, which were also given to the both models. For GLM-AED model, additional salinity, temperature, and pH information were also given. Since PCLake enables to define only 3 different phytoplankton groups, three dominant functional phytoplankton groups were selected (cyanobacteria, Chlorophyta and Bacilliarophyta) for both models since these phytoplankton groups constituted 80% of the total phytoplankton biomass in the lake. Both models enable to model 1 zooplankton group, thus zooplankton groups were pooled as one functional zooplankton group. Since monitoring was conducted for two years with monthly sampling frequency, whole data were used only for calibration and separate validation time series data was not available.

Table 4.2 Forcing data used to set-up the models. Plain text: data utilized for both models, bold text: only for GLM-AED, italic text: only for PCLake

Category	Data
Meteorological forcings	Shortwave radiation
	Precipitation
	Temperature
	Cloud cover
	Relative humidity
	Wind
Lake	*Evaporation from lake surface*
	Lake temperature
Inflows	O_2, **temperature, salinity, pH,**
	SRP, TP, NH_4, NO_3, TN, Organic N, Organic P
	Discharge volume
Outflow	Discharge volume

Both lake models have a high number of parameters. In order to reduce the calibration effort, the most sensitive parameters were determined. Sensitivity index for the parameters was calculated using the equation below (Chen et al., 2002):

$$S_{ij} = \frac{\Delta F_i / \bar{F}_i}{\Delta Parameter_j / Parameter_j}$$

Where ΔF_i is the change in variable i corresponding to change in parameter j, $\bar{F_i}$ is the default value of the variable i, $\Delta Parameter_j$ is the change in value of parameter j, $Parameter_j$ is the default value of the parameter j.

Each parameter was adjusted by ±10%, except temperature multipliers, which were adjusted by ±0.01. When sensitivity index was > 0.5, it was regarded as a sensitive parameter.

The most sensitive parameters were used in calibration which affects concentrations of dissolved oxygen, soluble reactive phosphorus, nitrate, ammonium, total Chl-*a*, and Cyanobacteria. Calibration was performed till the best match with a minimum error between observed and simulated variables were obtained. Root Mean Square Deviation (RMSD) was used as an objective function. The results were also visually inspected to check the seasonal trends. Also, for evaluating the model performance, RMSD, normalized bias, and R^2 were calculated. Calibrated parameters and fitted values are given in Table 4.3 and Table 4.4. During the calibration, the bottom-up principle was employed, first calibration of water balance, temperature, and dissolved oxygen concentration were achieved then, calibration of nutrients and phytoplankton groups were followed (Trolle et al., 2008b).

Table 4.3 Fitted parameter set of the calibrated GLM-AED model.

Parameter	Unit	Description	Fitted value
Pmax_diatom	day^{-1}	Phyto max growth rate at 20 ºC	1.85
Pmax_green	day^{-1}	Phyto max growth rate at 20 ºC	1.29
Pmax_cyano	day^{-1}	Phyto max growth rate at 20 ºC	0.625
vT_diatom	-	Arrenhius temperature scaling for growth function	1.06
vT_green	-	Arrenhius temperature scaling for growth function	1.09
vT_cyano	-	Arrenhius temperature scaling for growth function	1.11
Tstd_diatom	ºC	Standard temperature	18.0
Tstd_green	ºC	Standard temperature	19.0
Tstd_cyano	ºC	Standard temperature	23.0
Topt_diatom	ºC	Optimum temperature	16.0
Topt_green	ºC	Optimum temperature	26.0
Topt_cyano	ºC	Optimum temperature	27.6
Tmax_diatom	ºC	Maximum temperature	28.2
Tmax_green	ºC	Maximum temperature	30.0
Tmax_cyano	ºC	Maximum temperature	33.0
vr_diatom	-	Arrhenius temperature scaling factor for respiration	1.05
vr_green	-	Arrhenius temperature scaling factor for respiration	1.04
vr_cyano	-	Arrhenius temperature scaling factor for respiration	1.065
theta_sed_frp	-	Arrhenius temperature multiplier for sediment PO_4 flux	1.04
Ksed_frp	mmol m^{-3}	Half-saturation oxygen concentration controlling PO_4 flux	51.4
Fsed_frp	mmol m^{-3}	Sediment PO_4 flux	0.06
Rnitrif	day^{-1}	Maximum reaction rate of nitrification at 20 ºC	0.31
Rdenit	day^{-1}	Maximum reaction rate of denitrification at 20 ºC	0.20
theta_nitrif	-	Arrhenius temperature multiplier for nitrification	1.05
theta_denit	-	Arrhenius temperature multiplier for denitrification	1.07
theta_sed_nit	-	Arrhenius temperature multiplier for sediment NO_3 flux	1.06

Table 4.4 Fitted parameter set of the calibrated PCLake model. Diatoms: Bacilliarophyta, Bluegreens: Cyanobacteria, Greens:Chlorophyta, N: Nitrogen, P: Phosphorus, DW: Dry weight, T: Temperature, OM:Organic matter.

Parameter	**Unit**	**Description**	**Fitted value**
cAffPUptDiat	mgDW day^{-1}	Initial P uptake affinity of Diatoms	0.40
cAffPUptGren	mgDW day^{-1}	Initial P uptake affinity of greens	0.18
cChDBlueMax	mgChl $mgDW^{-1}$	max. chlorophyll/C ratio for Bluegreens	0.01
cChDGrenMax	mgChl $mgDW^{-1}$	max. chlorophyll/C ratio for greens	0.015
cDGrazPerBird	gD $coot^{-1}$ day^{-1}	Daily grazing of birds	0.00
cMuMaxBlue	day^{-1}	Maximum growth rate for Bluegreens	0.66
cMuMaxDiat	day^{-1}	Maximum growth rate for Diatoms	2.40
cMuMaxGren	day^{-1}	Maximum growth rate greens	2.30
cNDDiatMax	mgN $mgDW^{-1}$	max. N/day ratio for Diatoms	0.10
cPDDiatMax	mgP $mgDW^{-1}$	max. P/day ratio Diatoms	0.01
cPDDiatMin	mgP $mgDW^{-1}$	Minimum P/day ratio Diatoms	0.001
cPrefBlue	-	Grazing selection factor for Bluegreens.	0.15
cPrefDiat	-	Grazing selection factor for Diatoms	0.65
cPrefGren	-	Grazing selection factor for Greens	0.65
cSuspMin	-	Minimum value of logistic function for suspension	5.70
cTmOptBlue	ºC	Optimum T. for blue-greens	27.60
cTurbDifNut	-	Bioturbation factor for diffusion	5.50
cVNUptMaxBlue	mgN $mgDW^{-1}$ day^{-1}	Maximum N uptake capacity of Bluegreens	0.10
cVSetBlue	m day^{-1}	Sedimentation velocity for Bluegreens	0.05
cVSetDet	m day^{-1}	Max. sedimentation velocity of detritus	0.10
cVSetIM	m day^{-1}	Max. sedimentation velocity of inert OM	0.18
fDAssZoo	-	DW assimilation efficiency of herbivorous zooplankton	0.45
hFilt	mgDW L^{-1}	Half saturation food concentrations forfiltering	1.40

4.2.2 Scenarios and storylines

4.2.2.1 Climate Change Scenarios

Five different climate models (GFDL-ESM2M, IPSL-CMA-LR, HadGEM, MPI, and MIROC), hereafter will be written as GFDL, IPSL, HadGEM, MPI, and MIROC, were used for generating precipitation and temperature scenarios for two representative concentration pathways (RCPs): RCP 4.5 and RCP 8.5. The former, RCP 4.5, assumes that the greenhouse gas (GHG) emission will peak around 2040, followed by a decline, while the latter, RCP 8.5, assumes that emissions will increase throughout the 21st century. GFDL, IPSL and MIROC climate model outputs were downscaled by Deltares (Ferreria et al., 2016, EU-MARS project), while downscaled HadGEM and MPI model outputs were compiled from Turkish State Meteorological Office. Period of 2006-2015 was used as a reference period, and monthly linear correction was derived from the difference between observed climate data and scenario outputs, covering the reference period. Factors derived from linear correction was applied to projected temperature and precipitation data series through employing delta change approach. Two distinct periods, which include 2025-2034, 2055-2064, hereafter will be used as the 2030s and 2060s, respectively, were chosen for future scenario runs. For the 2030s, predicted climate scenarios indicated a +22 to -17% change in precipitation, whereas for the 2060s, precipitation change was predicted between 9% increase and -30% decrease (Table 4.5). Temperature outputs indicate 0.0-1.7 ^{o}C increase for the 2030s and 0.6-4.2 ^{o}C increase for the 2060s (Table 4.6).

Table 4.5 Precipitation change (%) in the climate change scenarios compared to baseline (reference) period (2006-2015)

	RCP 4.5		RCP 8.5	
	2030	2060	2030	2060
HadGEM	-3	-6	0	-18
MIROC	-17	-18	2	-19
MPI	-11	-12	-13	-23
GFDL	22	9	0	-16
IPSL	1	-17	2	-30

Table 4.6 Temperature change (ºC) in the climate change scenarios compared to baseline (reference) period (2006-2015)

	RCP 4.5		RCP 8.5	
	2030	2060	2030	2060
HadGEM	1.4	2.6	1.7	3.5
MIROC	1.4	2.5	1.4	4.2
MPI	0.6	1.3	0.5	2.0
GFDL	0.0	0.6	0.7	2.0
IPSL	0.6	1.7	1.3	3.4

4.2.2.2 Land use scenarios

Three different storylines were constructed for future land use scenarios, which were developed within the scope of the EU- FP7 funded "Managing Aquatic Ecosystems and Water Resources Under Multiple Stress (MARS, Contract No.: 603378)" project regarding possible future economic, environmental, political and climatic changes (Ferreria et al., 2016; Kriegler et al., 2012). They included Techno world, Consensus world, and Fragmented world scenarios.

In Techno world (economic focus) scenario, economic growth is the main focus. Higher economic growth will trigger an increase in energy demand and resources, resulting in agricultural expansion. In southern Europe, water consumption is expected to increase due to increased agriculture and tourism. In this scenario, 20% of the forest areas and 10% of the grassland is turned into cropland, and fertilizer amount and water abstraction are increased by 10%. Techno World land use scenario and RCP 8.5 climate scenario are used together.

In Consensus world (green focus) scenario, economic growth is as it is today. More efforts will be put in to promote sustainable use of sources. Water consumption would drop due to promoting drought-resistant crops and increased irrigation efficiency. Due to increased temperature, 5% of forest areas are turned into shrubland. In addition, fertilizer amount and water abstraction decrease by 20% and 10% respectively. Consensus World land use scenario, and RCP 4.5 climate scenario are used together.

In Fragmented world (survival of the fittest) scenario, there is no homogeneity across countries, as there is an increase in economic development in some countries, whereas some of them suffer from the big economic crisis (e.g. recession). Southern Europe is anticipated to suffer from the economic crisis since climate change is expected to decrease agricultural productivity. Protection of the environment is not a focus, while the main focus is the economy that causes explotation of natural resources. In this scenario, 30% of forest and 30% of cropland are turned into shrubland due to increased temperatures and decreased agricultural productivity. Fertilizer application and water abstraction rose 30%. Fragmented World land scenario and RCP 8.5 climate scenarios are used together.

4.2.3 Statistical analysis

Following the models' run for future scenarios given in 4.2.2, possible relationships between climatic variables (precipitation and temperature) and environmental variables (flow, NO_3 load, SRP load) were assessed through correlation analysis. In addition, correlation analysis was conducted to determine which of the catchment processes effect in-lake nutrients, Chl-*a*, and cyanobacteria biomass. To check if any hierarchical or complex relationships exist determining cyanobacteria biomass, we also applied Conditional Inference Trees (CIT) analysis with variables of temperature, flow, nutrient loadings, in-lake nutrient concentrations. Corrplot (Wei and Viliam, 2016) and Party packages (Hothorn et al., 2006) were used for correlation and CIT analysis, respectively.

4.3 Results

4.3.1 Performance of the models

4.3.1.1 SWAT

Since SWAT calibration for hydrological compartment has already been performed (Bucak et al., 2017, Chapter 3), only calibration for nutrients are given in Table 4.7. Nutrient calibration results mostly demonstrated a reasonable good fit as for nitrate calibration, since the PBIAS were below PBIAS <±40 (Table 4.7). The results showed that simulated and observed nitrate concenrations were in well accordance with low bias, however R^2 values were low.. For phosphorus calibration, all inflow model calibrations can be regarded as satisfactory in terms of PBIAS citeria (<±25). Though having a low bias, R^2 values were mostly low since SRP concentrations of the inflows were mostly very low, sometimes even under the detection limit, resulting in lower calibration statistics.

Table 4.7 Calibration statistics of SWAT outputs for SRP and Nitrate loadings. Q1, Q2, Q3, Q4, Q5, and Q6 are the coding for the inflows. Detailed explanation and location of the inflows are given in Chapter 3.

	SRP		Nitrate	
Inflows	**PBIAS**	**R^2**	**PBIAS**	**R^2**
Q1	5.4	0.30	23.8	0.09
Q2	0.5	0.01	-7.13	0.45
Q3	0.5	0.01	28.8	0.06
Q4	-3.0	0.19	-7.5	0.49
Q5	9.4	0.25	38.3	0.41
Q6	15.1	0.32	-19.2	0.47

4.3.1.2 Lake Models: PCLake and GLM-AED

GLM-AED model simulation results for the water temperature and oxygen profile matched well with the observed ones (Figure 4.2, Figure 4.3, Table 4.8). Both lake models' outputs for Chl-*a* and SRP corresponded well with the observed values considering the timing of the seasonal variations (Figure 4.4). However, the goodness of fit was low due to the low concentrations (lower than 10 μg L^{-1} for both, sometimes SRP levels were even lower than the detection limits.) and due to not having a strong seasonality (Figure 4.4). For the concentrations of NH_4 and NO_3, simulated results from GLM-AED matched better with observations; while PCLake model overestimated the nitrogen compounds. GLM-AED was able to model cyanobacteria concentrations reasonably well, and captured the autumn peaks in the second year of the calibration, while it did not fully represent the first year autumn peak. Whereas PCLake was able to capture the observed patterns for cyanobacteria though with under-estimation of autumn peaks (Figure 4.4).

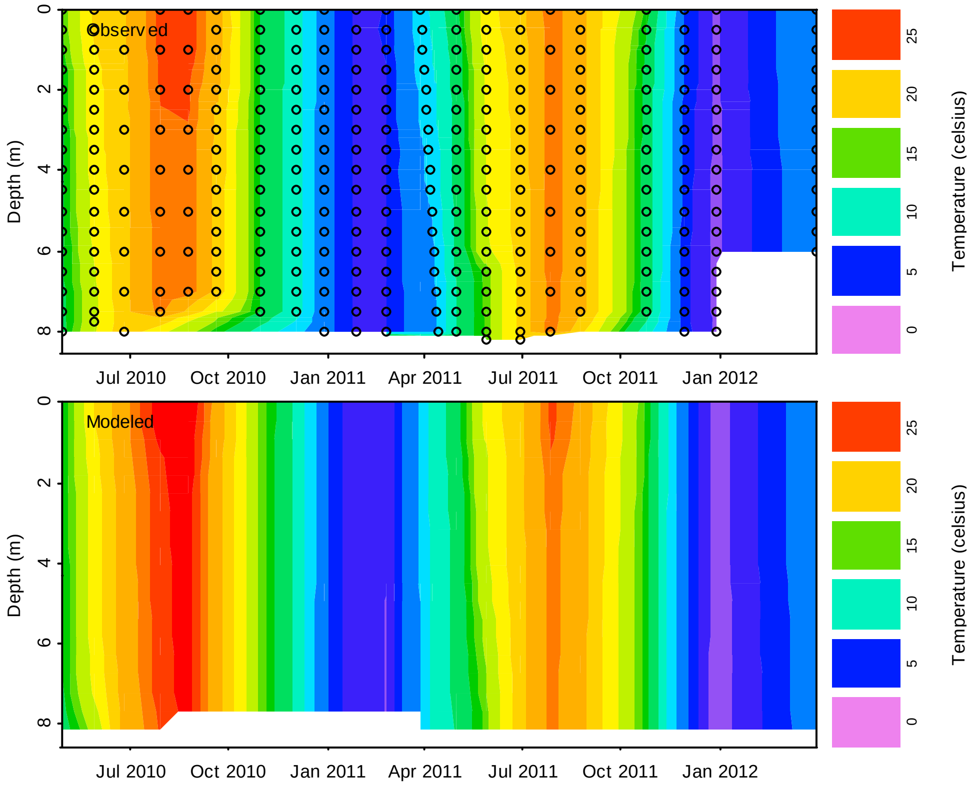

Figure 4.2 Comparison of observed and modeled (GLM-AED) water temperatures for the whole water column during the period of April 2010-March 2012.

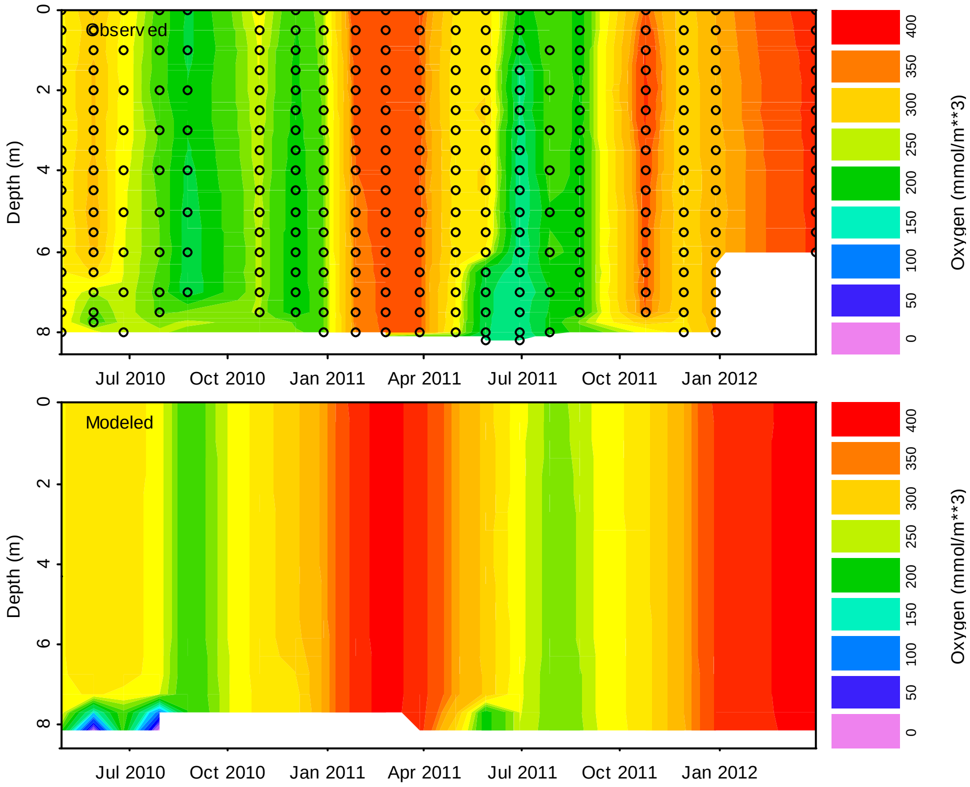

Figure 4.3 Comparison of observed and modeled (GLM-AED) dissolved oxygen concentration profiles for the whole water column during the period of April 2010-March 2012.

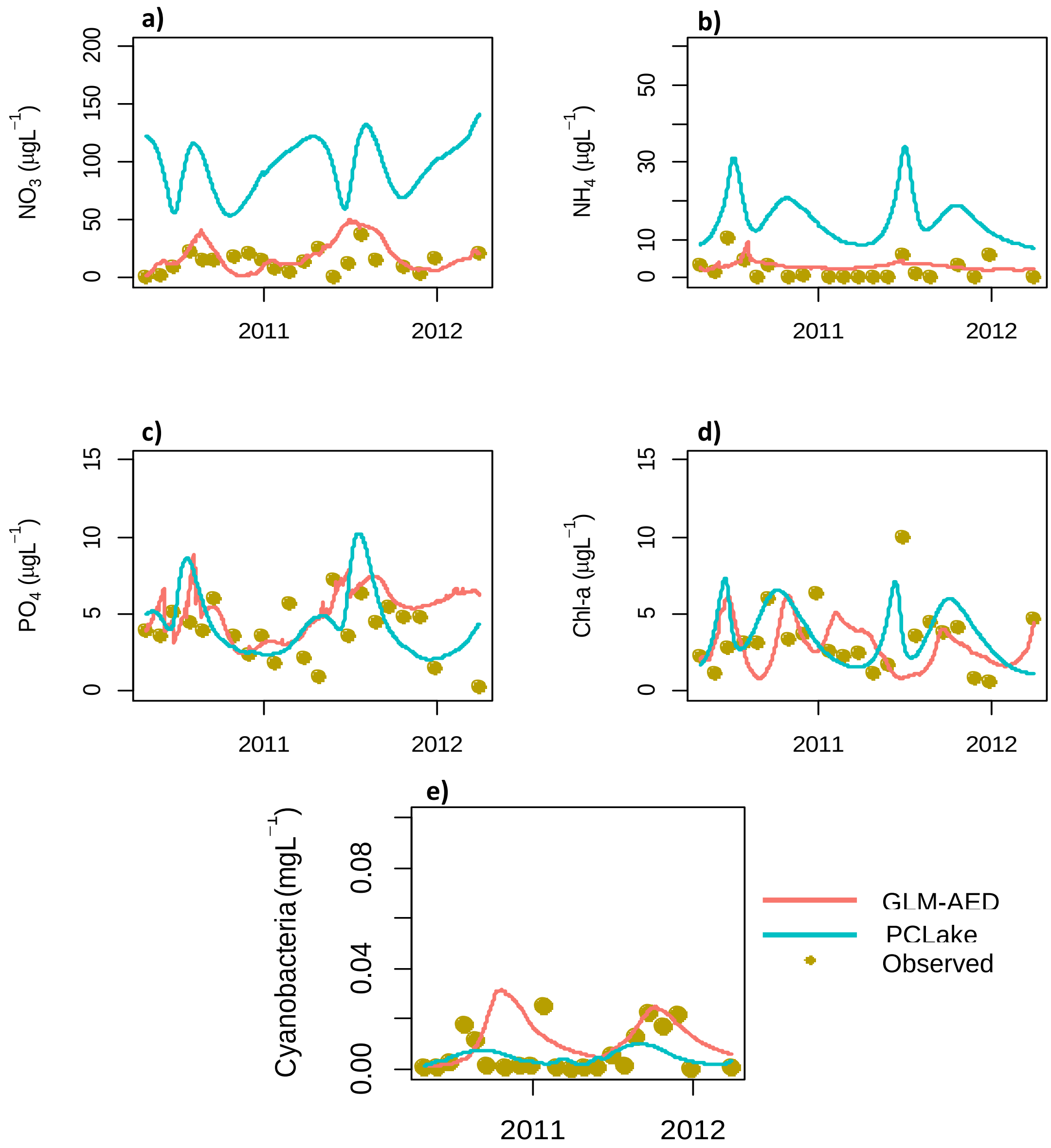

Figure 4.4 Calibration results of the lake models together with the observed values for a)NO_3, b)NH_4, c) PO_4 (SRP), d) Chl-*a*, e) Cyanobacteria. Red lines show the GLM-AED outputs, while blue lines show the PCLake outputs, and the circles indicate observed values.

Table 4.8 Calibration statistics for Temperature, Oxygen, Chl-*a*, SRP, NH_4 and NO_3 for GLM-AED and PCLake models. R^2: Coefficient of determination, RMSD: Root mean square deviation.

	R^2		Normalized bias		RMSD	
	GLM	PCLake	GLM	PCLake	GLM	PCLake
Temperature	0.99	-	0.025	-	-	0.87
Oxygen	0.68	-	0.45	-	-	1.38
SRP	0.17	0.14	0.34	0.41	2.01	2.4
NH_4	0.14	0.31	0.53	4.17	2.91	11.98
NO_3	0.13	0.03	0.86	8.39	16.39	83.71
Chl-*a*	0.02	0.31	-0.09	0.02	2.66	1.74
Cyanobacteria	0.07	0.22	0.67	1.493	0.012	0.017

4.3.2 Changes in hydraulic and nutrient loads to the lake

There were high variations in the SWAT predictions for total flow (total inflows from the catchment to the lake) and nutrient loadings, which were simulated by using five different GCMs. Minimum, maximum ranges and averages for relative changes in the total flow derived from 5 GCMs are given in Table 4.9. For the 2030s, relative changes in the flows predicted to be from +18% to -49 % for RCP 4.5 scenarios, without land use change, while for the 2060s flow rates, the range of predictions was from +21% to -50%. For RCP 8.5 scenarios without land use change, relative changes in the flow were between +1% and -23% for the 2030s, whereas it was -35% to -59% for the 2060s. Land use had a minor impact on total flow (Table 4.9). However, it had significant effects on nutrient loadings from the catchment (Table 4.10 and Table 4.11). For the 2030s, in most of the scenarios, nitrate load from the catchment decreased, excluding the Techno world land use scenario with RCP 8.5 climate change scenarios, where increased nitrate loads were observed for some of the climate models (Table 4.10, Appendix E, Table E.1). For the 2060s period, all scenarios resulted in nitrate loadings (Table 4.10, Appendix E, Table E.1). Variations in SRP loads were also higher among different climate change scenarios. Although there were reductions in average SRP loads to the lake for most of the scenarios, in the Techno world scenario with RCP 8.5 scenarios for all GCMs, increase in SRP loads were observed for the 2030s (Table 4.11).

Changes in the flow, Nitrate and SRP loadings relative to precipitation and temperature are given in Figure 4.5. The flows, NO_3 loading, and SRP loading generally decreased with increasing temperature and decreasing precipitation. Correlation matrix (Figure 4.6) showed that the flow had a strong correlation with temperature (r=-0.73) and precipitation (r=0.93). SRP loading had a negative correlation with temperature (r=-0.62), while it had a positive correlation with flow and precipitation (r=0.9 and r=0.82, respectively). However the relationships of NO_3 loading with the temperature, flow and precipitation were weaker (r=-0.47, 0.47, 0.44, respectively, Figure 4.6).

Table 4.9 Average percent changes in total flow generated from SWAT model from 5 different GCMs with 2 RCPs and three land use scenarios. Maximum and minimum relative changes for five different climate change scenarios were presented for the 2030s and 2060s. Current: No land use change. Relative changes were rounded to the nearest integer.

			2030			**2060**	
Climate	**LU**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**
RCP 4.5	Current	18	-49	-18	21	-50	-38
RCP 8.5	Current	1	-23	-9	-35	-59	-46
RCP 4.5	Consensus	22	-46	-15	25	-49	-23
RCP 8.5	Techno	6	-21	-5	-41	-60	-46
RCP 8.5	Fragmented	6	-19	-4	-30	-56	-42

Table 4.10 Average percent changes for nitrate loading generated from SWAT model from 5 different climate models with 2 RCPs and three land use scenarios. Maximum and minimum relative changes for five different climate change scenarios were presented for the 2030s and 2060s. Current: No land use change. Relative changes were rounded to the nearest integer.

		2030			2060		
Climate	**Land use**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**
RCP 4.5	Current	-12	-43	-27	-25	-38	-34
RCP 8.5	Current	-11	-42	-29	-28	-48	-39
RCP 4.5	Consensus	-27	-54	-39	-32	-54	-44
RCP 8.5	Techno	18	-31	-3	-19	-46	-34
RCP 8.5	Fragmented	-11	-42	-30	-44	-61	-53

Table 4.11 Average percent changes for SRP loading generated from SWAT model from 5 different climate models with 2 RCPs and 3 land use scenarios. Maximum and minimum relative changes for five different climate change scenarios were presented for the 2030s and 2060s.Current: No land use change. Relative changes were rounded to the nearest integer.

		2030			2060		
Climate	**Land use**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**
RCP 4.5	Current	-8	-83	-38	-28	-70	-46
RCP 8.5	Current	-11	-38	-28	-31	-78	-55
RCP 4.5	Consensus	3.5	-79	-30	-27	-74	-45
RCP 8.5	Techno	51	4.9	22	25	-76	-31
RCP 8.5	Fragmented	8	-21	-9	-8	-81	-47

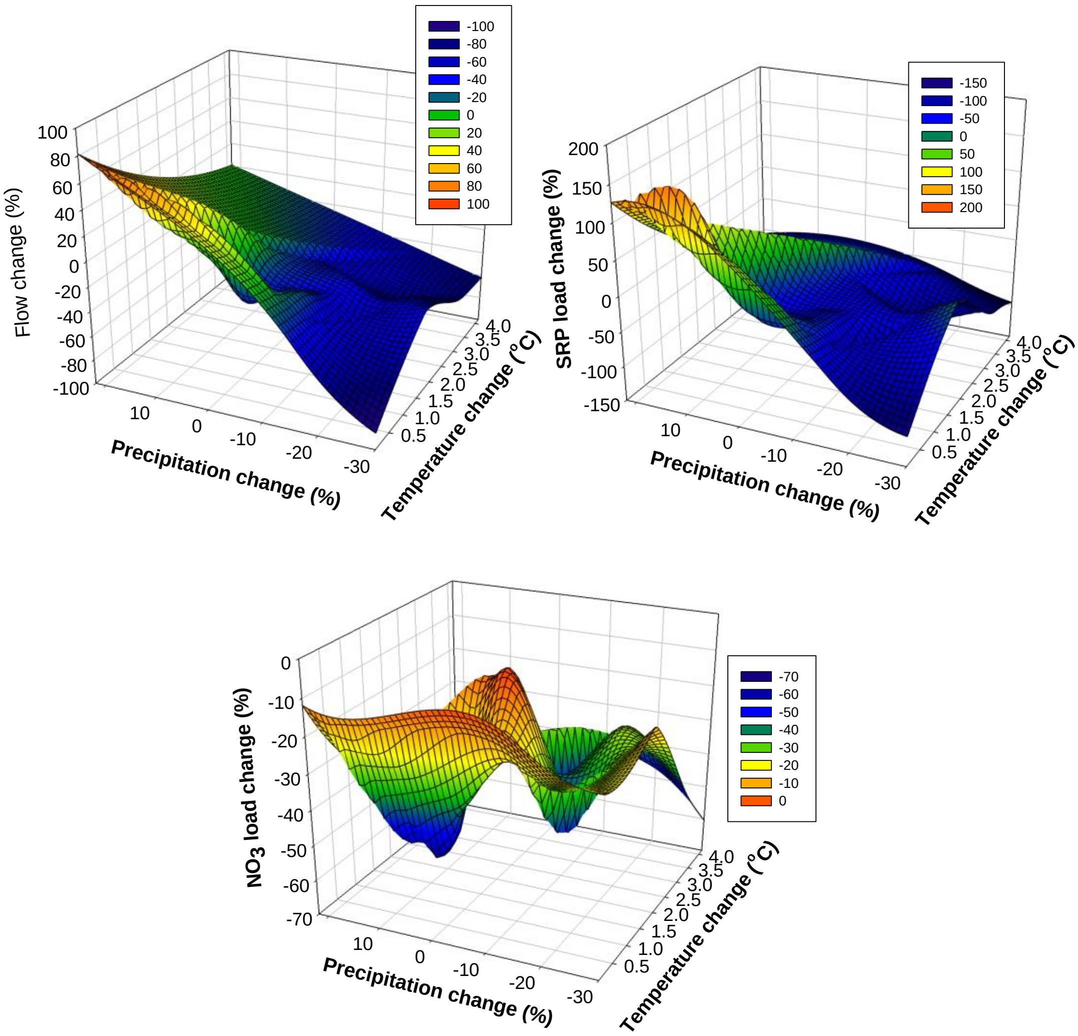

Figure 4.5 Relative changes in the average a) total inflow rate, b) SRP load and c) NO_3 load compared to change in precipitation and temperature.

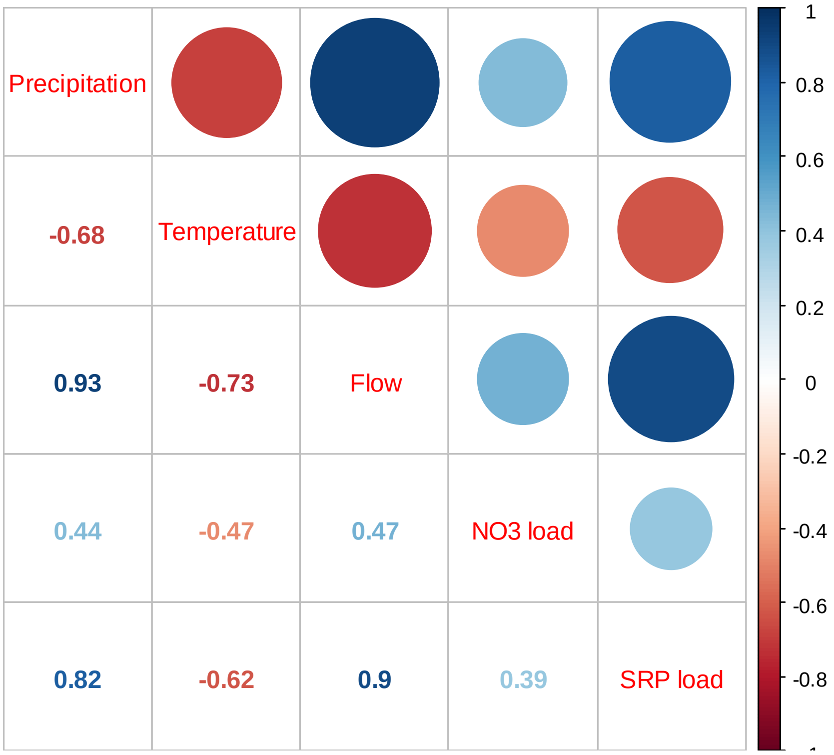

Figure 4.6 Correlation matrix for meteorological variables (precipitation and temperature) with SWAT outputs of flow, NO_3 load, and SRP load. Size and color of the circles and the numbers indicate the strength and direction of the correlation.

4.3.3 Effects of the climate change and land use scenarios on lake ecosystem

Future simulated water levels were mostly lower than the baseline average water level (Figure 4.7, Table 4.12). For the 2030s only six and for the 2060s only four scenarios were higher than the baseline water levels (Table 4.12). The highest water levels were found in the consensus land use with RCP 4.5, whereas the lowest water levels were found in fragmented land use scenario with RCP 8.5. While baseline average water level was 8.3 m, future water level ranges were 7.77-9.48 m for the 2030s and 7.24-8.78 for the 2060s period.

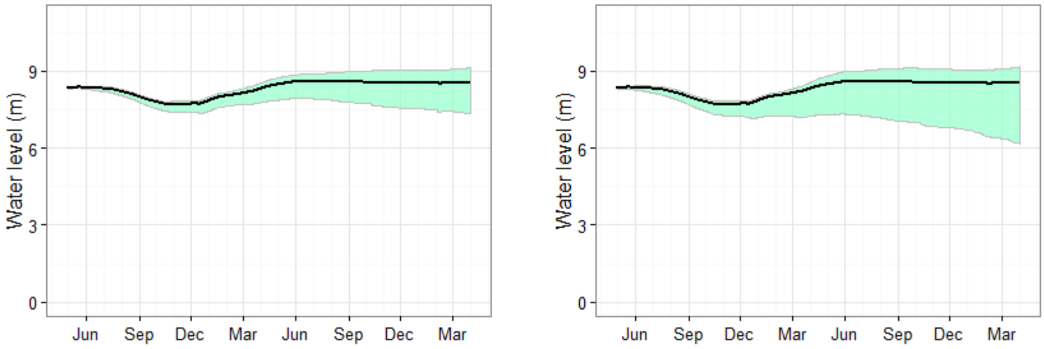

Figure 4.7 Future water levels for all climate change and land use scenarios for a) the 2030s, b) the 2060s. Black lines indicate baseline water level; light green areas indicate the band of all scenario results.

Table 4.12 Future water level predictions derived from GLM-AED model for the 2030s and 2060s period. Average water levels that were higher than the baseline water level are marked as bold.

GCMs	Scenarios	Land use	2030s	2060s
Baseline	Baseline	Baseline	8.3	8.3
HadGEM	RCP 4.5	Consensus	8.07	**8.6**
HadGEM	RCP 8.5	Current	**8.34**	7.77
HadGEM	RCP 4.5	Current	8.21	8.03
HadGEM	RCP 8.5	Fragmented	8.07	7.31
HadGEM	RCP 8.5	Techno	8.17	7.66
MIROC	RCP 4.5	Consensus	7.77	**8.54**
MIROC	RCP 8.5	Current	**8.33**	7.9
MIROC	RCP 4.5	Current	7.9	7.69
MIROC	RCP 8.5	Fragmented	8.07	7.5
MIROC	RCP 8.5	Techno	8.17	7.45
MPI	RCP 4.5	Current	8.09	8.14
MPI	RCP 8.5	Current	8.05	7.97
MPI	RCP 4.5	Consensus	8.21	8.26
MPI	RCP 8.5	Fragmented	7.78	7.7
MPI	RCP 8.5	Techno	7.87	7.78
GFDL	RCP 4.5	Current	**9.36**	**8.64**
GFDL	RCP 4.5	Consensus	**9.48**	**8.78**
IPSL	RCP 4.5	Current	**8.52**	7.73
IPSL	RCP 4.5	Consensus	**8.64**	7.85
GFDL	RCP 8.5	Current	8.21	7.88
GFDL	RCP 8.5	Techno	8.05	7.69
IPSL	RCP 8.5	Current	8.28	7.52
IPSL	RCP 8.5	Techno	8.13	7.31
GFDL	RCP 8.5	Fragmented	7.96	7.62
IPSL	RCP 8.5	Fragmented	8.02	7.24

The lake models predictions for TP and TN are presented in Figure 4.8. For GLM-AED model, changes in TP showed less variation compared to PCLake model outputs (Appendix E, Table E.1). For the GLM-AED outputs with most of the scenarios, there were minor changes compared to baseline for TP concentrations.

However, PCLake model results pointed out to higher variation among climate models, with a major increase in TP (0.7-1.4 fold, Appendix E, Table E.2) for RCP 8.5 climate scenarios for all land use combinations in the 2060s (Figure 4.8, Appendix E, Table E.1). GLM-AED model results showed smaller changes in future TN concentrations for both 2030s and 2060s (Figure 4.8). However, PCLake model results had considerable variation in the future scenarios. The highest increase in TN was observed in RCP 8.5 with no land use change and RCP 8.5 with Techno world scenarios in the 2060s, where 1.3-1.4 fold increase in TN was observed compared to the baseline period (Appendix E, Table E.2), though changes for the 2030s were relatively minor. Correlation analysis (Figure 4.9) pointed out that in-lake TP concentrations in GLM-AED model were positively related to flow and SRP load from the catchment (r=0.59 for both). However, in PCLake model, temperature and flow were the major predictors for in-lake TP though correlation coefficients were not very strong for neither of the models (r=0.66, r=-0.55 for temperature and flow, respectively). Lake TN concentrations were mostly correlated with temperature (r=-0.62, r= 0.54 for GLM-AED and PCLake respectively) for both models.

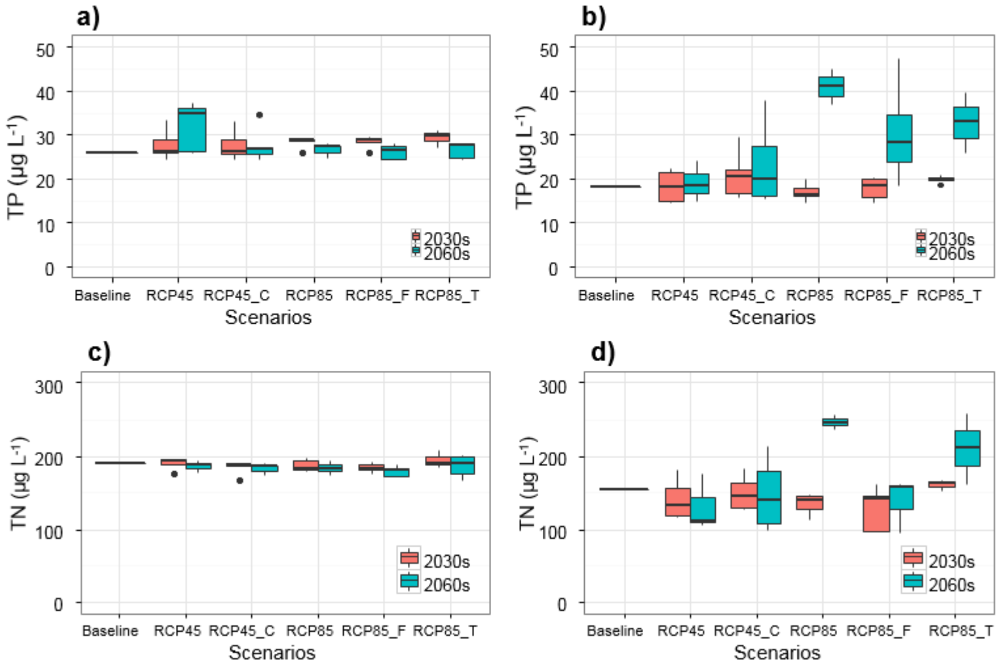

Figure 4.8 Future outputs of lake models for lake a-b) TP and c-d) TN. Left panels indicate the results of GLM-AED model; right panels indicate the results of PCLake model. RCP 4.5 and RCP 8.5: All GCMs without land use change for RCP 4.5 and RCP 8.5 snenarios, respectively. RCP45_C: RCP 4.5 with Consensus World Scenario; RCP 85_F: RCP 8.5 with Fragmented World Scenario; RCP85_T: RCP 8.5 with Techno World Scenario. Each boxplot was generated using averages of each GCM results.

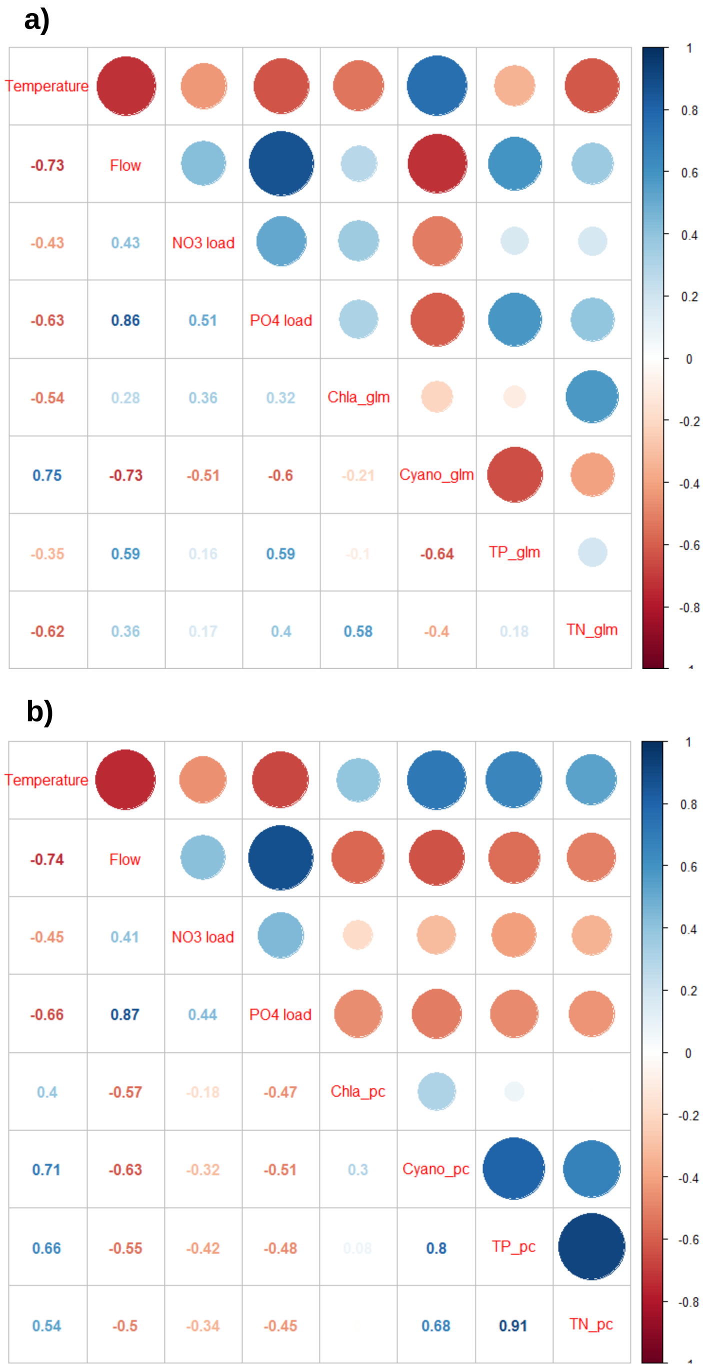

Figure 4.9 Correlation matrix for temperature, flow, NO_3 load, SRP load, Chl-*a*, Cyanobacteria, lake TP and lake TN for a) GLM-AED model, b) PCLake model. Cyano: Cyanobacteria biomass. Size and color of the circles and the numbers indicate the strength and direction of the correlation.

Lake model outputs for Chl-*a* concentration and cyanobacteria biovolume are given in Figure 4.10. GLM-AED model predicted a slight change in Chl-*a* concentration for both 2030s and 2060s compared to baseline, and the highest average Chl-*a* concentration remained around 4 μg L^{-1} in the future scenarios (Appendix E, Table E.1). PCLake model for most of the scenarios generally predicted an increase (0.5-0.9 fold, Appendix E Table E.2) in Chl-*a* concentrations, but increase for the 2060s were more prominent (Figure 4.10, Appendix E, Table E.1). In the worst scenario, the average Chl-*a* concentration was around 7.3 μgL^{-1}, which was more than double of the baseline Chl-*a* concentrations (Appendix E, Table E.1).

Predictions for cyanobacteria biomass produced by both models indicated a major increase for all scenarios, and the magnitude of the increase was greater for the 2060s period (Figure 4.10). While there was a high variation in cyanobacteria biomass in response to RCP 4.5 scenarios for both models (see boxplots in Figure 4.10), the variation in outputs of RCP 8.5 scenarios was less, and they produced a major increase in cyanobacteria biomass up to 15 and 17 fold for PCLake and GLM-AED, respectively (Appendix E, Table E.2). Moreover, even though all the outputs indicated an increase, most of the scenario results were still under the threshold limits of World Health Organization (WHO) (Table 4.13). For the 2030s time period, none of the scenario outputs exceeded the low-risk threshold. For the 2060s, 10 scenarios (out of 25) exceeded WHO limits and a number of days exceeded the limits for each scenario are given in Table 4.13. For two-year of simulation time, outputs of HadGEM 8.5 scenario with no land use change resulted in the highest number of days exceeding the WHO low-risk threshold with 80 days.

CIT analysis for cyanobacteria biomass showed that increased temperatures and decreased flow rates favored cyanobacteria biomass in GLM-AED model (Figure 4.11). However, for PCLake model, in-lake TP concentration was the major factor, followed by temperature and SRP loading to the lake.

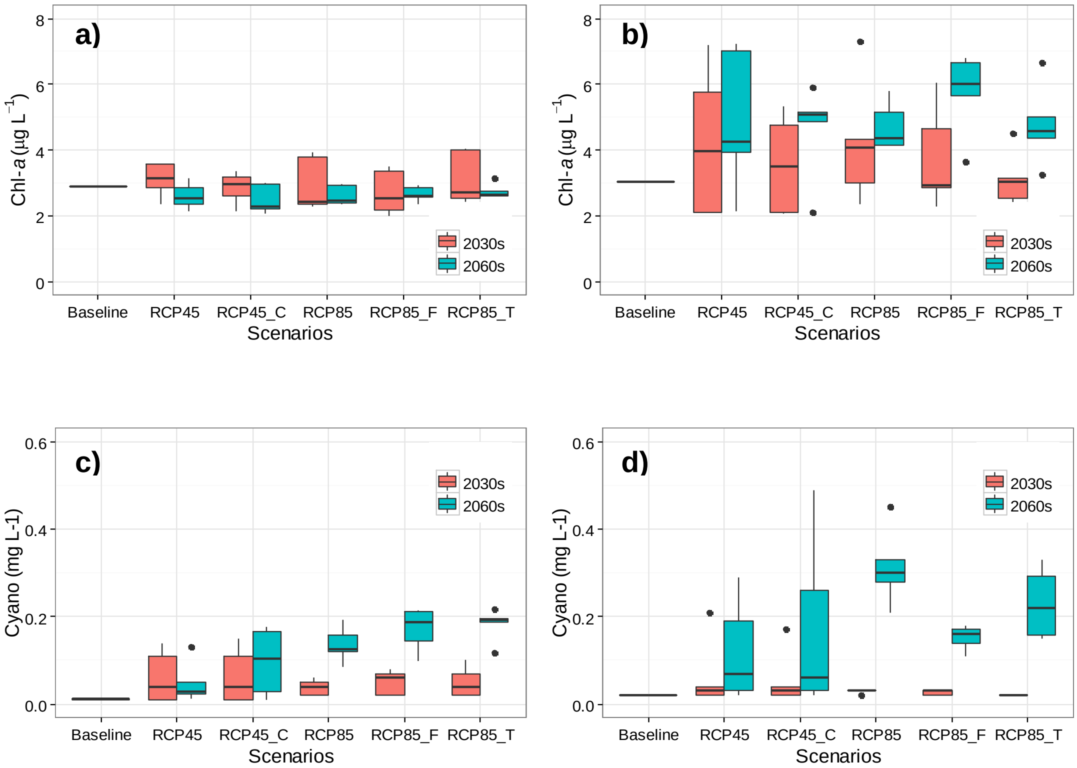

Figure 4.10 Predicted a-b) Chl-*a* concentrations and, c-d) Cyanobacteria biomass for future scenarios. Left panel represents the outputs of GLM-AED model, right panel represent the outputs of PCLake model. RCP 4.5 and RCP 8.5: All GCMs without land use change for RCP 4.5 and RCP 8.5 snenarios, respectively. RCP45_C: RCP 4.5 with Consensus World Scenario; RCP 85_F: RCP 8.5 with Fragmented World Scenario; RCP85_T: RCP 8.5 with Techno World Scenario. Each boxplot was generated using averages of each GCM results.

Table 4.13 Number of days exceeding the low risk WHO limits (10 mg m^{-3} cyanobacterial Chl-*a*) according to future land use and climate scenarios of 2060s period. The scenario outputs that did not exceed WHO limits are not shown in the table.

GCMs	**RCPs**	**Land use**	**Number of days exceeding WHO limits (cyanobacterial Chl-*a*)**
HadGEM	8.5	Current	80
HadGEM	8.5	Techno	52
MIROC	4.5	Current	38
MIROC	8.5	Current	31
MIROC	4.5	Consensus	17
MPI	8.5	Current	29
IPSL	4.5	Current	1
IPSL	8.5	Current	46
IPSL	8.5	Techno	45
IPSL	8.5	Fragmented	64

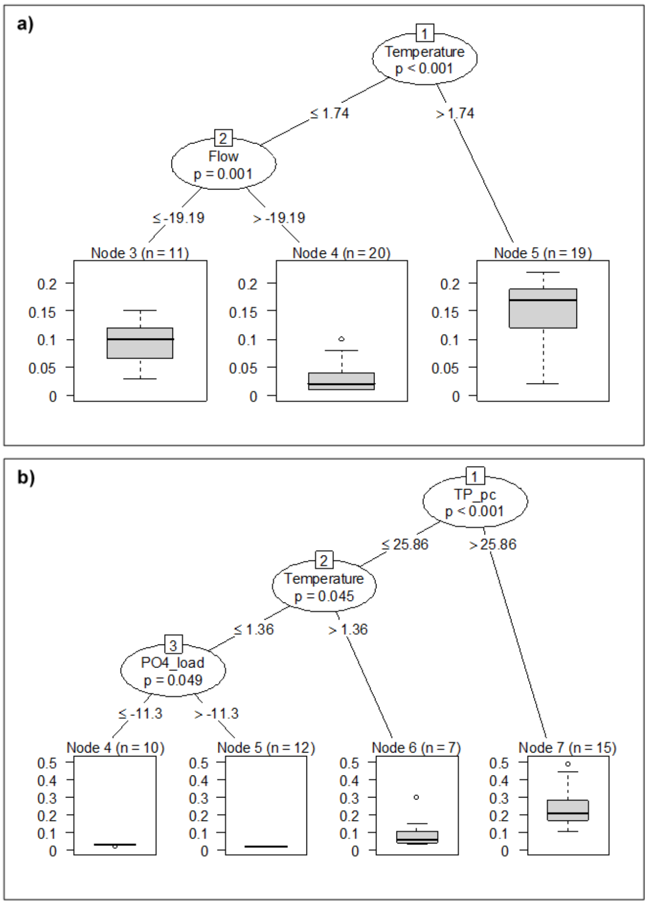

Figure 4.11 Conditional inference trees for Cyanobacteria biomass for a) GLM-AED model, b) PCLake model. Temperature: Relative change to baseline, PO_4 load and flow: % changes compared to baseline, TP_pc: Lake TP concentrations according to PCLake model

4.4 Discussion

In this study, to predict the future nutrient and phytoplankton dynamics of Lake Beyşehir under the impacts of climate and land-use changes, the output of the catchment model, SWAT, was linked to 2 distinct lake models (GLM-AED and PCLake). Our key findings were (i) strong decrease in total inflows for most of the scenarios was found, excluding RCP 4.5 scenarios in the 2030s, (ii) nutrient loading was mostly associated with hydraulic loading and, the most pronounced drop in flow led to the most noticeable drop in nutrient loads, (iii) land use had a minor impact on runoff but it had major impacts on nutrient loadings, (iv) PCLake and GLM-AED differed in their simulations of Chl-*a* concentrations since PCLake predicted an increase in future Chl-*a* concentrations for most of the scenarios whereas in GLM-AED Chl-*a* changes were minor, (v) Both lake models predicted an increase in cyanobacteria contribution in future scenarios.

The calibration statistics for the SWAT model was acceptable in terms of PBIAS, however R^2 values were mostly low. The results can be attributed to low resolution of forcing layers (land use, soil map) which may have an effect on the nutrient transport through the catchment. In addition, unmeasured sewage effluent from the nearby towns to the inflows, which was not included the model setup, may have contributed to the low calibration statistics. While calibrating the phosphorus and nitrogen compounds, some of the parameters were fitted according to basin or subbasin level and this simplistic approach also have some drawbacks not taking into account spatial differences in small scales.

We found a decrease in hydraulic loads in most of the scenarios, and for the 2060s period, the magnitude of the decreases from the baseline was more pronounced. Our results concurred with the findings from Mediterranean region which predicted a significant drop in flow in response to climate change scenarios (Coppens, 2016; Serpa et al., 2015; Shrestha et al., 2017). In Chapter 3, the similar results were demonstrated using only 2 GCMs (HadGEM and MPI, which were also included in this chapter) and decreases in water availability were more pronounced (15-52%) at the end of the century. Moreover, in this chapter, additional 3 GCMs also resulted in a similar trend in general, highlighting the risk of possible water scarcity in Mediterranean catchments in the future, with higher confidence. Moreover, we also found high uncertainty derived from climate models. This issue was also addressed in Chapter 3, where high variability in future predictions of total flows and water levels were found. Similar to our findings, Shrestha et al. (2017) also demonstrated large variations in flow rates in response to using 6 different GCMs. GCM-related uncertainty was covered in many studies (Eisner et al., 2012; Maurer, 2007; Wilby and Harris, 2006) and they all highlighted the importance of using ensemble models for more robust future changes anticipations.

Nutrient loadings also generally followed the same patterns of flows, and higher nutrient reductions were found in the scenarios leading lowest total flow. These results are in line with the studies that showed dependency of nitrogen, and phosphorus loadings on flow magnitude (Shrestha et al., 2017). However, in our study, the relationship between SRP load and flow was strong while NO_3 and flow relationship was weak. We attributed this pattern to the complex nature of nitrogen cycle in the model, compared to P cycle. In SWAT, denitrification, nitrification, and nitrogen fixation cycles are also included in the model structure, and, water availability and temperature are the mediators of these processes (Neitsch et al., 2011). Nitrogen fixation may also be the mechanisms behind the non-linear behavior between nitrate loading and flow, since one of the dominant crop types in the catchment was chickpeas, which is from the legume family and is known to contain rhizobia in their root nodules, enabling nitrogen fixation (Carranca et al., 1999).

We found minor impacts of land use on total inflow, while it had major impacts on nutrient loadings. This case was also demonstrated in many studies using SWAT model (El-Khoury et al., 2015; Molina-Navarro et al., 2014; Morán-Tejeda et al., 2014; Shrestha et al., 2017). In mixed land use and climate scenario, there are other factors such as fertilizer and change in land cover, appeared to be critical for NO_3 and SRP loadings. For instance in Techno World land use scenario, SRP loads increased in the 2030s despite decreased flow rates. Though NO_3 loadings also reduced in Techno World scenario, they were higher than RCP 8.5 scenarios without no land use change. This results can be attributed increased agricultural area and enhanced fertilizer application in Techno World scenario, which was also demonstrated in many studies (Cerro et al., 2014; Molina-Navarro et al., 2014; Panagopoulos et al., 2011). Changing the land cover from forest to agricultural land decreases the nutrient holding capacity of the system, and nutrient leaching and enhanced soil erosion (Wischmeier and Smith, 1978). Increased soil erosion is known to one of the major sources of particulate P from the catchments (Panagopoulos et al., 2011). In addition, increased fertilizer application is also contributed the higher nitrogen and phosphorus loads in Techno World scenario. As opposed to Techno World scenario, we observed decreased nitrate exports in the Consensus World scenario, where the fertilizer use was reduced. All these results concurred with the findings from various studies (Jeppesen et al., 2009; Nielsen et al., 2012) as expansion of agricultural lands has a potential to increase the nutrient loadings from the catchment and threaten the water quality in freshwaters as lakes are the mirror of their catchment and catchment processes have a direct influence on lake dynamics.

Calibration statistics of lake both model variables mostly have low R^2 values which may indicate a lower fit between observed and simulated variables. However, it should be noted that statistical good fit are not always the main criteria (Grimm V., 1994), and that visual fit is also vital (Elliott and May 2008), depending on the magnitude and range of the data (Elliott et al., 2000). Moreover, low calibration fits can also be attributed to low concentrations since most of the time SRP and NH_4 concentrations were below detection limits (5 µg L^{-1}). In this kind of datasets, notwithstanding the low relative error measures, R^2 values could also be low due to low variance and not having distinct seasonality (Trolle et al., 2011b).

GLM-AED model results pointed out decrease in water levels in most of the scenarios for both 2030s and 2060s with RCP 8.5 scenarios as a response increased evaporation, temperature and decreased precipitation. The lowest water levels were observed in Techno and fragmented land use scenarios with RCP 8.5 scenarios, in which the water abstraction increased. However, for GFDL and IPSL GCMs with RCP 4.5 scenarios and consensus land use scenarios, in which water abstraction decreased by 10%, the higher water levels were observed (Table 4.12). These results together with the results of Bucak et al., (2017) indicated an importance of outflow management to sustain water levels in Mediterranean region considering climatic changes (see Chapter 3 for a detailed discussion). However, it should also be noted that using delta change approach (applying relative changes in precipitation and temperature to baseline), and applying the future relative changes for the 2030s and 2060s to only two-year baseline period, may result in under/overestimation of the effects of future changes, since delta change approach is unable to capture the climatic variabilities and extreme events (El-Khoury et al., 2015).

GLM-AED and PCLake differed in their responses to climatic changes and land use regarding TP and TN concentrations. While GLM-AED model results demonstrated minor changes, nutrient concentrations increased in PCLake runs, especially in the 2060s. These different outcomes regarding TP and TN concentrations may be a result of structural differences of the lake models. For instance, PCLake model has zero-dimensional structure and considers the lake surface of Lake Beyşehir constant throughout the simulation. This situation might have led to an overestimation of the evaporation, resulting in enhanced up-concentration of the nutrients as it is also demonstrated by Coppens, (2016) who applied PCLake model to a semi-arid Mediterranean Lake Mogan. Also, sediment-water column interactions differed in model structures. PCLake model considers internal loading mechanisms through temperature mediated sediment release (Janse 2006). Hence, in addition to enhanced up-concentration through enhanced evaporation, increased temperature can trigger increased internal loading process and result in increased nutrient concentration in PCLake model. However, in GLM-AED model, sediment nutrient release is defined as a constant and did not change through time (Hipsey et al., 2013).

It is well known that phytoplankton productivity increases with temperatures (Kosten et al., 2012). Climate modeling studies from temperate lakes showed that substantial reduction in external loads is needed up to 75% in TN and 40-50% in TP to prevent the phytoplankton blooms (Trolle et al., 2008a) in a warmer world. Examples from New Zealand lakes also demonstrated that 25-50% reduction in nutrients is needed to sustain lakes' current trophic status in the future (Trolle et al., 2011b). Recent modeling studies from Danish lakes also indicated that in a 6 ^{o}C warming scenario, a nutrient reduction of 75% (Nielsen et al., 2014) and 60% (Rolighed et al., 2016) was required to maintain the future Chl-*a* concentrations in the lake. In our results with GLM-AED, we found minor changes in Chl-*a* concentrations despite having significant nutrient load reduction. However, increased Chl-*a* concentrations were simulated by PCLake model, especially for the 2060s probably owing to the increases in lake nutrient concentrations. Though the responses of two models differed, they all highlighted the necessity of nutrient load reduction to maintain the current productivity of the lake. While for GLM-AED models, climate-change mediated nutrient load reductions seem to sufficient at least for the modeled time period, PCLake model results indicated a more substantial reduction in nutrient load might be needed. Our scenarios covered the period till the 2060s, however, more enhanced temperatures anticipated for the end of the century (IPCC, 2013). Hence, we may need to consider more stringent measures (such as decreasing fertilizer use, more efficient irrigation technologies, decreasing agricultural areas) to maintain the low productivity of the lake in the future.

We also found a considerable increase in cyanobacteria biomass for both time periods and both models. This case was also evident from many studies as warming is predicted to increase cyanobacteria blooms (Paerl et al., 2011) due to their higher optimum growth temperature (25- 35°C) (Robarts and Zohary, 1987). CIT results of the both models for cyanobacteria also concurred with these findings as higher cyanobacteria growth was found at higher temperatures. In GLM-AED outputs, flow also found to be a significant factor determining cyanobacteria biomass. Similarly, Elliott, (2010) found minor changes in the Chl-*a* concentration with marked changes in phytoplankton composition as a response to changes in increasing inflow rates with higher temperatures using PROTECH model. Flushing had a major role in phytoplankton composition and increased flushing and mixing are known to favor green algae and diatoms over cyanobacteria due to their higher growth rate and lower sedimentation losses (Visser et al., 2015). Moreover, higher flushing is also known to limit the bloom through flushing the nutrients out (Elliott, 2010). In addition, throughout the simulation TN:TP ratio were mostly below 22, below which large N-fixing cyanobacteria are favored (Gophen et al., 1999; Smith et al., 1995). GLM-AED model also included nitrogen fixation processes of cyanobacteria, which may have resulted in increasing cyanobacteria biomass as well for GLM model outputs.

In PCLake model, however, in addition to temperature, TP and SRP loads were the main factors, explaining the cyanobacteria dominance. These results were also consisted with the findings indicating cyanobacteria abundance was mainly driven by synergistic nutrient-temperature interaction (Erdoğan, 2016), since high temperature and TP conditions generally favor cyanobacteria species (Paerl & Huisman 2008, 2009) due to high nutrient uptake ratio of cyanobacteria over diatom and algae and higher optimum growth temperatures (Janse, 2005). We also calculated the number of days exceeding the low-risk and high-risk threshold according to WHO for cyanobacteria. While none of the scenarios in neither of the lake models exceeded the high-risk threshold in the 2030s, 10 out of 25 scenarios in PCLake model exceeded the low-risk threshold in the 2060s. These scenarios were the ones having the most extreme reduction in flows and higher temperature, indicating low water levels with higher temperatures may pose a risk to the future water quality of Mediterranean ecosystems. This case was also reported in many studies as increased harmful cyanobacteria blooms had a significant impact on ecosystem functioning (such as fish kills) and ecosystem services as drinking and irrigation water supply (Havens *et al*., 2001; Qin *et al*., 2010; Paerl *et al*., 2011).

However, such low water levels may also favor macrophyte dominance (at least to a certain point) relative to phytoplankton, as macrophytes are able to extend their coverage during low water levels as evidenced from many studies from Mediterranean region (Beklioğlu et al., 2006; Özkan et al., 2010; Bucak et al., 2012; Ersoy, 2015). Unfortunately, GLM-AED model did not include macrophyte processes. Even though PCLake included macrophyte dynamics, due to limited macrophyte data, we did not test and validate the data for macrophytes growth. As also stated by Coppens, (2016), the 0D structure of the PCLake model can be ineffective in revealing the effects of water level fluctuations on macrophyte growth, which is the key features of the Mediterranean lakes. In Mediterranean lakes, water level fluctuation governs macrophyte growth (Beklioğlu et al., 2006) by directly affecting the area available for macrophytes and through the indirect mechanisms, such as by affecting the nutrient concentrations in the water column (Beklioğlu et al., 2017; Coppens et al., 2016). Therefore, this model seems to be more convenient for the temperate lakes having smaller seasonality regarding water levels.

The current study highlights the crucial role of nutrient control in maintaining the clear water state of Mediterranean lakes in future dry and warmer periods, since we found only minor changes in Chl-*a* despite reduced nutrient loading. However, notwithstanding the still low Chl-*a* (for most of the scenarios), increased cyanobacteria contribution may deteriorate the drinking water status of the lake to a certain extent in the future as we found low-risk in some scenarios. In addition, extended periods of decreased hydraulic loads from the catchment and increased evaporation may lead to water level reductions and reduced ecosystem services of the lake as an irrigation water supply. Our results also highlight the importance of land use management since consensus world scenario with efficient irrigation, lower water abstraction, and less fertilizer application leads to higher water yield and reduced nitrate load compared to other scenarios. However, increased agricultural areas with fertilizer application increased the nutrient leaching from the catchment despite reduced runoff. In Mediterranean region, adopting efficient irrigation technologies, promoting drought-resistant crops, not only have a potential to decrease the water scarcity but also enable to reduce nutrient leaching from the soil. Such measures may have a potential to decrease nutrient reduction to mitigate the impacts of warming on lakes in Mediterranean region.

CHAPTER 5

LONG-TERM ECOSYSTEM SERVICES OF LAKE BEYŞEHİR FROM PAST TO THE FUTURE

5.1 Introduction

Shallow lakes are characterized by large littoral zones with dense submerged macrophyte beds, and higher productivity (Jeppesen, 1998). They are more sensitive to environmental disturbances than deep lakes, due to a higher probability of nutrient availability and more noticeable impact of climatic events (Dokulil, 2014). These environmental disturbances are mainly nutrient loadings from the catchment (Jeppesen et al., 2009), global climate change with extreme weather events and hydrological changes (Jeppesen et al., 2015), the latter of which is the inherent characteristics of the Meditarrean lakes. Particularly in the Mediterranean region, hydrological changes have a prominent role in shaping the structure and functioning of the shallow lakes. Water level fluctuations can have direct and indirect effects on the whole lake ecosystem structure through nutrient, growth dynamics, primary production, fish spawning, and biodiversity (Beklioglu et al., 2007; Beklioğlu et al., 2017; Blindow, 1992; Levi et al., 2016). In addition to natural inter- and intra-WLF, growing demands for irrigation in dry years result in further degradation of quantity and quality of freshwater ecosystems (Jeppesen et al., 2015). Water level drops due to high temperatures can initiate many responses like up-concentration of nutrients through evaporative water loss, as well as release from the sediment and result in water quality deteoriation (Beklioğlu et al., 2017; Coppens et al., 2016; Özen et al., 2010). However, low water levels can also favor macrophyte development (Beklioğlu et al., 2017, 2006; Bucak et al., 2012). Macrophytes have fundamental roles in dynamics of shallow lakes via its stabilizing mechanisms and serving as a complex habitat for many organisms like fish, birds, and macroinvertebrates (Meerhoff, 2006; Meerhoff et al., 2007b).

Ecosystem structure, processes, and functions of the lake ecosystems are highly coupled to ranges of ecosystem services (Tolonen et al., 2014), which are defined as various direct and indirect benefits to humans from the ecosystems (Millenium Ecosystem Assessment (MEA), 2005; TEEB, 2010). MEA (2005) defined the ecosystem services in four main categories. Three of them, namely are *provisioning*, *regulating*, and *cultural* services are direct services that human populations benefit. The last category, *supporting* services, includes ecosystem processes, and functions that constitute the infrastructure of other ecosystem services (Truchy et al., 2015). Primary ecosystem services of aquatic ecosystems are given in Table 5.1. The initial motivation for developing the concept of ecosystem services is to increase the awareness for the benefits and the key role of the ecosystems, in turn, to improve the conservation and management of ecosystems for sustainable growth (Alahuhta et al., 2013). Nowadays, the necessity of monetary evaluation of ecosystem services is highly acknowledged due to the need for increasing the public awareness and convey the importance of ecosystems to policy makers (de Groot et al., 2012).

While evaluating the ecosystems services, both the *actual flow* of services used by humans and the capacity of ecosystems to provide the service (i.e. the *sustainable flow*) should be evaluated (TEEB, 2010). According to MEA (2005), supporting services (i.e. biodiversity) and ecological integrity are vital for sustaining ecosystem services since higher species diversity increases the stability and resilience of the ecosystems to disturbances (Yachi and Loreau, 1999). However, as stated by Montoya et al. (2003), final services of the ecosystems depend on biodiversity of several trophic levels, their interactions, and on the structure of the food webs as well.

Freshwaters also have significant regulatory services, such as climate regulation, through their role in the carbon cycle. However, until recently, the roles of freshwater ecosystems on global carbon budget are underestimated, and they are called as a “passive conduit” for carbon transfer from land to ocean (IPCC, 2007). With the availability of high-frequency data, there is an increase in lake metabolism studies, and the roles of freshwaters in carbon cycling and climate regulation service of the lakes are being acknowledged (Cole et al., 2007; Tranvik et al., 2009). However, particular emphasis mostly placed on provisioning services, like food production and water for drinking and irrigation, while the importance of regulating and supporting services are often neglected, thus resulting in the overexploitation of the provisioning services. Aquatic ecosystems, especially freshwater ecosystem are one of the most degraded ecosystems, and their ecological integrity has adversely been affected by the heavy use of their services such as water for irrigation and fisheries (Poikane et al., 2014). According to WWF Living Planet Index (2016), freshwater populations decreased in all over the world by 81% between 1970 and 2012, mostly due to habitat loss and degradation. Hence, defining the relationships between the services and ecosystem structure and functioning is crucial, and it can contribute to the successful sustainable management of the system.

Table 5.1 Ecosystem services of freshwater bodies.

	Ecosystem services
Provisioning services	Fisheries and aquaculture
	Water for drinking
	Biotic raw materials
	Water for irrigation
	Water for industry
	Raw materials for energy
Regulatory services	Water purification
	Air quality regulation
	Erosion prevention
	Flood protection
	Pest and disease control
	Soil formation and composition
	Carbon sequestration
	Local climate regulation
Cultural services	Recreation
	Intellectual and aesthetic appreciation
	Spiritual and symbolic appreciation
Supporting services	Maintaining populations and habitats
	Nutrient cycling
	Primary production

Ecosystem services assessment requires comprehensive long term data, which is one of the main challenges revealing the changes in ecosystem services through time. However, paleolimnological records, *natural archives* of the ecosystems, stand for a great source for filling the gaps in assessment of the long-term ecological change. With the progress in analyzing paleolimnological proxies and use of advanced statistics, tracking environmental changes through long-term scales has been possible for the last few decades. Biological, geochemical, and physical proxies that are deposited in the lake sediments provide information on ecological changes in local and regional scale (Dearing et al., 2012). These proxies can be from both allochthonous (from the lake-catchment or airborne) and autochthonous (within the lake itself) sources, enabling scientists to reveal and reconstruct past environmental changes, such as eutrophication, hydrology, and climate (Frey, 1988; Last and Smol, 2001). Other than constructing past environmental changes, recently, paleolimnological proxies were also being used for long term ecosystem services assessment (Xu et al., 2017). In their extensive review, Dearing et al. (2012) provided relationships between >50 ecosystem processes and ecological status using paleolimnological proxies from the main categories of supporting, provisioning, regulating, and cultural services.

In this chapter, the aim is to assess long-term ecosystem services of the lake from past to the future using paleolimnological multi-proxies, literature records, and modeling results with special attention was paid to "provisioning," "supporting" and "regulating" ecosystem services. For quantifying provisioning services: fish stocks, water level, water abstraction and cyanobacteria (for irrigation and drinking water); for supporting services: biodiversity indices, and total organic carbon; and lastly for regulatory services: organic carbon burial and water purification proxies were used. We also test the effects of water level on ecosystem services since climate change predictions on Lake Beyşehir indicate significant drops in future water levels, and projections show that lake may even dry out by the 2040s in the worst scenario with the current water abstraction regime (Chapter 3, Bucak et al., 2017). If such relationship exists between water level and ecosystem services, it can provide insights for water managers to take into account other ecosystem services as well, while setting water level thresholds for future.

5.2 Materials and Methods

Long-term ecosystem services of Lake Beyşehir were assessed considering three major services: i) supporting, ii) provisioning and, iii) regulatory. Paleolimnological records of Lake Beyşehir (Levi et al., 2016) and documentary records were compiled to infer the ecosystem services of the lake in the last century.

Additionally, future provisioning ecosystem services were also evaluated using the outputs of Chapter 3 and Chapter 4.

5.2.1 Long-term ecosystem services assessment

The indicators of the ecosystem services and their interpretation are given in Table 5.2. Water level and water abstraction for irrigation, and fish biomass were used for assessing provisioning services. Hydrological data e.g. water level, water abstraction were retrieved from the State Hydraulics Works; fish data from Lake Beyşehir fish cooperation.

Sampling and laboratory methods for paleolimnological analyses are given in Levi et al. (2016). Summary diagram of littoral and pelagic core of Lake Beyşehir is given in Figure 5.1. Remains of Diatoms, Cladocera, and macrophytes were identified, counted, and analyzed by Gizem Bezirci, Ayşe İdil Çakıroğlu, and Eti Ester Levi from Limnology Laboratory, METU, respectively (Levi et al., 2016). Simon Turner, at University College London (UCL) conducted X-Ray Fluorescence (XRF) and loss on ignition (LOI) analysis on ^{210}Pb and ^{137}Cs dated cores in UCL laboratories (Levi et al., 2016). LOI indicates the percentage of organic carbon, carbonate, and mineral matter in the sediment. XRF analysis includes sedimentation rate and heavy metal concentrations sediments. As an indicator of primary production (supporting ecosystem services), total organic carbon (TOC) data was used. Total organic carbon was calculated from the dry weight of the sediment and LOI at 550 ^{o}C values. Organic carbon burial from sediments, indicating carbon sequestration (regulating ecosystem services) was also calculated from LOI (550 ^{o}C) and sedimentation rate (Dong et al., 2012). TP-diatom transfer function (Bennion et al., 2001) was constructed based on the data from 45 lakes including Lake Beyşehir using sediment diatom subfossils in Limnology Laboratory, METU (Bezirci et al. unpublished, TÜBİTAK-ÇAYDAĞ-104Y308, TÜBİTAK-ÇAYDAĞ-110Y125).

Table 5.2 Paleolimnological proxies and data retrieved for quantifying the ecosystem services. The table is modified from Xu et al., (2017).

	Ecosystem services	Literature records	Paleolimnological proxies	Explanation
Provisioning services	Fish	Total fish catch per year		High fish catch indicates the ability of lake to provide fish as provisioning services.
	Water capacity	Water level		The water level is a proxy for the capacity of the lake to provide ecosystem services such as irrigation water supply and drinking water supply.
	Irrigation service	Water abstraction		Water abstraction for irrigation indicates the direct use of lake water for agriculture.
Supporting services	Primary productivity		Total organic carbon (TOC) in the sediment	TOC indicates primary productivity in autochthonous lakes. High values indicate high productivity.
	Biodiversity and richness		Shannon-diversity and richness of diatom, and cladoceran	Biodiversity and richness metrics demonstrate the lake's ability provide habitat and maintenance for organisms. High biodiversity values indicate an ability of lake to provide high supporting services.
Regulatory services	Climate regulation		Carbon sequestration per year	The ability of the lake to mineralize terrestrial organic Carbon (C) and bury autochthonous C is vital for the terrestrial C cycle and thus on the global climate climate. High carbon sequestration indicates the high ability of climate regulation.
	Water purification		TP inferred from diatoms	TP concentration is one of the important indicators of the water quality. High TP concentrations are associated with low water quality and low water purification capacity of the lake.
	Water purification		Potential risk of heavy metal pollution	Heavy metal concentrations indicate the potential risk of water purification loss since heavy metal concentrations affect whole biological organisms. High levels of heavy metals show the low capacity of lake ecosystem to regulate water quality.

Heavy metal concentrations in the sediment were used for calculating the ecological risk potential, indicating water purification potential of the ecosystem (Xu et al., 2017). Hakanson (1980) developed equations for calculating the potential ecological risk factor (ER) for heavy metals, and it is formulated as:

$$ER^i = Tr^i * C_f^i$$

$$C_f^i = C_o^i / C_n^i$$

Where ER^i is the potential risk factor for a given heavy metal *i*, Tr^i is the toxic-response factor for element *i* (Cd= 30, Cu =Pb = Ni= 5, Zn =1, As=10, Yi et al., (2011)), C_f^i is the contaminaton factor for element *i* (Cd=0.5, Cu=30, Pb=25, Ni=29.2, Zn=80, As=15, Hakanson, 1980; Yi et al., 2011; Zhuang and Gao, 2014), C_o^i is the concentration in the sediment, C_n^i is the background reference level for heavy metal *i*. While it is possible to calculate the ecological risk factor for each element, calculation of aggregated risk factor (*RI*) is also used for assessment of potential risk factors. Thresholds for individual *ER* and aggregated *RI* are given in Table 5.. *RI* is calculated as:

$$RI = \sum_{i}^{n} ER^i$$

Table 5.3 Ecological risk (*ER*) thresholds for individual heavy metal and aggregated risk factor (*RI*) derived from the sum of the 6 individual *ER* (Hakanson, 1980).

ER^i	**Risk**	**RI**	**Risk**
<40	Low risk	150	Low risk
40-80	Moderate risk	150-300	Moderate risk
80-160	Considerable risk	300-600	Considerable risk
160-320	High risk	>600	High risk
>320	Very high		

Once ecosystem services have been quantified, the effects of water level to other services were examined by simple regression to determine if marked changes in water level affect the other ecosystem services. R programme (R Core Team, 2016) *lm* function was used to assess these relationships. If such a relationship exists, we also checked if the threshold for minimum water level management of Lake Beyşehir (1122.40 m.a.s.l. as determined by General Directorate for Protection of Natural Assets) was critical for ecosystem services of the lake. Additionally, the factors governing long-term water level changes of the lake (provisioning services capacity) were also investigated using multiple linear regression with R leaps package (Lumley, 2017).

5.2.2 Future ecosystem services

Only irrigation and drinking water services were evaluated in future projections. For irrigation water service, the outputs of Chapter 3, which indicated a maximum water abstraction allowed to sustain lake levels for each climate change scenario was used. The details of the methodology is given in Chapter 3.2. For future drinking water service, cyanobacteria outputs of the lake models' simulations regarding future climate and land use scenarios were investigated considering World Health Organization (WHO) risk thresholds for cyanobacterial bloom (Chorus and Bartram, 1999). Detailed methodology is given in Chapter 4.2.

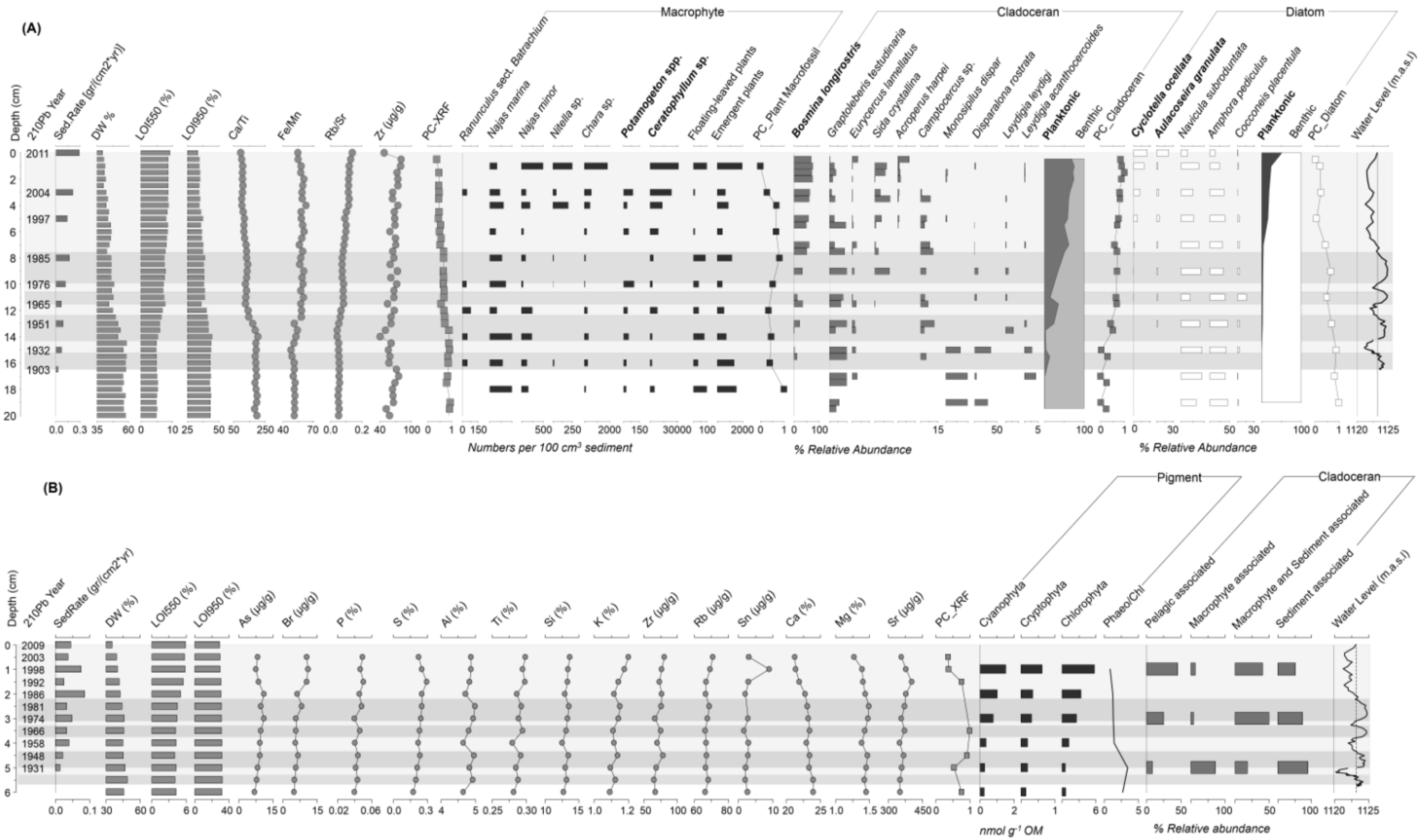

Figure 5.1 Summary diagram of Lake Beyşehir (A) littoral and (B) pelagic cores with biological, geochemical and physical variables. Light grey shading and dark grey shading indicate low and high water periods, respectively. Species names in bold indicate the pelagic environment. Only most dominant sub-fossil cladoceran and diatom species are demonstrated in the graph (taken from Levi et al. 2016)

5.3 Results

5.3.1 Long-term ecosystem services assessment

5.3.1.1 Provisioning services

Water level, which is used as an indicator of the capacity of the lake to provide drinking and irrigation water as provisioning services, showed considerable variations throughout the century. Major water level peaks were recorded in 1949, 1970 and 1981 in which the water levels were above 1124.5 m.a.s.l., while the lowest water levels were recorded in 1934 and 2001 (Figure 5.2). Figure 5.3 shows the individual and combined effects of different predictors including precipitation, inflow, outflow (total water abstraction from the lake), and evaporation on the provisioning services capacity of the lake. Multiple linear regression analysis indicated that outflow and precipitation explained 75% of the variance and adding the inflow and evaporation only resulted in a slight increase in the explained variation, with the full model explaining 76%. Hence climatic processes (precipitation) and water abstraction (outflow) for irrigation were found to be the main drivers of the change in provisioning services capacity of Lake Beyşehir through time. Particularly for some periods increased water abstraction resulted in the major drops (Figure 5.4, gray shaded areas). Though the water abstraction decreased over the recent decades, for the period of 1980-2000 (average of 25 hm^3 $month^{-1}$) the abstraction was still higher than the period of 1950-1980 (average of 20 hm^3 $month^{-1}$), resulting in major water level drops. Considering regulatory board’s decision on the minimum water level permitted for management of Lake Beyşehir, especially for the period between 1991-2010, the lake’s water level were mostly below the recommended water levels required for ecosystem integrity, and sustainable use of ecosystem services, which outflow abstraction should have been ceased (Figure 5.4).

Fish provisioning data is only available from the 1980s. The data showed that there was an increase in fish provisioning services till the 2000s, then it declined (Figure 5.2). Water level did not have a significant effect on fish provisioning service.

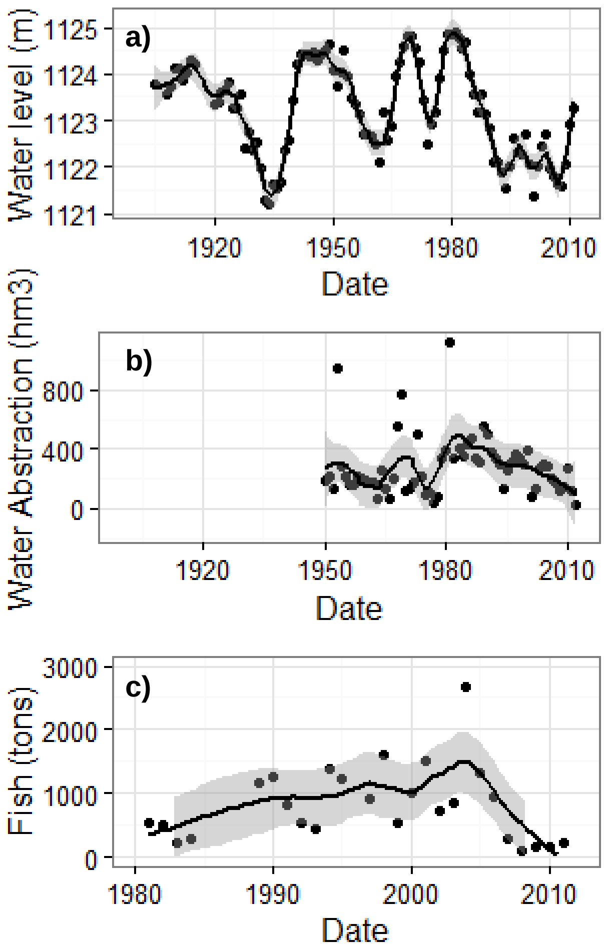

Figure 5.2 Provisioning service indicators of Lake Beyşehir a) Water level, b) Water abstraction, c) Fish catch. Solid blue lines indicate curve fitting with Loess function. Gray band indicates the confidence interval of the curve fitting.

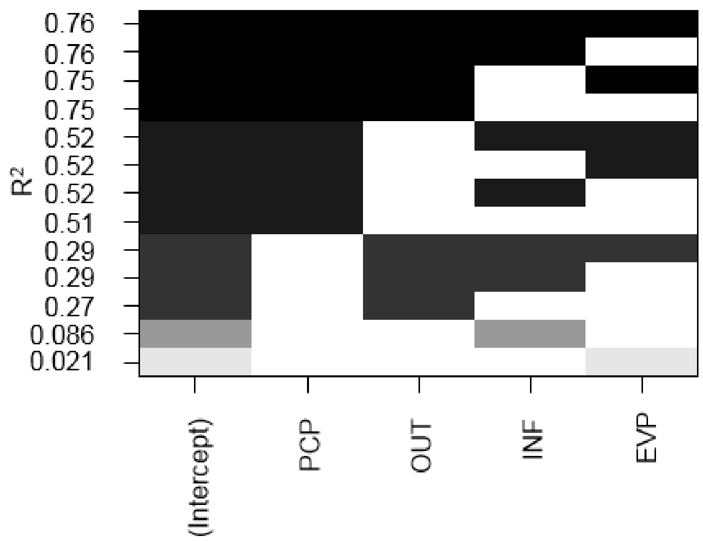

Figure 5.3 R^2 values of different linear model subsets, determining water level change. The black boxes indicate a strong relationship, while gray boxes indicate a weak relationship. PCP: Precipitation, INF: Inflow, OUT: Water abstraction from the lake, EVP: Evaporation. Each row in the graph indicates different subsets of models. For example, the first row at the bottom shows that including only evaporation in the model explains 2% of the variation in water level, while the first row at the top shows full model, which including all variables, explained the 76% of the variation in water level together.

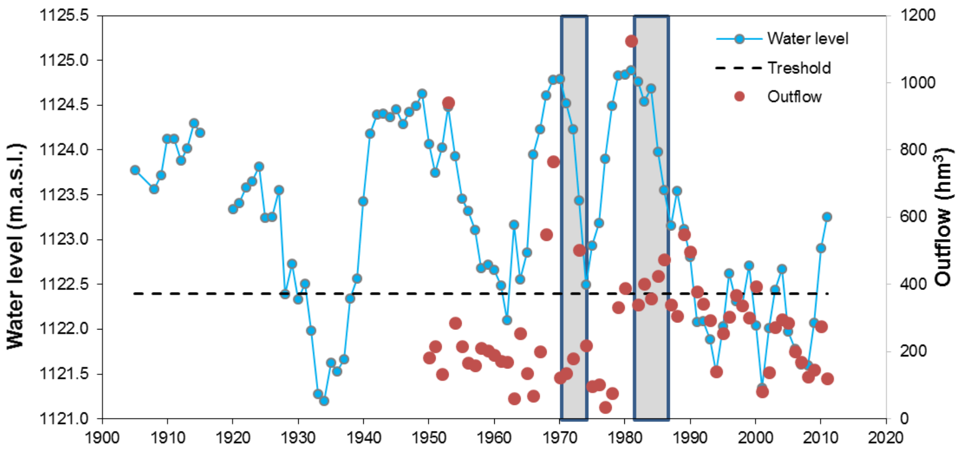

Figure 5.4 Water level and water abstraction for the period of 1950-2011. Gray shaded areas indicate the periods with significant water drops coincided with increased water abstraction. Threshold: Minimum water level that was determined by General Directorate for Protection of Natural Assets.

5.3.1.2 Supporting services

Total organic carbon (TOC), which indicates lake productivity, increased from the 1950s to 2000s, then showed a declining trend till present in pelagic, whereas in the littoral, the productivity increased from the 1930s onward. No significant effect of water level was found on TOC ($p>0.05$).

Species richness and diversity calculated from paleolimnological data (littoral core), indicating supporting services of the lakes showed variation throughout the last century. Diatom richness and diversity increased through time, while the trends in cladoceran and macrophyte richness were less apparent (Figure 5.5). For cladoceran richness there was an increasing pattern till the 2000s, then it decreased. Cladoceran diversity increased towards the 1980s, but it decreased afterward (Figure 5.5). Both for the cladocerans and diatom remains, planktonic species increased through time (Figure 5.6). Cladocera and macrophyte diversity were positively correlated with water level (Figure 5.7). We also checked if the minimum water level management threshold (1122.4 m.a.s.l.) that was determined by General Directorate for Protection of Natural Assets had any effects on supporting services of the lake. As the Table 5. demonstrated both cladoceran, diatom and macrophyte diversity were higher in water levels greater than the threshold; however, only macrophyte diversity significantly differed between periods ($p<0.01$), while for cladoceran the difference was marginally significant ($p<0.1$). Richness did not differ between these periods.

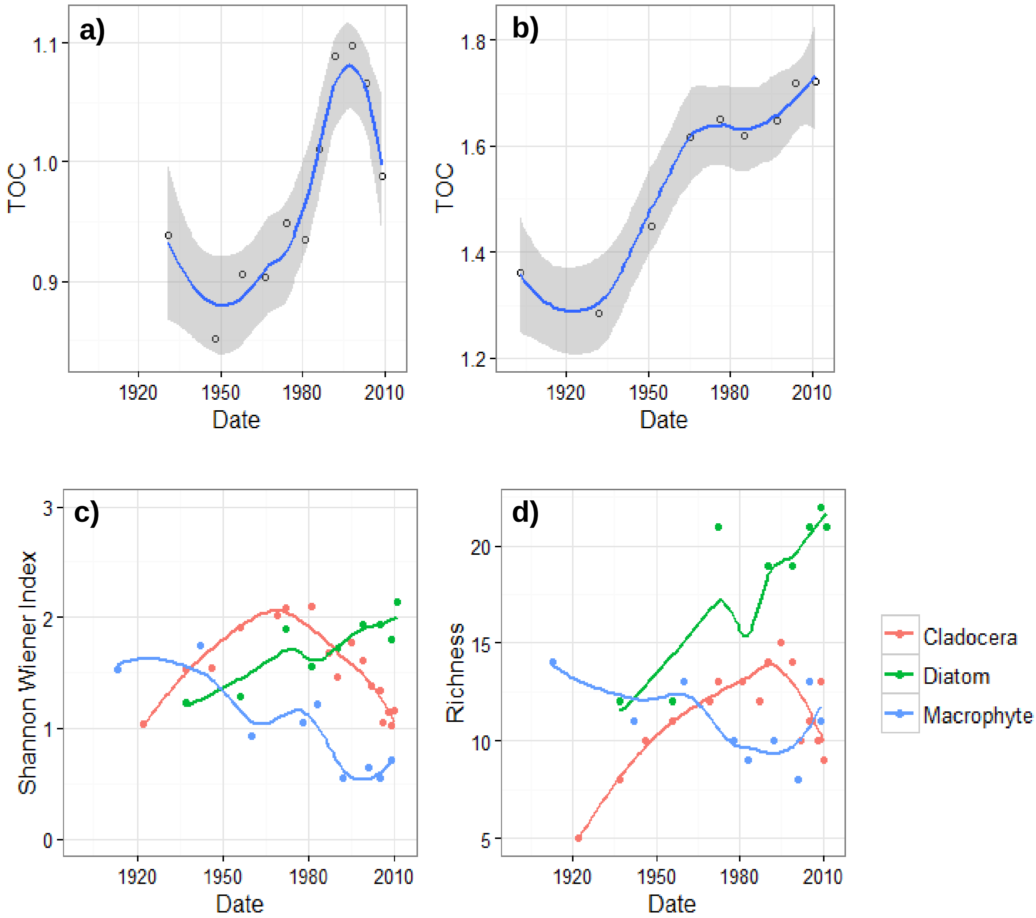

Figure 5.5 Supporting services indicators of Lake Beyşehir a-b) Total organic carbon for pelagic (left) and littoral (right), c) Shannon-Wiener index, d) Richness for Cladocera, Diatoms, and Macrophytes. Solid lines indicate curve-fitted with Loess function. Gray band indicates the confidence interval of the curve fitting.

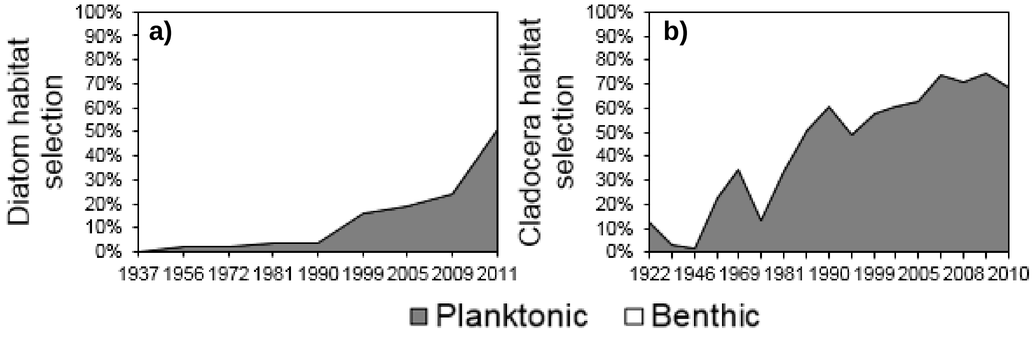

Figure 5.6 Relative distribution of benthic and planktonic species in the sediment a) Diatoms, b) Cladocera.

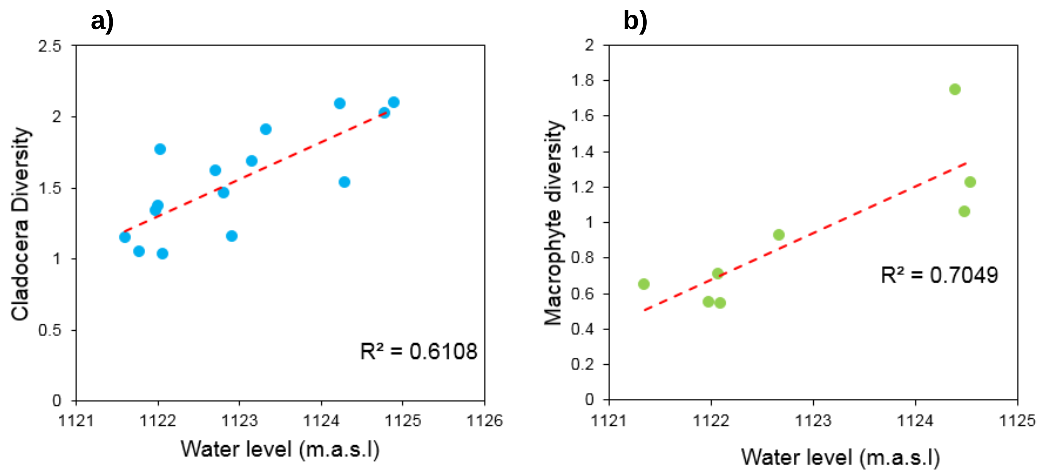

Figure 5.7 Water level relationship with Shannon-Wiener Diversity of a) Cladocera, b) Macrophyte.

Table 5.4 Diatom, Cladoceran and Macrophyte richness and diversity in the littoral core of Lake Beyşehir. Lower indicates water level periods which were less than minimum water management threshold, while higher indicates the opposite.

	Threshold	Diversity	Richness
Diatom	Lower	1.66	18
	Higher	1.76	18
Cladoceran	Lower	1.32	11
	Higher	1.66	11
Macrophyte	Lower	0.62	11
	Higher	1.3	11

5.3.1.3 Regulatory services

There was a trend of increase in organic carbon burial (carbon sequestration) for both littoral and pelagic throughout the century. However, the magnitude of the increase was higher for the littoral (Figure 5.8). Ecological risk (ER) calculated from heavy metals in the sediments showed large variations throughout the study period. The littoral risk factors (RIs) were slightly higher than the pelagic RI values. Most of them were lower than the critical threshold (150), except in 2003 in pelagic and, the period between 1976-1981 and 2009 in littoral (Figure 5.8). Though there was a slight increase in most of the heavy metals throughout the century, their values were still below the thresholds for single ER (<40), excluding Cadmium. The major proportion of the contamination originated from Cadmium, and the ER of Cadmium values were mostly above the threshold >40, indicating moderate contamination for both littoral and pelagic sediments (Figure 5.9), pointing out to decreased water purification capacity of the lake. Diatom-inferred TP values showed slight variation from the 1930s to 2010s, demonstrating the lake maintained its low TP status throughout the century. Diatom-inferred TP concentrations and the measured concentrations were close to each other. None of the indicators used here had a significant correlation with water level.

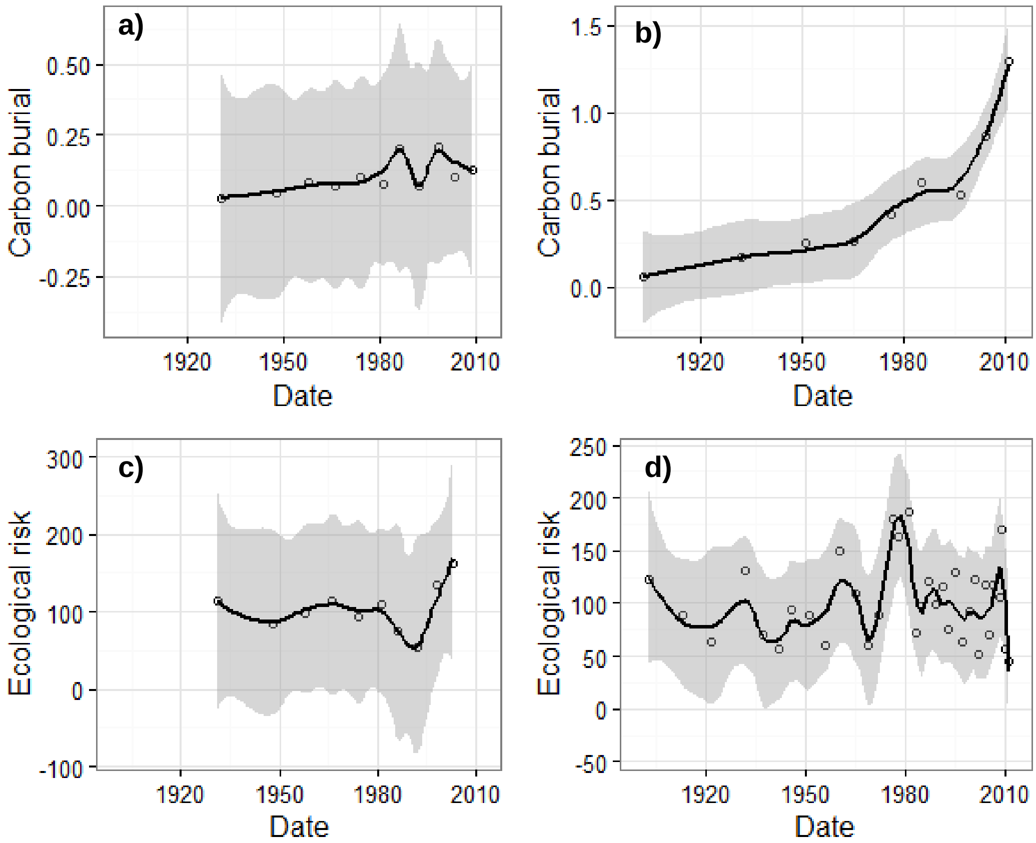

Figure 5.8 Regulatory service indicators of Lake Beyşehir. a-b) Organic carbon burial calculated for pelagic and littoral cores, c-d) ecological risk factor calculated for pelagic and littoral cores. Solid blue lines indicate curve fitting with Loess function. Gray band indicates the confidence interval of the curve fitting.

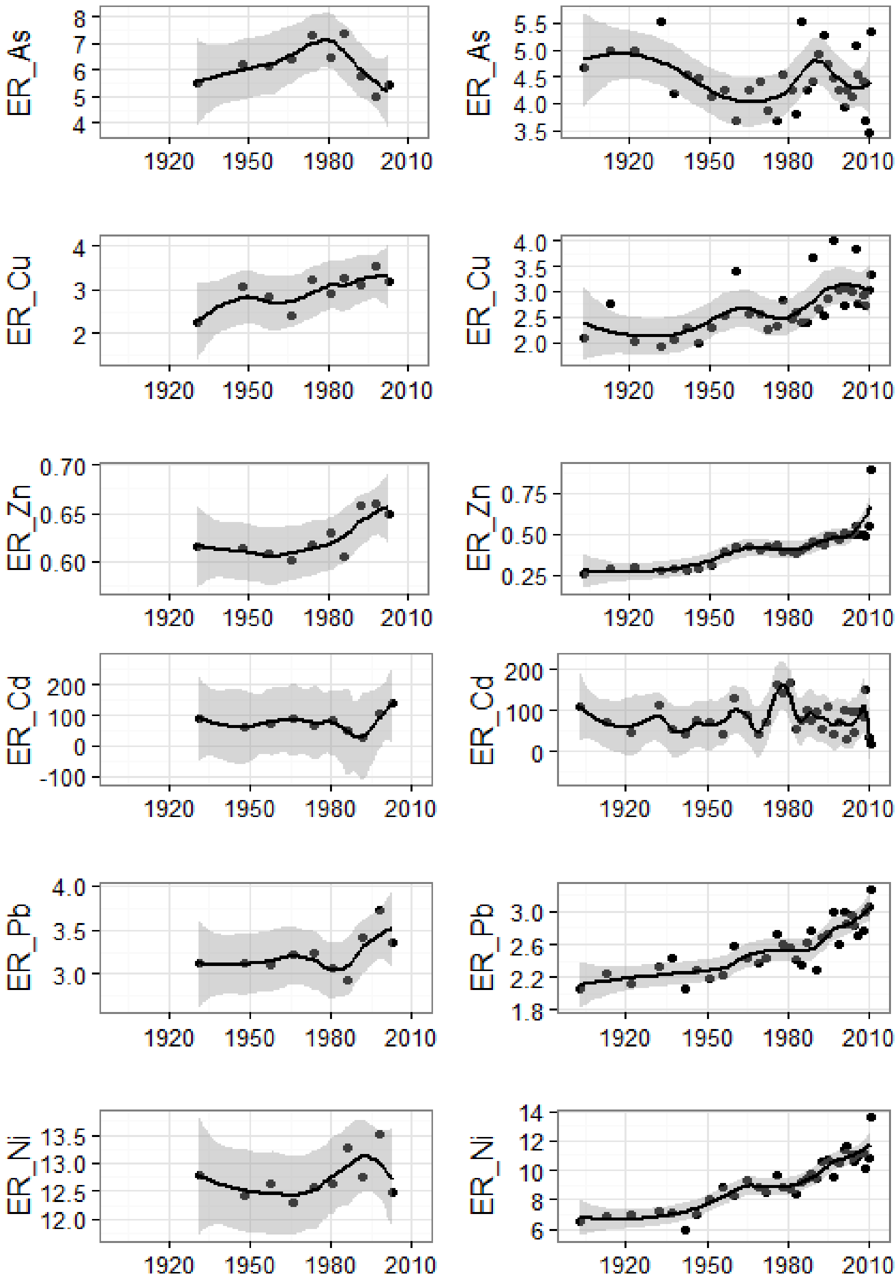

Figure 5.9 Ecological risk factors for heavy metals calculated from sediment. Left panels for pelagic, right panels for the littoral core. ER: Ecological risk. Cd: Cadmium, Pb: Lead, Ni: Nickel, As: Arsenic, Cu: Copper, Zn: Zinc. Solid red lines indicate curve fitting with Loess function. Gray band indicates the confidence interval of the curve fitting.

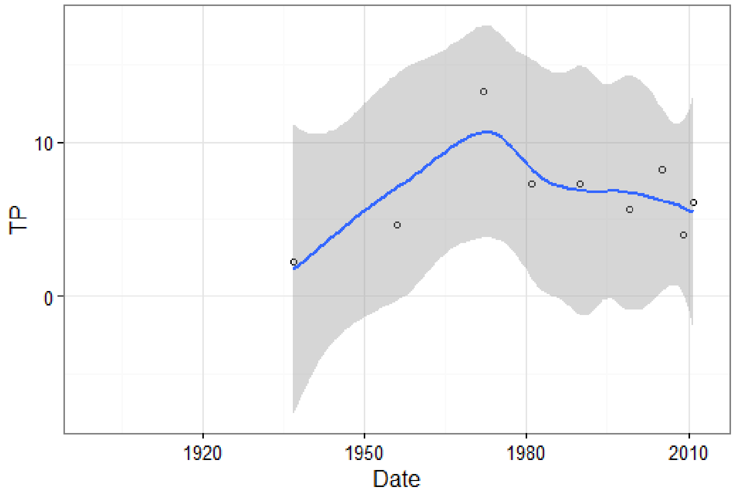

Figure 5.10 Reconstructed TP concentrations inferred from Diatom. The solid blue line shows curve fitted with Loess function. Gray band indicates the confidence interval of the curve fitting.

5.3.2 Future ecosystem services

Regarding different climate change projections, irrigation water service decreased in future time periods, however the extent of change differed among climate models and RCP scenarios (Figure 5.11). Especially after the 2060s, all models indicated a significant decrease in irrigation water services and for MPI model RCP 8.5 scenarios, the decreases were more prononunced. According to MPI model RCP 8.5 scenario (the most pessimistic scenario), in the last two decades of the 21th century, the lake may not function as a irrigation water supply. However, in the most optimistic scenario (HadGEM RCP 4.5 scenario) -21% to -48% decrease in irrigation water service was calculated after 2060s.

According to World Health Organization (WHO) thresholds for cyanobacteria, for 2060s time period, 10 scenarios (out of 25) exceeded WHO limits and a number of days exceeded the limits for each scenario are given in (Figure 5.12). For two-year of simulation time, outputs of HadGEM 8.5 scenario with no land use change resulted in the highest number of days exceeding the WHO low-risk threshold with 80 days; indicating the lake may not serve as a drinking water supply for 80 days in a 2-year period of time.

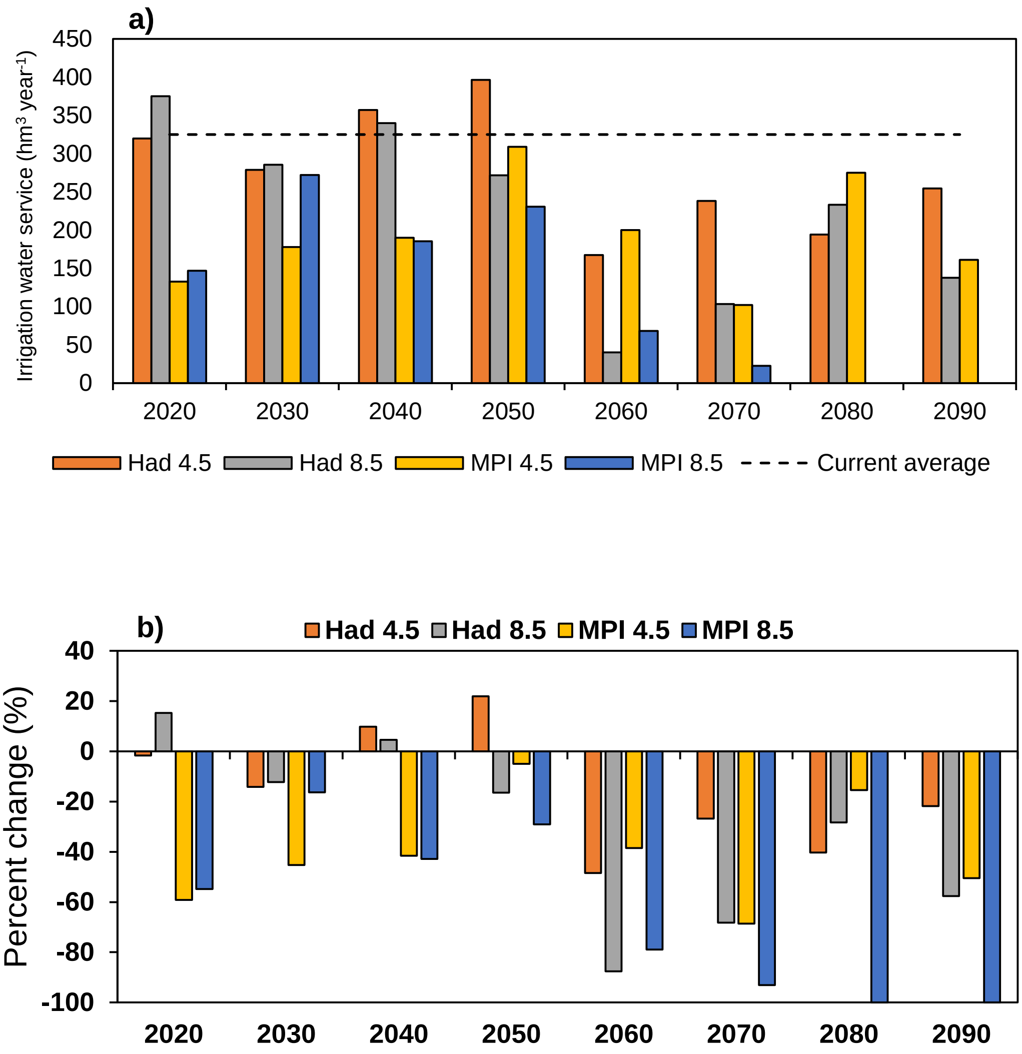

Figure 5.11 Future irrigation service of Lake Beyşehir regarding climate change scenarios. a) Annual water abstraction (irrigation service) should be allowed to sustain lake levels in the future considering climate change scenarios. Current average indicates the average annual water abstraction within the period of 1960-2012. b) Percent change in irrigation water service compared to period 1960-2012.

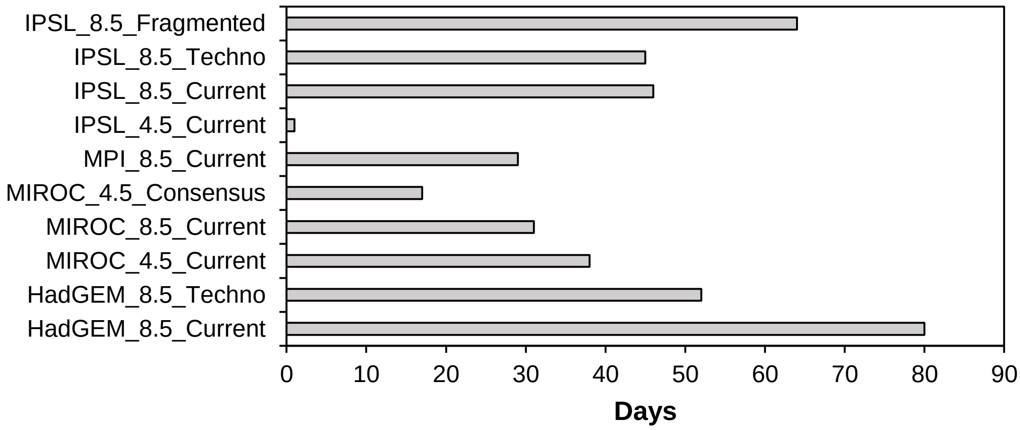

Figure 5.12 Number of days exceeding the low risk WHO limits (10 mg m^{-3} cyanobacterial Chl-*a*) according to future land use and climate scenarios of 2060s period. These outputs were extracted from PCLake results given in Chapter 4. The scenario outputs that did not exceed WHO limits are not shown in the figure.

5.4 Discussion

In this chapter with taking advantage of paleolimnological records, documentary records, together with the future scenario outputs of Chapter 3 and Chapter 4, the past and future ecosystem services of Lake Beyşehir was explored. Marked changes in provisional service indicators (water abstraction and water level) were found throughout the century, and decreasing trend in fish provisioning services was found after the 2000s. We also observed generally increasing trends in total organic carbon and carbon burial in the lake sediments, indicating increased productivity and carbon sequestration capacity of the lake through time. In addition, ecological risk calculated from heavy metal concentrations showed considerable variation throughout time and risk was found to be in low to moderate levels. Future scenario results also indicated a decreased irrigation service capacity of the lake in the future with the probability of low-risk thresholds for cyanobacterial blooms.

Provisioning services are the direct benefits of the humans from the ecosystem (Grizzetti et al., 2015). Lake Beyşehir's water level, indicating the water provisioning service capacity of the lake showed considerable variation through time. The analysis revealed that precipitation and water abstraction are the major drivers of the change in provisioning service capacity of the lake. This is notable because water abstraction for irrigation is an ecosystem service that the lake provides, at the same time it is the major pressure for the provisioning service capacity of the lake, which raises the necessity of the concept "sustainable use of ecosystem services." There are many examples from all over the world that point out the drastic outcomes of intensive irrigation, as has already been observed in Lake Chad (Gao et al., 2011) and the Aral Sea (Micklin, 2007). The Aral Sea, the fourth largest lake in the world, has been exposed to extreme water level reduction of up to 23 m due to the diversion of its primary inflows for irrigation and the lake area has shrunk by 74%. The area of Lake Chad has also been reduced by 90% due to irrigation and drought (Gao et al., 2011). As presented in Chapter 3, Lake Beyşehir can also be at risk of drying out in future as a response to future climatic changes and substantial reduction (9-60%) in water abstraction is required to maintain the water levels and the ecosystem services that the lake provides. Hence, it is critical to find the balance between the capacity of the provisioning services and sustainable use of the services. In particular for the period of 1991-2012, due to mismanagement and overabstraction of the lake water levels, Lake Beyşehir was exposed for an extended period of low water levels, and the lake water levels were most of the time lower than the recommended minimum water level ranges that are required for ecosystem integrity.

Not only through direct water abstraction through lake outflow, but increased groundwater abstraction is also one of the biggest problems in the basin as 1 m $year^{-1}$ decrease in groundwater levels was reported (WWF, 2010). According to WWF report (2010), in the entire Konya closed basin, there are 76382 groundwater wells, and 70% of them are unregistered. Hence it is very likely that unexplained variance in the decreased provisioning service capacity of the lake in the last decades may also be attributed to increased groundwater consumption in the basin.

Commercial fishing as a provisioning service of the lake also had increased till the beginning of the 2000s and it is followed by a decrease. Increase in fish provisioning service till 2000s can be attributed to increased *Sander lucioperca* stocks till 2000s. After *Sander lucioperca* has been introduced to the lake in the late 1970s, *Sander lucioperca* population increased through time and since it has a high economic value, most of the fish catch was dominated by *Sander lucioperca* (data were taken from Beyşehir fish cooperation). However, after 2000s, the population of *Sander lucioperca* decreased in the lake.

Fisheries were the main income of the people living around the lake till the 2000s, but afterward, there was a substantial decrease in fish population, coinciding with invasive fish introductions (Babaoğlu, 2007). It was also reported that due to reduced commercial fish, the number of fisherman boats also dropped to 300 from 3000 in the last years (data were taken from Beyşehir fish cooperation). In addition, the introduction of *A. boyeri*, which feeds on fish eggs and larvae, to the lake, may have contributed to the decrease in commercial fish population as well, thus also to the decline of fish provisioning service (Babaoğlu, 2007). Moreover, in our sampling campaign (Chapter 2), we also recorded invasive *P. parva* in high abundance. Both *A. boyeri* and *P. parva* were characterized by a high reproductive rate and wide adapting capacity in diverse environments (Ekmekçi and Kirankaya, 2006; Kottelat and Freyhof, 2007; Maugé, 1990) that they can invade new environments fast. Veer et al. (2015) indicated that *P. parva* had a significant ecological and economic impacts on the water bodies that they are introduced. Not only through their competition and high survival ability, but the biggest threat that they pose is also the transmission of infectious pathogens may result in loss of native fauna. Pindera et al. (2005) showed that *P. parva* introduction resulted in complete inhibition of spawning of endangered sun break *Leucaspius delineates*. Though the data is lacking to validate the reasons for the decrease in fish provisioning services, fish introduction may be the causes since these events coincided with the decline in lake fish stocks. Drastic effects of fish introductions also recorded in the past in Lake Beyşehir as the introduction of *S. lucioperca* resulted in the extinction of endemic *Alburnus akili* from the lake (Yeğen et al., 2006).

One of the main ecosystem services of the lakes is the providing habitat (supporting services), and diverse niches to organisms (e.g., different species of fish, phytoplankton, zooplankton and macrophyte), and ecological structure determines the supporting services that the lake provides. Recent studies from Mediterranean climatic regions showed that water level fluctuations are very critical in controlling the growth of macrophytes and ecosystem structure (Beklioğlu et al., 2017; Bucak et al., 2012; Özkan et al., 2010; Stefanidis and Papastergiadou, 2013). In paleolimnological records, positive relationship between water level and macrophyte diversity was found contradicting to findings in the monitoring period (Chapter 2), which shows the increased diversity in low water years. In their studies, Levi et al. (2016) investigated plant macrofossils of the Lake Beyşehir in the littoral core, and their records showed a high amount of low-light tolerant, tall-growing plant remains during low water level period, suggesting that this observation could be related to increased turbidity in the lake. Moreover, it should also be noted that both years of the monitoring period (2010-2011) coincided with the aforementioned low water levels. Though lower water levels are generally related to the enhanced macrophyte community, it might also increase resuspension, thus decreasing water clarity, depending on the prevailing meteorological conditions (Jeppesen et al., 2015). All in all, the results point out the complex structure of water-level macrophyte diversity relationship in Lake Beyşehir, driven by both water level and turbidity. While high water levels have a potential to support more diversity (supporting services) due to the possibility of reduced turbulence, macrophyte diversity may also be favored in low waters depending on the meteorological conditions.

The results also revealed that Cladocera diversity was higher for the periods having higher water level (although it is marginally significant). The effects of water level on zooplankton community and diversity are less studied and mediated through indirect mechanisms (Jeppesen et al., 2015). There are studies indicating increased zooplankton richness in high water level periods, probably due to lower conductivity and lower suspended solids concentrations (Chaparro et al., 2011). Lower water levels can also trigger eutrophication symptoms, may result in high nutrients, and low diversity (Jeppesen et al., 2015). Sedimentary remains of Diatom and Cladocera also pointed out to shift towards planktonic species abundance, coinciding with the long-term low water level period (1989-2011), possibly as a result of the augmented turbidity with decreasing water levels, which may have negative effect on diversity. However, fish predation may be also one of the major pressures for zooplankton composition (Jeppesen et al., 2000), and especially the abundance of planktonic *Bosmina* (Levi et al., 2016) also indicates high fish predation in the lake (Kitchell and J.F, 1980). Throughout the littoral core of Lake Beyşehir, *Bosmina* was the dominant species, supporting enhanced fish predation in the lake. All in all, in addition to water level, for cladoceran, fish predation could also be one of the major factors determining diversity.

In this chapter, carbon burial rate was used as a proxy for climate regulation service. We found a generally increasing trend in organic carbon burial, especially in the littoral zone throughout the century. It should be noted that carbon can be originated from both allochthonous and autochthonous sources. However, we did not have data to test its origin, but the results showed that increased carbon burial (sink) coincided with the total organic carbon –indicating autochthonous sources through increased primary production– may be lead to enhanced carbon burial in sediments (Figure 5.5, Figure 5.8). Studies show that eutrophic lakes can have higher carbon burial rates due to higher primary production rates (von Wachenfeldt and Tranvik, 2008). However, CO_2 sink capacity of the lake should not be only attributed to the phytoplankton, macrophyte growth can also increase the CO_2 sink capacity of the lake by storing the carbon as plant material in the sediments (Jeppesen et al., 2016). Since paleolimnological data did not give precise information about biomass but only give relative abundances of macrophytes and phytoplankton, it was also likely that macrophytes were the primary avenue for carbon burial through time. In conclusion, our results show that climate regulation services of the lake have increased over the course of the century.

Heavy metal contamination is a significant threat to ecosystem integrity, biodiversity, and regulatory services (Chen et al., 2000; Yi et al., 2011), and they can affect the organisms by accumulating in their body. It also affects the drinking water quality of the water bodies. Hence its effects can also be observed in provisioning (drinking water quality, bioaccumulation in fish), regulating and supporting services (through its effects on organisms). Heavy metal contamination, is defined as an ecological risk factor (ER) calculated from 6 different heavy metals illustrated that ER remained mostly low throughout the century, except cadmium which had low-considerable ER throughout the century. Our results are in accordance with an earlier study carried out by Nas et al., (2009) who also found out that heavy metal concentrations in the lake water (2005-2006) did not exceed the thresholds of WHO (World Health Organization), US ESPA (Environmental Protection Agency), TWQCR (Turkish Water Pollution and Control Regulations). Hence, the results of the current study pointed out that though having low heavy metal contamination for most of the heavy metal indicators, cadmium may set a potential source of ecological risk for both provisioning services (drinking water quality, accumulating in fish) and integrity of ecosystem dynamics arising.

Though the use of paleolimnological proxies in assessing ecosystems services was highly valued, there were also some problems exist, like the non-uniqueness of the driving factors of proxies, difficulties arose from dating of the sediments (Dearing et al., 2012). Additionally, the approach is not direct but it is indirect as we are able to trace the services which leave paleolimnological traces (Birks and Birks, 2006).

Another limitation of this study is the low number of samples in both monitoring dataset and also from the paleolimnological proxies. Since the sedimentation rate of the Beysehir lake is very low; in the pelagic core, 5 cm corresponded to 1930s, while in the littoral core 17 cm corresponded to 1900s which make it difficult to detect short-term changes (Figure 5.1, Levi et al., 2016). Hence, more fine-resolution data is needed to determine critical water level which supports high ecosystem services. In addition, there are many other factors may have an influential role in long-term ecological services of the lake, such as land use, nutrient loadings, human interventions. However, given the limitations of available data, it was not possible to disentangle the possible causes of ecosystem services changes in a more robust manner. Therefore, we also emphasize the necessity to develop long-term monitoring programs in Turkey and to improve data sharing.

Future projections for ecosystem services indicated that the irrigational water service capacity of the lake may decrease in the future regarding climatic changes. Though the magnitude of changes differed among decades, in overall 9-60% of decrease in irrigational water capacity of the lake was predicted in order to sustain lake water levels in the future (Bucak et al., 2017, Chapter 3). Especially in the most pessimistic scenario, for the last two decades of 21th century, irrigation water services should be stopped in order to prevent the lake from dry out. Future cyanobacteria biomass, indicating the drinking water quality, demonstrated that for some of the scenarios the lake may not function as a drinking water supply for certain periods in the 2060s. These results indicate that climate change may both threat irrigation and drinking water services of Lake Beyşehir.

Overall, we observed decreasing trends in water level of the lake in the last decades due to increased water abstraction and climatic patterns. Though the effects of water level on regulatory services were less evident, due to its noticeable effects on biological organisms and supporting services, it demonstrates the necessity of taking into consideration of all ecosystem services together to prevent overexploiting one service at the expense of the others. We also emphasize the need for sustainable water abstraction to maintain provisioning services in the future as well, since considering the climate change effects on Lake Beyşehir (Bucak et al., 2017), warmer and drier conditions may result in decreased water levels (Chapter 3) and decreased irrigation water service of the lake. Furthermore, increased cyanobacteria contribution (Chapter 4) may lead to further reduction in ecosystem service capacity of the lake. In addition, this study also highlights one more time the consequences of unconscious species introduction to the lakes, which may give rise to drastic changes in the lake ecosystems and ecosystem services that they deliver.

CHAPTER 6

CONCLUSIONS

This thesis considers the past, current and future hydrological and ecological changes of Lake Beyşehir, with the perspective of ecosystem services. The second chapter gives a detailed description of Lake Beyşehir based on a 2-year monitoring data. The third chapter focuses on predicting the impacts of climate change and land use on water availability in the catchment and lake water levels, and how to regulate lake outflow to sustain lake levels in a warming world. The fourth chapter is an extension of the third chapter, includes coupling catchment models with two different lake models, with the aim of predicting future nutrient and phytoplankton dynamics considering climatic and land use changes. The final chapter focuses on the assessment of the long-term ecosystem services of Lake Beyşehir from past to the future, using paleolimnological proxies, documentary records and the modeling outputs of Chapter 3 and Chapter 4.

The results of the 2-year monitoring period revealed that Lake Beyşehir has a low productivity and it does not have a strong seasonality regarding physicochemical variables. Moreover, water depth and water clarity are found to play an important role in macrophyte development. Four endemic fish species were also recorded in the lake during monitoring survey. However, their abundance was very low, and the lake was dominated by invasive species *Pseudorasbora parva*, *Atherina boyeri* and *Carassius carassius* (Chapter 2).

Hydrological modeling revealed that climate change may have a substantial impact on hydrological processes in Lake Beyşehir catchment, resulting in a significant decrease in water availability in the catchment and severe lake level drops. We also demonstrated the importance of water level management and calculated how much reduction in outflow withdrawal is needed to prevent the lake from drying out. However, it should also be noted that climate change may further increase the water demand in the catchment, due to predicted increases in temperature and reductions in precipitation. Hence, in the future, outflow management may not be feasible. That is why we acknowledge the necessity of adopting measures like changing the current crop pattern with drought-resistant ones and promoting efficient irrigation technologies to decrease the water need in the catchment. Moreover, the performance of the ε-SVR model indicated that potential evapotranspiration (PET) could be used as an input variable to predict water levels when the direct calculation of lake area is not possible. However, the high uncertainty derived from general circulation models (GCMs) and necessity of running several of these in order to have more robust predictions for the future water levels was also highlighted in this chapter (Chapter 3).

The fourth chapter focused on the effects of climate change and land use on lake nutrients, phytoplankton and water level, which are the indicators of lake water quality for drinking and irrigation. Within this scope, the outputs of SWAT model (hydraulic and nutrient loads) were coupled to two different complex ecosystem models, and these models were run by using five different GCMs and 3 land use scenarios. Our results indicated that climate change and land use had significant impacts on nutrient loadings from the catchment to the lake, and most of the scenarios predicted decreased hydraulic and nutrient loads in the future. However, the results also showed that increased agricultural areas, with higher fertilizer use, could lead to increased nutrient loading despite lower hydraulic loading. We also found differed responses from lake models in future scenarios regarding total phosphorus, total nitrogen, and chl-*a* predictions, while both models predicted an increase in future cyanobacteria biomass. Though for most of the scenarios cyanobacteria biomass was still lower than the WHO's thresholds for cyanobacteria bloom, the temperature was expected to increase further, especially at the end of the century, which may further increase cyanobacteria abundance and result in degradation of water quality. We also highlighted that in modeling studies all sources of uncertainties should be included. Though uncertainties derived from GCMs are mostly acknowledged in the literature, uncertainties derived from the structure of lake models can also be high and they should be considered as well, while interpreting future predictions (Chapter 4).

Lake Beyşehir provides numerous ecosystem services, such as supplying water for drinking and irrigation, providing an opportunity for fisheries and providing habitat for many species (including endemic species). The final chapter focuses on ecosystem services assessment of Lake Beyşehir from the past to future. Long-term ecosystem service assessment of Lake Beyşehir revealed that lake provisioning services (i.e. water supply and fishing) had a declining trend for the last two decades. Not only through its impacts on commercial fisheries but also its effects on the endemic fauna of the lake, the fish introduction was one of the major threats to the lake. Our results also showed that high water levels generally promoted high species diversity, indicating high supporting services during high water level. Moreover, the results also pointed out increased climate regulation service of the lake throughout the century, but underlying reasons were not clear. Though our data was not vast to reveal significant interactions among ecosystem services of the lake, this study highlighted the importance of considering all these services together, instead of exploiting one service at the expense of the others. Future projections also indicated that irrigation water service may decrease in the future as a result of climatic changes. The results also demonstrated that cyanobacteria contribution may increase in the 2060s and may threaten the drinking water service of the lake for certain periods (Chapter 5).

Overall, our results demonstrate that the ecology and hydrology of the Lake Beyşehir are highly dependent on changes in climate and land use. Hence, for sustainable management of future ecosystem services of the Lake Beyşehir, long-term management plans should be put forward, considering all the dynamics in the catchment and projected climatic changes. Otherwise, the largest freshwater lake of Mediterranean region may be at risk of significant water level drops and losing its ecosystem services.

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APPENDIX A

Table A.1. List of Phytoplakton species recorded in Lake Beyşehir throughout sampling period.

Species		
Alucoceria granulata	*Jaaginema sp.*	*Peridinium sp.*
Asterionella sp.	*Kricheniella sp.*	*Pediastrum simplex*
Anabaena sp.	*Melosira varians*	*Phacus sp.*
Ceratium sp.	*Merismopedia glauca*	*Phormidium sp.*
Closterium aciculare	*Merismopedia sp.*	*Planktothrix sp.*
Closterium sp.	*Monoraphidium arcuatum*	*Plantothrix agardii*
Cryptomonas sp.	*Monoraphidium contortum*	*Rhicospenia sp.*
Cyanophyta	*Monoraphidium komarkovae*	*Rhicospenia curvata*
Cyclotella sp.	*Monoraphidium sp.*	*Rhodomonas sp*
Cyclotella ocellata	*Monorphidium irregulare*	*Rhopalodia gibba*
Coconeis sp.	*Mougeotia sp.*	*Scenedesmus dimorphus*
Coconeis placentula	*Navicula sp.*	*Scenedesmus sp.*
Crucigenia tetrapedia	*Nitzschia acicularis*	*Spirulina sp.*
Dinobryon divergens	*Nitzschia palea*	*Staurastrum sp.*
Euglena sp.	*Nitzschia sp.*	*Synedra sp.*
Golenkinia radiata	*Oocyctis sp.*	*Synedra ulna*
Gomphonema sp.	*Pediastrum duplex*	*Tetraedron sp.*
Gomphonema truncatum	*Pediastrum sp.*	*Tabellaria sp.*
Gymnodinium sp.	*Pediastrum tetras*	*Tetraedron minimum*
Gyrosigma sp.	*Peridiniopsis sp.*	
Gyrosigma acuminatum	*Peridinium cunningtoni*	

Table A.2. List of Zooplankton genus recorded in Lake Beyşehir throughout the sampling period.

Zooplankton genus	
Asplancha	*Diaphanosoma*
Bosmina	*Calanoid copepod*
Cyploploid copepod	*Rotaria*
Daphnia	*Herpet*
Diaphanosoma	*Euchlanis*
Keratella	*Filinia*
Nauplii	*Ascomorpha*
Polyarthra	*Leptodora*
Trichocerca	*Pompolyx*
Ceriodaphnia	*Hexarthra*

Table A.3. List of macrophytes species recorded in Lake Beyşehir throughout the sampling period.

Macrophyte species	**2010**	**2011**
Ceratophyllum sp.	1	1
Myriophyllum spicatum	1	1
Myriophyllum verticillatum	1	1
N. lutea	1	
Najas sp.	1	1
Najas marina	1	1
Polygonum sp	1	
Potamageton lucens	1	1
Potamageton nodosus	1	
Potamageton pectinatus	1	
Potamageton perfoliatus	1	1
Potamageton salicifolius	1	
Potamageton sp.	1	1
Potamageton gramineus	1	
Utricularia australis	1	
C. demersum		1

APPENDIX B

Table B.1. Management operations for the dominant crop types in the catchment. N: Nitrogen, P:Phosphorus.

Crop	Year	Month	Day	Operation	Detail
Winter wheat and Winter barley	1	2	15	Fertilizer application	30 kg N/ha
	1	3	31	Fertilizer application	30 kg N/ha
	1	7	10	Harvest and kill operation	
	1	10	15	Tillage operation	Moldboard Plow 2-way 4-6b
	1	11	8	Fertilizer application	60 kg P/ha
	1	11	9	Fertilizer application	30 kg N/ha
	1	11	10	Sowing	
Chick peas	1	3	10	Fertilizer application	70 kg P/ha
	1	3	11	Fertilizer application	25 kg N/ha
	1	3	25	Sowing	
	1	7	15	Harvest and kill operation	
	1	11	15	Tillage operation	Moldboard Plow 2-way 4-6b
Sugar beet	1	3	5	Fertilizer application	30 kg P/ha
	1	3	6	Fertilizer application	170 kg N/ha
	1	3	15	Sowing	
	1	5	1	Auto irrigation initialized	
	1	10	1	Harvest and kill operation	
	1	10	2	Tillage operation	Moldboard Plow 2-way 4-6b
	1	11	1	Fertilizer application	60 kg P/ha
	1	11	11	Tillage operation	Moldboard Plow 2-way 4-6b

Table B.2. Monthly temperature (^oC) increase in the climate change scenarios.

	MPI		HadGEM	
Months	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Jan	1.8	2.7	3.2	4.7
Feb	2.2	3.0	3.3	4.1
Mar	1.9	2.6	2.4	3.9
Apr	1.1	2.2	2.8	3.6
May	1.5	2.4	2.7	3.5
Jun	1.6	3.1	2.2	3.3
Jul	1.5	2.8	3.7	5.3
Aug	1.1	2.5	3.1	4.6
Sep	0.9	1.9	2.9	3.8
Oct	0.9	2.0	2.5	3.2
Nov	1.7	2.3	2.8	4.2
Dec	1.5	2.1	1.8	3.1

Table B.3. Monthly precipitation change (mm) in the climate change scenarios.

	MPI		*HadGEM*	
Months	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Jan	-4	-6	2	13
Feb	-4	-5	-6	-1
Mar	-2	-10	-1	-3
Apr	-8	-16	8	-4
May	-11	-21	2	8
Jun	-2	-11	3	7
Jul	-6	-6	-1	-1
Aug	-3	-3	-5	-6
Sep	-3	-2	-4	-6
Oct	16	10	11	-1
Nov	-12	-14	-2	-7
Dec	4	2	4	-6
Sum	-35	-82	11	-6

Table B.4. Fitted parameter values after hydrological calibration of the model. Basin parameters were fixed for each sub-catchment, while the other parameters differed between all sub-basins.

SWAT Parameter	SWAT Parameter definition	Unit	Fitted parameters	Default parameters	Recommended ranges*	Mediterranean ranges
SNO50COV	Snow water equivalent that corresponds to 50% snow cover	%	0.3	0.5	0-1	
SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover	mm H_2O	418.58	1	0-500	
SOL_BD	Moist bulk density	mg m^{-3}	0.9 – 2.09	1.39-1.72	0.9-2.5	0.1[a], 1.14[c], 1.15-1.44[d]
SOL_Z	Depth from soil surface to bottom of layer	mm	24.7 – 445	25.4-300	0-3500	500[b]
SOL_AWC	Available water capacity of the soil layer	mm H_2O mm^{-1} soil	0 – 0.26	0-0.16	0-1	0.083-0.166[a], 0.22[b], 0.03-0.14[d], 0.06-0.11[e]
CH_K2	Effective hydraulic conductivity in main channel alluvium	mm $hour^{-1}$	0 – 135	0	-0.01- 500	45[c], 5-500[f]
CH_N2	Manning's "n" value for the main channel		0.01 - 0.29	0.014	-0.01- 0.3	0.05[b], 0.034[c], 0.17[e]
ALPHA_BNK	Baseflow alpha factor for bank storage	Days	0.04 – 0.89	0	0-1	
HRU_SLP	Average slope steepness	m m^{-1}	0 – 0.59	0-0.59	0-1	
ESCO	Soil evaporation compensation factor		0.4 – 0.95	0.95	0-1	0.21[a], 0.95[b], 0.86[c], 0.89[e], 0.01-1[f]
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	mm H_20	211 – 4241	1000	0-5000	4925[a], 124.3[c], 700[d], 1202[e], 0-1000[f]
GW_REVAP	Groundwater revap coefficient		0.02 – 0.16	0.02	0.02-0.2	0.038[a], 0.13[c], 0.05[d], 0.09[e], 0.02-0.2[f]
RCHRG_DP	Deep aquifer percolation fraction		0.05 – 0.47	0.05	0-1	0.02-0.076[a], 0.62[c], 0.33[e], 0-1[f]
GW_DELAY	Groundwater delay	Days	0.37 – 499	31	0-500	5.5-55[a], 50[b], 65[c], 60[d], 1.8-6[e], 0-500[f]
CN2	SCS runoff curve number		25 – 98	35-92	25-98	53-75[a], 71-86[b], 25-85[d]

[a] Panagopoulos et al., 2014, [b] Akiner & Akkoyunlu, 2012, [c] Güngör & Göncü, 2013, [d] Ertürk et al., 2014, [e] Molina-Navarro et al., 2014, [f] Malagò et al., 2016, *Abbaspour 2013

Table B.5. Key papers addressing the effects of climate change on water availability in the Mediterranean basin.

Study	Model and Scenarios	Study site (Location/Area/Precipitation)	Key results
1-Milano et al 2013	Model: Water Balance Model Four GCMs (CSIRO-Mk3.0, HadCM3, ECHAM5/MPI-OM, CNRM-CM3) with A2 emission scenario Water use: "Business as usual", improved water efficiency in irrigated areas	Mediterranean basin/Spain-France-Italy-Slovenia-Croatia-Bosnia and Herzegovina-Montenegro-Albania-Greece-Turkey-Malta-Cyprus-Syria-Lebanon-Israel-Egypt-West Bank-Gaza Strip-Libya-Tunisia-Algeria-Morocco/1,500,000 km^2/50-1000 mm	• By 2050, a 30-50% decline in water availability is predicted. • Total water withdrawal is expected to double in the southern and eastern Mediterranean region. • Efficiency of water distribution networks decreases water stress.
2-Koutroulis et al 2013	Model: SAC-SMA rainfall-runoff model Scenarios: Three GCMs (CNCM3, ECHAM, IPSL) and ensembles of RCMs with B1,A2, A1B emission scenario	Crete/Greece/8265 km^2/934 mm	• Estimated water deficit predicted to increase by 10-74% in the climate change scenarios. • Scenarios show that the future water availability cannot meet the current demand.
3-Kalogeropoulos et al 2013	SWAT model: Climate scenarios: Combination of T increase by 1-2-3 C and precipitation decrease by 5-10%	Afrouses catchment/Greece/12.9 km^2/570 mm	• Scenarios testing only temperature demonstrate a negligible effect on runoff. • A 3 ^{o}C temperature increase and a 10% precipitation decrease result in a 14.3% reduction of runoff.
4-Ertürk et al 2014	Model: SWAT Scenarios: ECHAM5-r3, IPSL, CNRM and HADCM3-Q0 GCMs were downscaled using RCA3 RCM	Small catchment in Köyceğiz-Dalyan Lagoon Catchment/Turkey/69 km^2/NA	• Climate change scenarios display an increased number of water-stressed days. • Aquifer storage, soil water storage, evaporation, and water yield will decrease. • Baseflow decreases up to 80%.
5-Smiatek et al 2014	Model: WASIM Scenarios: HadCM3 GCM with A1B emission scenario	Upper catchment of Jordan river/Lebanon-Israel-Syria border/863 km^2/590.3 mm	• A 12% reduction of runoff for 2030-2060 and a 26% reduction for 2070-2099 are predicted. • Discharge decrease related to reduced number of years with high flow. • Higher elevation regions will be exposed to higher reductions in flow.
6- López-Moreno et al 2014	Model: RHESS Scenarios: Twelve RCMs (ENSEMBLES project) Land use scenario: Shrubs shift to evergreen needle forest	The Upper Aragón River/Spain/2181km^2/800-1500 mm	• Combined effects of increase in forest cover and climate change scenarios reduce the flow by 29.6%. • Marked decrease in runoff in all months except January and February. • Most extreme trends in warming expected to occur in summer, making it difficult to meet the current water demand.

Table B.5. (continued)

Study	Model and Scenarios	Study site (Location/Area/Precipitation)	Key results
7-Molina-Navarro et al 2014	Model: SWAT and Vollenweider empirical model Scenarios: Climate scenarios were generated by the Spanish Meteorological Service with B1, A1B, B2 emission scenarios Land use: Land abandonment, aridity, fertilization reduction, agricultural expansion, rotation of winter barley and peas, increase of sunflower	Tagus river basin/Spain/88 km^2/600 mm	• Climate change scenarios show reductions in river flow of up to 48.7%. • Increased surface flow and decreased groundwater level occur. • Impacts of climate change are more prominent than those of land use change.
8-Serpa et al 2015	Model: SWAT Scenarios: ECHAM5 GCM with A1B and B1 emission scenarios Land use: Decrease in agricultural area	São Lourenço/Portugal/6.20 km^2/900 mm Guadalupe/Portugal/4.49 km^2/533 mm	• Climate change scenarios demonstrate decreased stream flow in both catchments. • Reduction of agricultural areas results in increased stream flow.
9-Sellami et al 2016	Model: SWAT Scenarios: Four best GCMs (outputs of EU-FP6 ENSEMBLES) representing catchment A1B emission scenario	Thau catchment/South France/280 km^2/600 mm Chiba catchment/Tunisia/200 km^2/450 mm	• Decreased precipitation and increased temperatures lead to increased PET and drop in soil water content. • Projected changes in water availability are higher in wet periods than in dry periods. • Significant increase in low flow frequency.

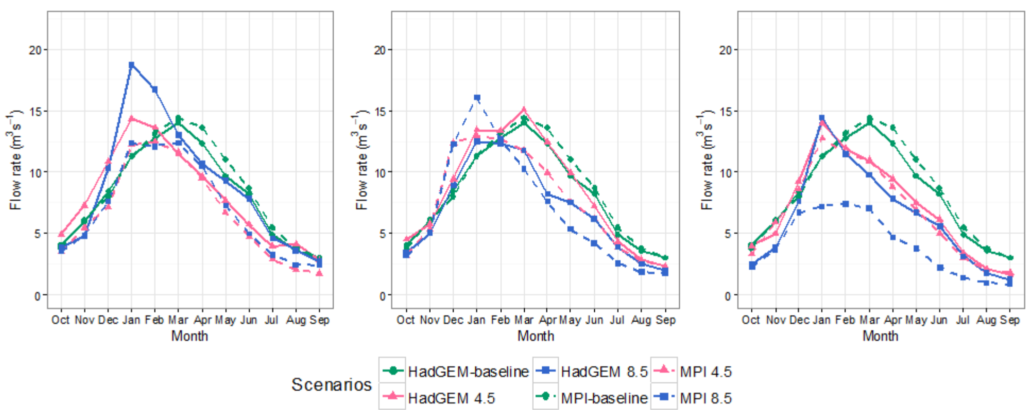

Figure B.1. Changes in average monthly discharges for the different climate scenarios. Baseline period covers 1971-2000, while future scenarios cover the period 2012-2099.

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APPENDIX C

MODEL EVALUATION METRICS

Coefficient of Determination (R^2)

R^2 indicates the collinearity between observed and simulated values and it ranges between 0-1. Higher R^2 values indicate high collinearity and less error variance. The equation is given below:

$$\boldsymbol{R^2} = \frac{\left[\sum_{i=1}^{n}(y_i^{obs} - y^{mean})(y_i^{sim} - \hat{y}^{mean})\right]^2}{\sum_{i=1}^{n}(y_i^{obs} - y^{mean})^2 \sum_{i=1}^{n}(y_i^{sim} - \hat{y}^{mean})^2}$$

where y_i^{obs} denotes ith observation, y_i^{sim} denotes ith simulated value, y^{mean} is the mean of the observed values, $\hat{y}^{mean}$ is the mean of the simulated values, and n is the number of the total data points. The same notation is used for the metrics given below.

Nash–Sutcliffe model efficiency coefficient

NS coefficient (Nash and Sutcliffe, 1970) is a measure used mainly for the calibration efficiency of hydrological models and it ranges between $-\infty$ to 1. While NS=1 represents the perfect match between observed and simulated values, NS<0 indicates unacceptable performance where the residual variance is greater than the data variance. The equation is given below:

$$NS = 1 - \frac{\sum_{i=1}^{n}(y_i^{obs} - y_i^{sim})^2}{\sum_{i=1}^{n}(y_i^{obs} - y^{mean})^2}$$

Per cent bias (PBIAS)

Per cent bias (PBIAS) measures if model overestimates/underestimates the observed values (Gupta et al., 1999). For a perfect model, PBIAS should be 0, while positive values indicate underestimation and negative values overestimation. It is formulated as:

$$PBIAS = \frac{\sum_{i=1}^{n}\left(y_i^{obs} - y_i^{sim}\right) * 100}{\sum_{i=1}^{n} y_i^{obs}}$$

Mean Absolute Error (MAE) and Root Mean Square Error (RMSE)

These metrics are scale dependent and the magnitude of the errors is linked with the magnitude of the data measured (Moriasi et al., 2007). They are formulated as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_i^{obs} - y_i^{sim}\right|$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i^{obs} - y_i^{sim})^2}{n}}$$

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APPENDIX D

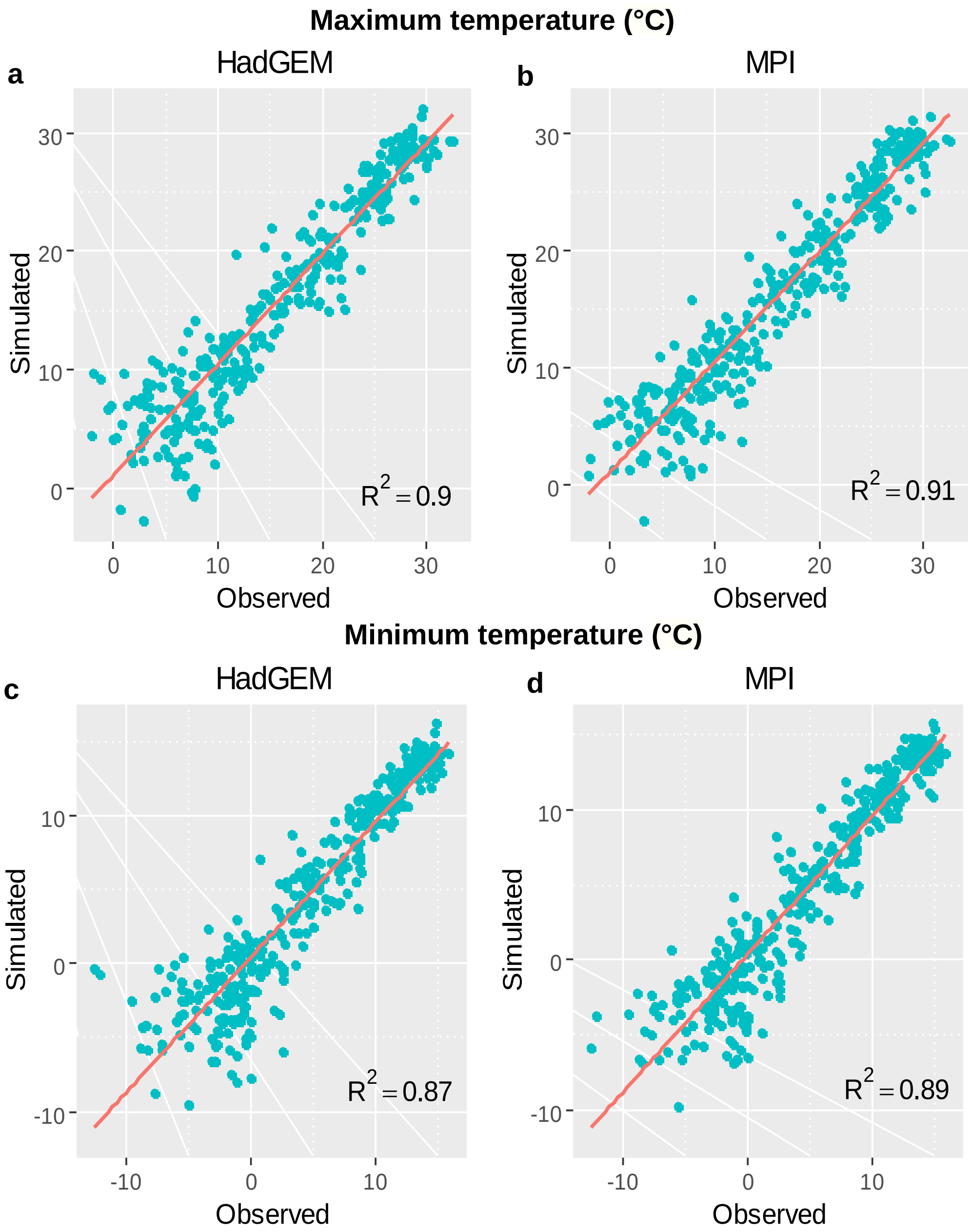

Figure D.1. Comparisons of the observed and bias-corrected simulated values for maximum temperature: (a) HadGEM model, (b) MPI model; and minimum temperature: (c) HadGEM model; (d) MPI model, for the period 1971-2000.

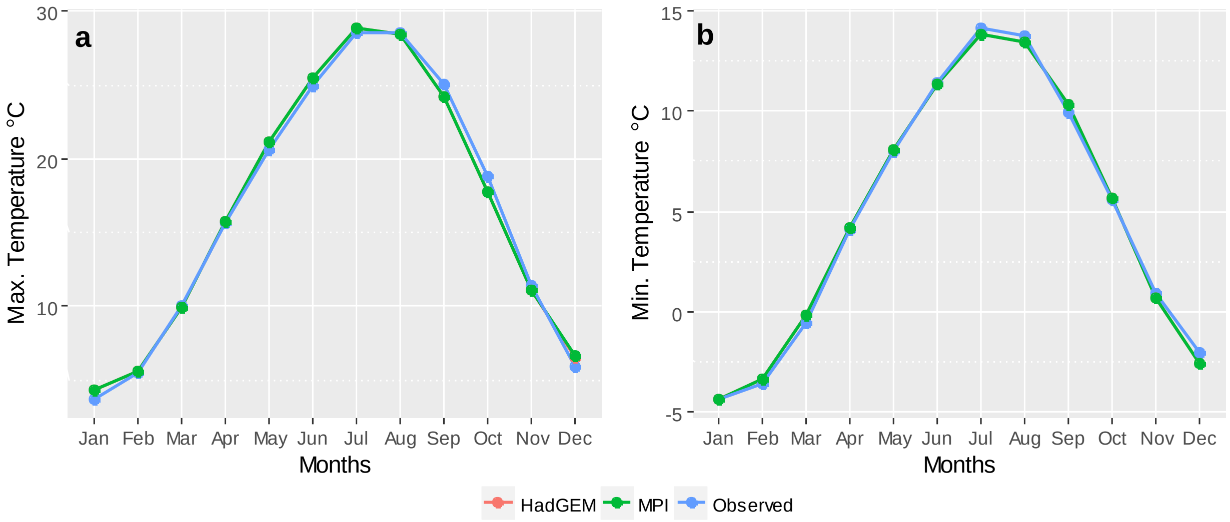

Figure D.2. Comparisons of long term monthly averages of observed and bias-corrected simulated values for the period 1971-2000 for (a) maximum temperature; (b) minimum temperature.

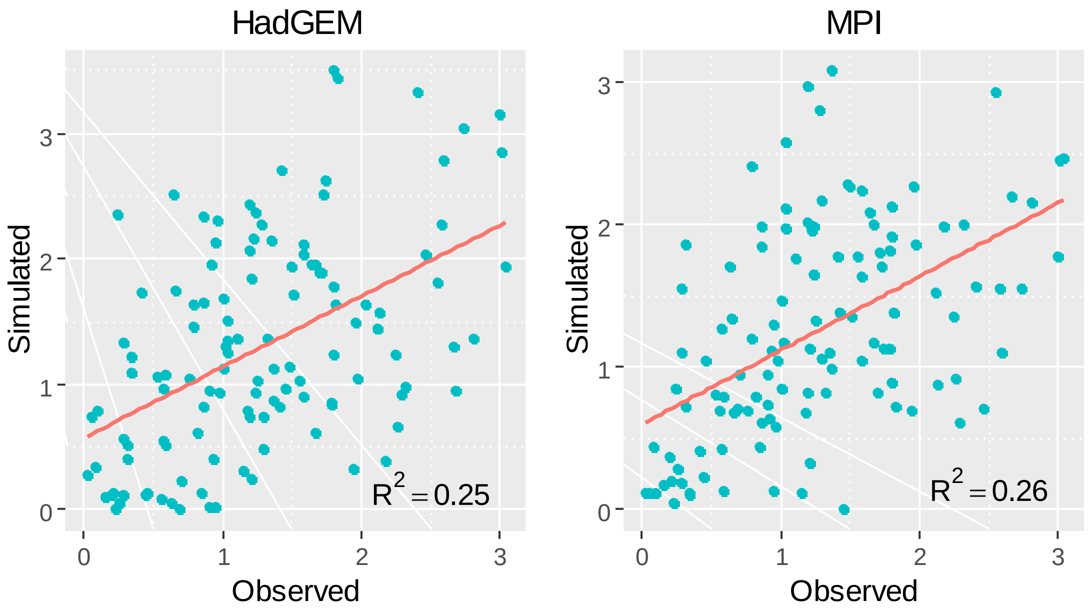

Figure D.3. Comparisons of the observed and bias-corrected simulated values for precipitation (mm) for the period 1971-2000: (a) HadGEM model, (b) MPI model.

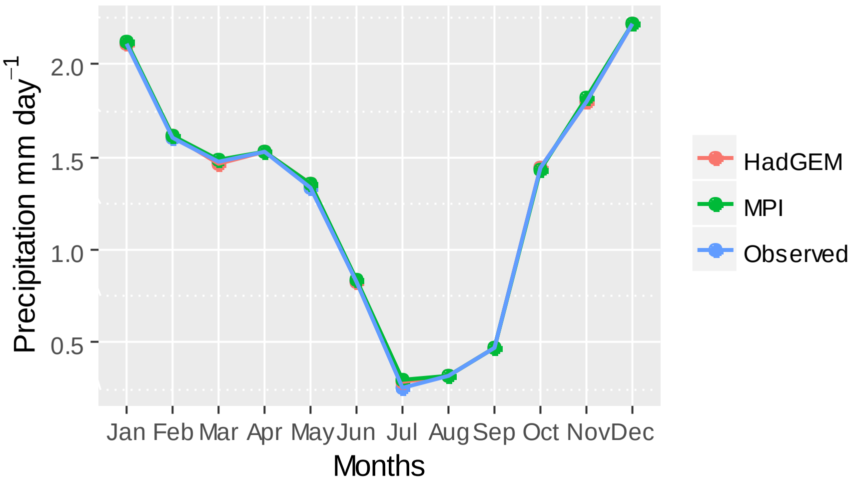

Figure D.4. Comparisons of long term monthly averages of observed and bias-corrected simulated values for the period 1971-2000 for precipitation: (a) HadGEM model and (b) MPI model

APPENDIX E

Table E.1. Average future predictions for NO_3 load, SRP load, Chl-*a* and Cyanobacteria biomass for 2030s and 2060s.

			Nitrate load (% Change)		SRP load (% Change)		Chl-*a* ($\mu g\ L^{-1}$)				Cyanobacteria biomass ($mg\ m^{-3}$)			
							PCLake		GLM-AED		PCLake		GLM-AED	
Scenario	**GCM**	**Land use**	**2030s**	**2060s**	**2030s**	**2060s**	**2030s**	**2060s**	**2030s**	**2060s**	**2030s**	**2060s**	**2030s**	**2060s**
RCP 4.5	GFDL	Current	-12	-38	127	103	2.1	2.15	3.57	2.35	0.02	0.02	0.01	0.01
RCP 4.5	GFDL	Consensus	-12	-44	133	102	2.09	2.12	3.36	2.08	0.02	0.02	0.01	0.01
RCP 8.5	GFDL	Current	-38	-42	-11	-41	4.31	4.15	3.78	2.94	0.03	0.21	0.05	0.12
RCP 8.5	GFDL	Techno	-31	-36	24	-21	3.15	5.02	4.04	2.75	0.02	0.16	0.1	0.19
RCP 8.5	GFDL	Fragmented	-50	-54	-7	-35	2.84	5.67	3.35	2.85	0.02	0.17	0.08	0.15
RCP 4.5	HadGEM	Current	-12	-38	-37	-28	7.2	7.22	2.84	2.53	0.04	0.07	0.11	0.05
RCP 4.5	HadGEM	Consensus	-27	-54	-26	-38	4.75	5.9	2.6	2.29	0.04	0.06	0.11	0.18
RCP 8.5	HadGEM	Current	-11	-32	-23	-52	3	5.14	2.44	2.37	0.03	0.45	0.02	0.16
RCP 8.5	HadGEM	Fragmented	-16	-47	8	-36	6.04	6.8	2	2.58	0.03	0.15	0.02	0.21
RCP 8.5	HadGEM	Techno	18	-25	51	-13	4.51	4.59	2.72	2.64	0.02	0.33	0.02	0.19
RCP 4.5	IPSL	Current	-32	-35	-8	-50	2.11	3.93	3.16	2.87	0.02	0.19	0.01	0.13
RCP 4.5	IPSL	Consensus	-36	-32	4	-44	2.08	4.88	2.98	3	0.02	0.49	0.01	0.1
RCP 8.5	IPSL	Current	-42	-48	-38	-78	4.09	4.16	2.29	2.39	0.03	0.28	0.02	0.19
RCP 8.5	IPSL	Techno	-18	-44	5	-76	3.05	4.35	2.54	2.6	0.02	0.28	0.02	0.22
RCP 8.5	IPSL	Fragmented	-40	-60	-21	-81	2.92	3.66	2.18	2.61	0.03	0.11	0.02	0.21
RCP 4.5	MIROC	Current	-43	-33	-83	-70	3.96	4.25	2.34	2.13	0.21	0.29	0.14	0.02
RCP 4.5	MIROC	Consensus	-54	-51	-79	-74	5.33	5.09	2.15	2.2	0.17	0.26	0.15	0.17
RCP 8.5	MIROC	Current	-32	-46	-32	-73	2.35	4.38	2.36	2.45	0.02	0.33	0.04	0.13
RCP 8.5	MIROC	Fragmented	-25	-61	-13	-78	4.65	6	2.55	2.35	0.03	0.18	0.06	0.19
RCP 8.5	MIROC	Techno	2	-46	15	-73	2.53	3.25	2.42	2.29	0.02	0.2	0.04	0.19
RCP 4.5	MPI	Current	-22	-25	-24	-37	5.78	7.02	3.56	3.16	0.03	0.03	0.04	0.03
RCP 4.5	MPI	Consensus	-39	-40	-20	-27	3.52	5.16	3.18	2.96	0.03	0.03	0.04	0.03
RCP 8.5	MPI	Current	-20	-28	-34	-31	7.3	5.81	3.92	2.95	0.03	0.3	0.06	0.08
RCP 8.5	MPI	Fragmented	-19	-44	-10	-8	2.27	6.67	3.51	2.94	0.02	0.15	0.07	0.1
RCP 8.5	MPI	Techno	14	-21	20	25	2.27	6.67	4.01	3.16	0.02	0.15	0.07	0.12

Table E.2 Future changes in TP, TN, Chl-*a* and cyanobacteria compared to baseline. Values indicate the fold change

	PCLake								
Scenario	**Land use**	TP		TN		Chl-*a*		Cyanobacteria	
		2030	2060	2030	2060	2030	2060	2030	2060
RCP 4.5	Baseline	0.0	0.8	0.3	0.9	0.4	0.6	2.0	5.0
RCP 8.5	Baseline	-0.1	1.7	-0.1	1.3	0.4	0.6	0.5	15.0
RCP 4.5	Consensus	0.2	0.7	0.0	0.5	0.2	0.5	1.5	7.5
RCP 8.5	Fragmented	0.0	0.7	-0.2	0.3	0.2	0.9	1.2	6.5
RCP 8.5	Techno	0.1	1.4	0.0	1.4	0.0	0.6	0.0	10.5
	GLM								
RCP 4.5	Baseline	0.0	0.2	0.0	0.0	0.1	-0.1	5	4
RCP 8.5	Baseline	0.1	0.0	0.0	0.0	0.0	-0.1	3	13
RCP 4.5	Consensus	0.1	0.1	0.0	0.0	0.0	-0.1	5	9
RCP 8.5	Fragmented	0.1	0.0	0.0	-0.1	-0.1	-0.1	4	16
RCP 8.5	Techno	0.1	0.0	0.0	0.0	0.1	-0.1	2	17

CURRICULUM VITAE

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EDUCATION

Degree	**Institution**	**Year of Graduation**
MS	METU Biology Dept.	2011
BS	ITU Molecular Biology & Genetics	2008
High School	Kocaeli Anadolu Lisesi	2004

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2014-2017	*Project:*EU FP7-MARS (2014ABH67840004)	Research Assist.
2010-2013	*Project:* TÜBİTAK ÇAYDAG 110Y125.	Research Assist.
2010-2014	*Project:* EU FP7- REFRESH (244121)	Research Assist.

LANGUAGE & COMPUTER SKILLS

English: TOEFL IBT:99

R, Python

LABORATORY SKILLS

DNA and protein isolation, DNA amplification, cDNA synthesis, cloning, DGGE, FISH, Northern &Western blotting, ELISA methods, culturing techniques, silver staining, water chemistry analysis, zooplankton identification

HONOUR& AWARDS

AGU Travel Grant	2016
ULAKBIM TÜBİTAK Publication Award	2012
TÜBİTAK Scholarship for PhD Education	2011-2015
TÜBİTAK Scholarship for MSc Education	2008-2010
Ranked 2nd among graduates of İTÜ Molecular Biology and Genetics	2008
İTÜ High Honour List	2006-2008

PUBLICATIONS

1. Meryem Beklioğlu, **Tuba Bucak**, Jan Coppens, Gizem Bezirci, Ü. Nihan Tavşanoğlu, Eti E. Levi, Şeyda Erdoğan, Nur Filiz, Korhan Özkan, Arda Özen. Restoration of eutrophic lakes with fluctuating water Levels: A 20-year monitoring study of two inter-connected lakes. *Water* (2017). 9(22):127

2. Tuba Bucak, Dennis Trolle, Hans Estrup-Andersen, Hans Thodsen, Şeyda Erdoğan, Eti Ester Levi, Nur Filiz, Erik Jeppesen, Meryem Beklioğlu. Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model. *Science of the Total Environment* (2017). 581-582: 413-425.

3. Erik Jeppesen, Sandra Brucet, Luigi Naselli-Flores, Eva Papastergiadou, Kostas Stefanidis, Tiina Noges, Peeter Noges, Jan Coppens, **Tuba Bucak**, Meryem Beklioğlu et al. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. *Hydrobiologia* (2015). 750(1): 201-227.

4. Ülkü Nihan Tavşanoğlu, Sandra Brucet, Eti E. Levi, **Tuba Bucak**, Gizem Bezirci, Arda Özen, Liselotte S. Johansson, Erik Jeppesen & Meryem Beklioğlu.

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5. Ayşe İdil Çakıroğlu, Ü. Nihan Tavşanoğlu, Eti E. Levi, Thomas A. Davidson, **Tuba Bucak**, Arda Özen, Gürçay K. Akyıldız, Erik Jeppesen & Meryem Beklioğlu. Relatedness Between Contemporary Cladocera and Surface Sediment Sub-Fossil Cladocera Assemblages in Turkish Lakes. *Journal of Paleolimnology* (2014), 52:367–383.

6. Arda Özen, **Tuba Bucak**, Ülkü Nihan Tavşanoğlu, Ayşe İdil Çakıroğlu, Eti Ester Levi, Jan Coppens, Erik Jeppesen & Meryem Beklioğlu. Water level and fish-mediated cascading effects on the microbial community in eutrophic warm shallow lakes: a mesocosm experiment. *Hydrobiologia* (2014), 740:25-35.

7. Eti E. Levi, A. İdil Çakıroğlu, **Tuba Bucak**, Bent V. Odgaard, Thomas A. Davidson, Erik Jeppesen & Meryem Beklioğlu. Similarity between contemporary vegetation and plant remains in the surface sediment in Mediterranean lakes. *Freshwater Biology* (2014), *59:724-736*.

8. Tuba Bucak, Ece Saraoğlu, Eti Ester Levi, Ü. Nihan Tavşanoğlu, A. İdil Çakıroğlu, Erik Jeppesen, Meryem Beklioğlu. The role of water level for macrophyte growth and trophic interactions in eutrophic Mediterranean shallow lakes: a mesocosm experiment with and without fish. *Freshwater Biology* (2012), 57:1631–1642.

REVIEWING EXPERIENCE

- Turkish Journal of Fisheries and Aquatic Sciences
- Hydrobiologia
- Global Change Biology
- Hydrological Sciences Journal
- Inland Waters
- Environmental Monitoring and Assessment
- Chemistry and Ecology

EXTRACURRICULAR ACTIVITIES

- Singing in the Ankara Polyphonic Choir (Alto)
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