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The Influence of Lake Level Fluctuations on Fisheries in Lake Van

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A B S T R A C T

The impact of hydrological regimes on the productivity in lake ecosystems has received considerable attention in recent decades. This study tested the hypothesis that water level fluctuations influence the fisheries productivity of Lake Van. Monthly water level data from 2000 to 2014 were obtained from Hydroweb and fisheries data corresponding to the same time period were acquired from the Turkish Statistical Institute. In order to test whether water level fluctuations demonstrated significant concordance with fish landings, landings data as a dependent variable, and seasonal water level amplitude and mean annual water level as independent variables were used in a linear regression analysis. The regression analysis proved insignificant results. The general trend of a linear decline, with a rate of -575 tonnes per year, observed in the landings did not match the seasonal and inter-annual water level variations which occurred in the lake during the same period. The consistently declining yields might result from a prolonged overexploitation and/or a constant recruitment failure. The estimated values of the seasonal and inter-annual relative fluctuation index (0.402 and 0.097, respectively) were rather low indicating that Lake Van is hydrologically stable with limited aquatic/terrestrial transition zone interactions and a relatively low nutrient load.

Keywords: Lake Van, water level fluctuations, productivity, fisheries

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Su Seviyesi Değişimlerinin Van Gölü'ndeki Balıkçılığa Etkisi

Öz: Hidrolojik rejimlerin göl ekosistemlerindeki verimlilik üzerindeki etkisi son yıllarda büyük ilgi görmektedir. Bu çalışmada, Van Gölü su seviyesindeki değişimlerin balıkçılık üretimini etkilediğini öngören hipotez test edilmiştir. 2000-2014 yılları arasına ait aylık su seviyesi verileri Hydroweb'den, aynı döneme karşılık gelen balıkçılık verileri ise Türkiye İstatistik Kurumu'ndan alınmıştır. Su seviyesindeki değişimlerin, avlanan balık miktarları ile anlamlı bir ilişki gösterip göstermediğini test etmek için doğrusal regresyon analizinde bağımlı değişken olarak avcılık verileri ile bağımsız değişken olarak mevsimsel su seviyesi genliği (amplitüt) ve ortalama yıllık su seviyesi değerleri kullanılmıştır. Regresyon analizi sonucunda anlamlı bir ilişki bulunamamış, avcılık miktarlarında gözlenen yıllık -575 tonluk doğrusal düşüş trendi, aynı dönemde gölde meydana gelen mevsimsel ve yıllık su seviyesi değişimleriyle uyumluluk göstermemiştir. Av ürün miktarlarındaki kalıcı düşüşün sebebi, uzun süreli aşırı avcılık ve/veya stoka katılımda süregelen azalmalar olabilir. Mevsimsel ve yıllık bağıl dalgalanma endeks değerleri sırasıyla 0,402 ve 0,097 olarak hesaplanmıştır. Bu değerlerin oldukça düşük olması Van Gölü'nün hidrolojik olarak kararlı olduğunu, su/kara geçiş bölgesi etkileşimlerinin sınırlı düzeyde kaldığını ve göle nispeten düşük nütrient girişi gerçekleştiğini göstermektedir.

Anahtar kelimeler: Van Gölü, su seviyesi değişimleri, verimlilik, balıkçılık

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Introduction

Lake levels vary as a result of environmental and anthropogenic factors such as climate elements, tectonic activities, rivers, underground waters, infiltrations from lake floors and human exploitation of water resources (Zohary and Ostrovsky 2011, Shafaei and Kisi 2016). Water flowing into lakes is generally the main source of nutrient supply. In addition, seasonal water level fluctuations may influence the productivity and nutrient recycling (Kolding and van Zwieten 2012). Especially in relatively shallow and highly fluctuating lakes, seasonal changes in levels of water carrying nutrients from rivers or surrounding terrestrial ecosystems are important. In deeper lakes, water level fluctuations drive internal nutrient mixing (Zohary and Ostrovsky

2011). Furthermore, with changes in water level, interactions occur within the aquatic/terrestrial transition zone and lead to terrestrial originated accumulation of nutrient rich organic matter which also enhances the productivity in the lake system. In addition, water level fluctuations may impact lake ecosystems negatively by enhancing eutrophication and algal blooms. In short, seasonal and inter-annual water level fluctuations have a crucial impact on the productivity of lakes and fisheries landings (Gownaris et al. 2018). The degree to which water level fluctuations affect any given lake is highly dependent on that lake's average depth (Gownaris et al. 2018). Kolding and van Zwieten (2012) suggested an index called relative lake level fluctuation (*RLLF*), which uses the amplitude (i.e. the range between the maximum and minimum water level) and the average depth of the lake. This index is useful to categorize lakes as a proxy to productivity and classifies lake systems as high *RLLF* and low *RLLF*, and can reflect the system stability. The *RLLF* also serves as a proxy for nutrient input and fish production.

In this study, the hypothesis that water level fluctuations will demonstrate significant concordance with fish landings is tested. For this purpose, Lake Van, Turkey's largest lake, was chosen. Interestingly, only one fish species inhabits Lake Van, *Alburnus tarichi*, which is endemic and commercially exploited. The contribution of *A. tarichi* landings to Turkey's total inland capture fisheries is quite considerable. In 2019, for instance, the landings of *A. tarichi* were 9970 tonnes, and formed approximately 31% of the country's total inland fisheries production (Turkstat 2020). The aim of this study was to investigate whether there was a relationship between water level fluctuations and fish production in Lake Van for the period of fifteen years between 2000 and 2014. Another objective here is to apply the *RLLF* to Lake Van in order to clearly understand its system stability and to predict productivity.

Materials and Methods

Lake Van (Figure 1) is the world's largest soda lake. It is characterized by highly alkaline-saline water with a pH range of 9.7-9.9 and a 22g kg^{-1} salt content (Reimer et al. 2009). The lake itself is a closed basin with a volume of about 600 km^3, a maximum depth of 451 m and is located at an altitude of 1648 m above sea level. The only fish species living in Lake Van, *A. tarichi* is an anadromous fish which migrates to breeding grounds of freshwater inlets from April to July (Sarı 2008; Oğuz 2013). *A. tarichi* is a planktivorous fish and reaches sexual maturity at about three years old and has an average life span of seven years (Sarı 2008). The major part of the *A. tarichi* population lives in Lake Van, but it also inhabits the smaller lakes of Erçek, Nazik and Aygır in the Lake Van drainage basin (Figure 1) albeit in relatively small numbers (Şen et al. 2015).

Data on the water levels of Lake Van were obtained from Hydroweb, an internet database (http://hydroweb.theia-land.fr) which records time series of water levels of rivers and lakes in various places in the world by using satellite altimeter data (Crétaux et al. 2011). Water levels are given in meters above sea level (m asl). The Hydroweb water level data of Lake Van start in January 2000 and end in February 2015 and were recorded in intervals of roughly 30 days (Figure 2). Since the data for 2015 only consisted of the two first months of that year, they were excluded from the analysis. Lake Van fisheries data corresponding to the same time period of the available water level data (2000-2014) were acquired from the website of the Turkish Statistical Institute (http://www.turkstat.gov.tr) (Turkstat 2020).

In order to test whether water level fluctuations would demonstrate significant concordance with fish landings, a linear regression analysis was carried out with landings data as a dependent variable and hydrological variables as independent predictors. The hydrological variables were seasonal water level amplitude (WL_{amp}) and mean annual water level ($\overline{WL_Y}$). The value of WL_{amp} was calculated for each year as the difference between the maximum and minimum water levels recorded in that year. The $\overline{WL_Y}$ value for a given year was the mean of all water levels recorded for that year. Prior to the linear regression analysis, a correlation analysis was also done to check whether the two independent predictors were correlated with each other. A single-factor analysis of variance was also conducted to explore whether $\overline{WL_Y}$ values differed among the years from 2000 to 2014. Following the analysis of variance, Tukey's honestly significant difference (HSD) test (Sokal and Rohlf 2012) was used for pairwise comparisons among the years. All variables were checked for normality using the Shapiro-Wilk test and the homogeneity of variances was checked with Levene's test (Sokal and Rohlf 2012). Statistical analyses were performed with R software version 3.5.3 (R Core Team 2019) with a significance level set at 5%.

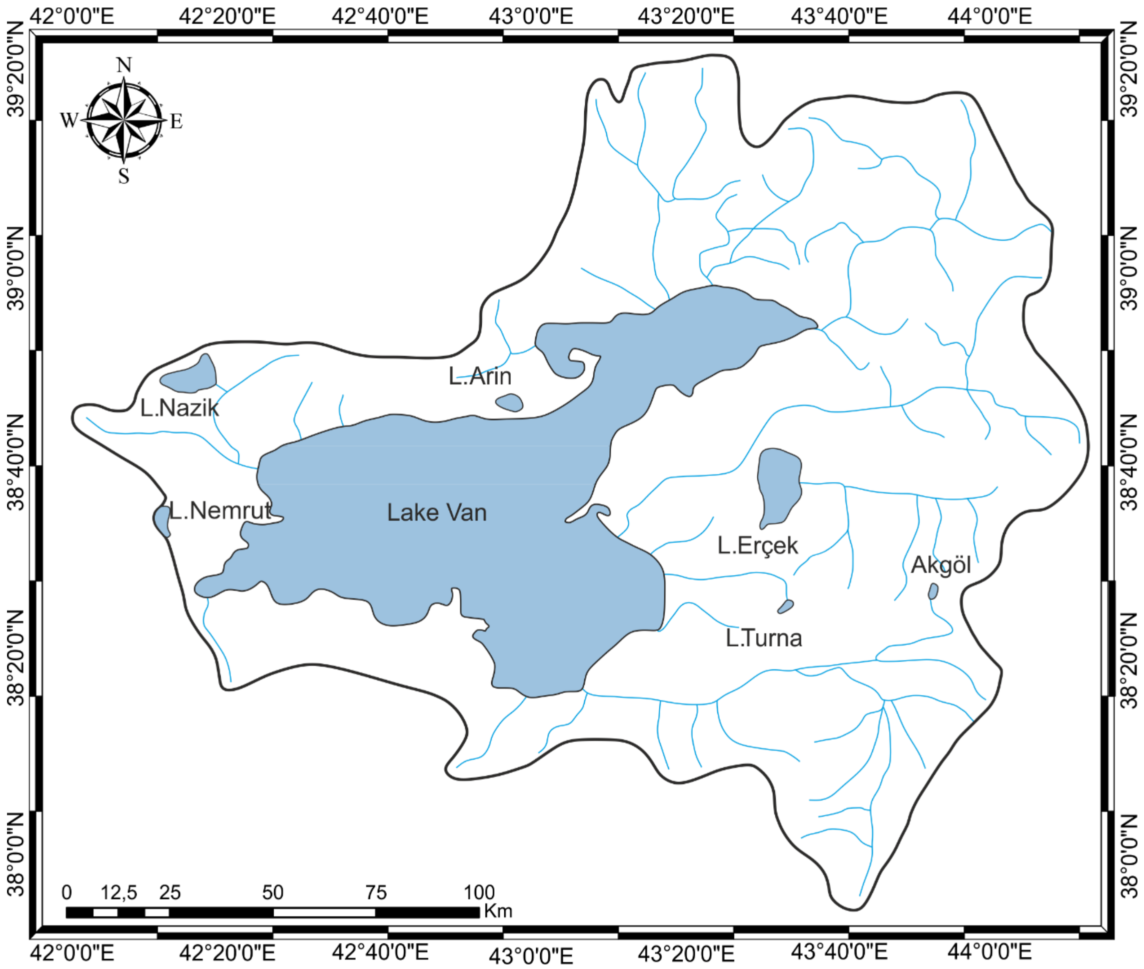

Figure 1. Lake Van and its water drainage basin

The relative lake level fluctuation index (*RLLF*) proposed by Kolding and van Zwieten (2012) is defined as the percentage ratio of the average lake level amplitude to the average depth of the lake. The average lake level amplitude, hence the *RLLF*, can be calculated from a time series of data in two different ways. One way is to calculate the average seasonal pulse amplitude, which is the average of the differences between the maximum (max) and minimum (min) water levels recorded within *i*th year. This form is called *RLLF-s*:

$$RLLF - s = \frac{\frac{1}{n} \times \sum_{i=1}^{n} \max(WL_i) - \min(WL_i)}{\text{Average depth}} \times 100.$$

Here n is the total number of years. So the numerator in the above equation is simply the average of the WL_{amp} values described previously. In the second form, referred to as *RLLF-a*, the average lake level amplitude is calculated as the average amplitude of inter-annual water levels, i.e. the average of the absolute differences between the mean water levels ($\overline{WL}$) of two sequential years (i and i+1):

$$RLLF - a = \frac{\frac{1}{n-1} \times \sum_{i=1}^{n-1} |\overline{WL}_i - \overline{WL}_{i+1}|}{\text{Average depth}} \times 100.$$

While the *RLLF-a* is used to show the long term inter-annual stability of a system, the *RLLF-s* indicates the average strength of the seasonal pulse with which different systems could be scaled in terms of stability over different time scales (Kolding and van Zwieten 2012). The value of average depth used for Lake Van in the calculations with the above equations is 170 m (Degens et al. 1984).

Results

Water levels of Lake Van from January 2000 to February 2015 obtained by using satellite altimeter data are presented in Figure 2. The minimum and maximum lake levels measured corresponding to 1646.41 and 1648.13 masl, were observed in November 2001 and June 2007, respectively.

The monthly variations in the water level of Lake Van during the fifteen-year period from January 2000 to December 2014 are presented in Figure 3. Although year to year variations exist (Figure 2), water levels on average rose from April through May and peaked in June and then started to decrease reaching the lowest level in December (Figure 3). Variances associated with the monthly average water level values were homogenous (Levene's test). In other words, when all data were combined, year to year variations for each month were similar (Figure 3).

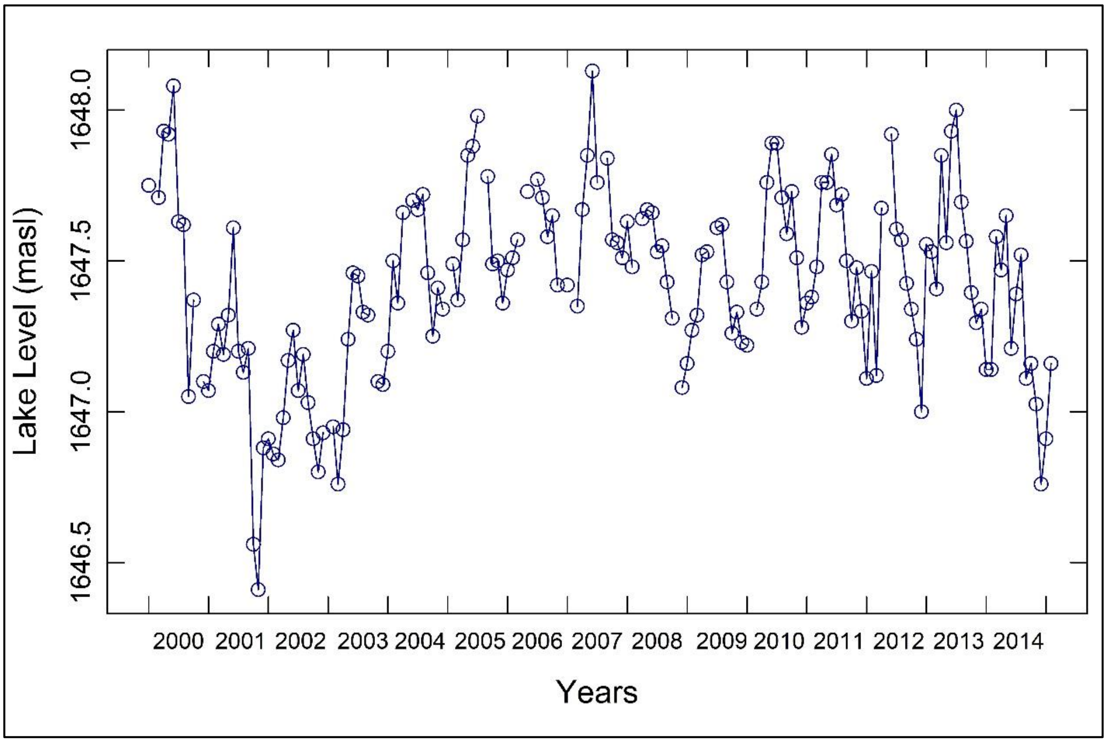

Figure 2. The Hydroweb water level data of Lake Van from January 2000 to February 2015 with approximately monthly intervals, obtained by using satellite radar altimeters

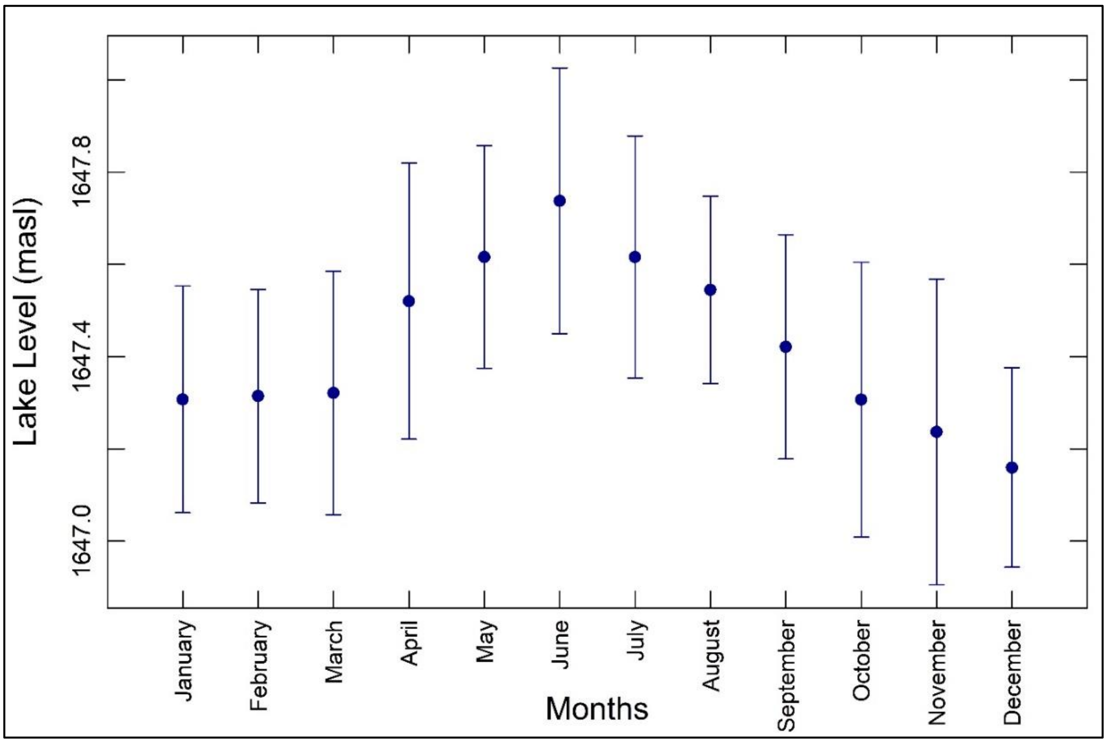

Figure 3. Monthly variations in the water level of Lake Van during the fifteen-year period from January 2000 to December 2014. The dots represent monthly mean values and the vertical bars denote ± standard deviations associated with those means

The linear regression analysis carried out with the landings data of *A. tarichi* as the dependent variable, and the WL_{amp} and $\overline{WL_Y}$ as the independent predictors did not yield any significant coefficients. Nor were the two independent predictors correlated with each other. The lack of concordance between any two of these three variables can also be inferred from Figure 4 which depicts the year to year variations in the landings, WL_{amp} and $\overline{WL}_Y$ from 2000 to 2014 in Lake Van. During this time, the highest *A. tarichi* landing was observed in 2001 as 15848 tonnes. Thereafter the landings began to decrease linearly at a rate of -575 tonnes per year (linear regression analysis with an adjusted R^2 of 0.95) and the total catch amounted to only 8310 tonnes in 2014 (Figure 4). In contrast, there were no discernable linear or nonlinear trends in the time series data of the WL_{amp} and $\overline{WL}_Y$ (Figure 4). The analysis of variance revealed that the $\overline{WL}_Y$ values were not homogenous among the years from 2000 to 2014 and according to the follow-up Tukey's HSD test, three year groups; low, middle and high lake levels can be distinguished based on the pairwise comparisons of and $\overline{WL}_Y$ values. The low $\overline{WL}_Y$ years were 2001, 2002 and 2003, and the middle $\overline{WL}_Y$ years were 2004, 2009, 2012 and 2014. The remaining years were the high $\overline{WL}_Y$ years (Figure 4). The minimum and maximum values of $\overline{WL}_Y$ were 1646.99 and 1647.67 masl, respectively, and were observed in 2002 and 2007. However, the minimum and maximum WL_{amp} values were recorded in 2006 and 2001 as 0.35 and 1.05 m, respectively (Figure 4). The average values (and ± standard deviations) of the WL_{amp} and $\overline{WL}_Y$ were 0.68 (±0.203) m and 1647.44 (±0.209) m asl, respectively, over the fifteen years.

The estimated values of *RLLF-s* and *RLLF-a* for Lake Van between 2000 and 2014 were 0.402 and 0.097, respectively.

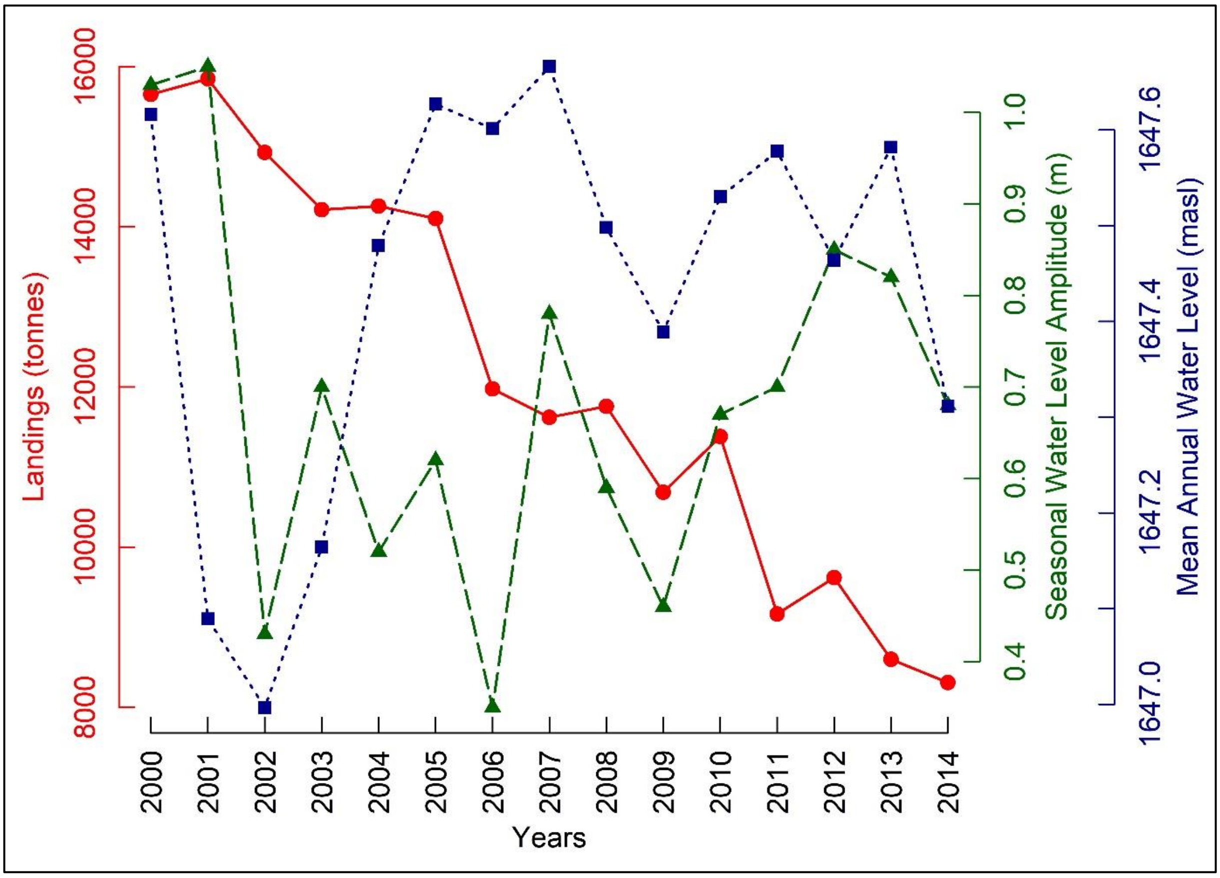

Figure 4. Variations in the landings of *A. tarichi* (red dots), seasonal water level amplitude (green triangles) and mean annual water level (dark blue squares) in Lake Van between 2000 and 2014

Discussion

Impact of water level fluctuations on the ecological processes in lake ecosystems, particularly regarding the biological productivity, has received considerable attention, especially in the last three decades (e.g., Coops et al. 2003; Leira and Cantonati 2008; Wantzen et al. 2008; Kolding and van Zwieten 2012; Gownaris et al. 2018). However, most of the research focused on effects of water level fluctuations on macrophyte communities in lakes and reservoirs (Leira and Cantonati 2008; Gownaris et al. 2018). Only a limited number of studies investigated the functional relationship between fisheries productivity and magnitude of water level fluctuations in lakes. Williams (1972) reported highly significant correlations between the catch per unit effort of the most common species in the commercial catch *Tilapia macruchir* and the water levels two years previously in Lake Mweru in northern Zambia. Furse et al. (1979) providing no statistical results noted that species composition and magnitude of catches in the shallow Lake Chilwa in Malawi were related to the level of the lake. Davies and Sloane (1988) documented the impact of variations in lake water level on the population dynamics of two introduced trout species (*Salmo trutta* and *Oncorhynchus mykiss*) in the Great Lake in Tasmania. Tweddle and Magasa (1989) examined the catch data of three cichlid species (*Oreochromis* spp.) from a multigear (ring net, midwater and demersal trawl) fishery in Lake Malawi in Malawi and showed that the catches were related to changes in annual mean lake level three years previously. Kolding (1992) established a significant linear regression between annual commercial catch per boat and mean lake level of the previous year in Lake Turkana in Kenya. Karenge and Kolding (1995) found no significant correlation between the catch per unit effort estimates from the man-made Lake Kariba located between Zambia and Zimbabwe and mean annual lake water levels. However, the catch per unit effort values were highly significantly correlated to the lake's seasonal water level amplitude and the differences between the mean lake water levels of two sequential years (Karenge and Kolding 1995). In another man-made lake, Lake Nasser in Egypt, Agaypi (2000) used linear regression analysis and demonstrated a significant functional relationship between the log-transformed catch per unit effort of *Oreochromis niloticus* and the mean lake levels two years previously. Gownaris et al. (2017) regressed log-transformed annual catch data from Lake Turkana on seasonal water level amplitude and preceding year's lake level and obtained significant linear regression coefficients. According to Gownaris et al. (2017), the variations in Lake Turkana's fish stocks appeared to have been linked to changes in the lake's hydrology rather than to fishing pressure.

The present study is the first attempt to investigate water level fluctuations and their probable impact on capture fisheries production in Turkey's standing inland waters. The linear regression analysis carried out in this study attempting the relate the landings data of *A. tarichi* from Lake Van to the two independent hydrological variables, WL_{amp} and $\overline{WL}_Y$, was an approach similar to that of Gownaris et al. (2017). However, unlike the above mentioned works, the regression analysis did not yield any significant coefficients in the current investigation. Repeating the linear regression analysis with the mean lake levels of one or two previous years (i.e. $\overline{WL}_{Y-1}$ and $\overline{WL}_{Y-2}$) instead of $\overline{WL}_Y$ (Kolding 1992; Gownaris et al. 2017; Williams 1972; Agaypi 2000) did not change the outcome. The fisheries production from Lake Van between 2000 and 2014 appeared to be independent of the hydrological conditions prevailed in the lake in the same time period. The general trend observed in the landings was a linear decline and this linearly decreasing trend did not match the seasonal and inter-annual water level variations occurred in the lake during the studied period (Figure 4).

Caution has been suggested when using fisheries landings data from the Turkish Statistical Institute since the accuracy, precision, coverage and representativeness of these statistics have long been debated (Tıraşın and Ünlüoğlu 2012). Tıraşın and Ünlüoğlu (2012) stated that not only many fisheries scientists but also a considerable number of people involved in the fisheries sector are in a general consensus that the catch figures reported in these statistics are underestimates of the fish actually caught and that a substantial amount goes unreported. For example, illegal catches have routinely been taken in Lake Van during the annual spawning migration of *A. tarichi* to the freshwater inlets from April to July even though all fisheries activities have officially been banned in the entire lake between 15 April and 30 June every year since the late 1990s (Sarı 2008). It is very difficult to estimate the amounts of these unauthorized catches (Sarı 2008), any attempt to adjust the catch statistics is, therefore, also problematic. In spite of all valid concerns regarding the official catch statistics, Tıraşın and Ünlüoğlu (2012) acknowledge that they are still considered by many in the field as a useful index reflecting the overall variations in the stocks of major fisheries resources. As the demand for consumption of this fish did not change for the duration of the investigated time period, it is reasonable to assume that the total fishing effort in the lake did not vary substantially from one year to another either. Thus, the observed linear decay trend in *A. tarichi* landings from 2001 to 2014 depicts clearly the decline of the population in the lake during this time period. Such a consistent decline in a fish population often results from a prolonged overexploitation or in other terms overfishing. The overfishing problem in Lake Van was also stated by Sarı (2008) and Şen et al. (2015). Another likely explanation for the population decline might be a continued failure in recruitment of *A. tarichi* to Lake Van. Previous studies (Elp et al. 2006; Şen et al. 2015; Atıcı 2017) documented various destructive anthropogenic activities in the streams flowing into Lake Van such as sand extraction, pollution, construction of regulators and embankments, channeling water for irrigation which caused degradation and loss of the breeding grounds of this endemic species. According to Şen et al.

(2015), ongoing devastation of the breeding grounds has a more adverse impact on the *A. tarichi* population in Lake Van than the overfishing.

The general trend observed in monthly variations in the water level of Lake Van from the satellite altimeter data from January 2000 to December 2014 was that the lake's water level rose from April through May and peaked in June and then started to decrease (Figure 3) and the lowest level in December is congruent with the earlier studies describing the relationship between the prevailing climatic conditions in the region and lake water level (Kadıoğlu et al. 1997, Altunkaynak et al. 2003). Detailed description of seasonal dynamics of the meteorological processes (i.e. precipitation, evaporation, inflow etc) considered to be affecting the water level of Lake Van can be found in Kadıoğlu et al. (1997).

There is a growing evidence that water level fluctuations, particularly in tropical lakes and reservoirs, have an important role in the injection and re-suspension of nutrients, and accordingly has a crucial impact on the productivity of these water bodies (Kolding and van Zwieten 2012; Gownaris et al. 2018). The simple empirical index, *RLLF*, proposed by Kolding and van Zwieten (2012) to categorize lakes as a proxy to productivity may serve as a practical and useful means to provide some indication of the production in Lake Van. Reminding that the estimated values of *RLLF-s* and *RLLF-a* for Lake Van in the present study are 0.402 and 0.097, respectively. According to Kolding and van Zwieten (2012), *RLLF* values less than 1 indicates hydrologically stable lakes with low production per unit area. Based on these low *RLLF* values, the natural hydrological regime of Lake Van can be classified as steady meaning that the aquatic/terrestrial transition zone interactions in the lake are considered limited, and nutrient load is relatively low. In order to provide more insight for interpretation of the present *RLLF* estimates, Lake Van can be compared with some other studied lakes whose *RLLF* values are available (Table 1). Two larger and deeper lakes than Lake Van, Tanganyika and Malawi, and a slightly smaller but deeper one, Lake Kivu have low *RLLF* and production values comparable to those of Lake Van. Similar to Lake Van, all these three lakes were classified as steady or hydrologically stable by Kolding and van Zwieten (2012). On the other hand, Lake Nasser, the larger but much shallower lake has higher *RLLF* and production values. The remaining two smaller and shallower lakes (Lake Edward and Lake Mweru) were also associated with higher *RLLF* and production values. As Kolding and van Zwieten (2012) pointed out, the impact of water level fluctuations on productivity in the studied lakes (Table 1) is inversely proportional with the size and depth of the system.

Drastic recruitment failure due to the destruction of the breeding grounds in the connected streams and the strong overfishing occurring in Lake Van might have masked the relatively subtler effects of the lake level fluctuations on the fisheries productivity. However, studying the possible effects of variations in a lake's hydrology on the fisheries production may prove to be very useful in other lakes in Turkey. In addition, application of the simple empirical index, *RLLF*, in other Turkish lakes may serve as an easy and practical tool to get some indication of their productive status.

Table 1. Morphometric, hydrological and fish production data on some lakes

Lakes	**Country**	**Area (km^2)**	**Average depth (m)**	**Landing (kg/ha)**	***RLLF-s***	***RLLF-a***
Van	Turkey	3574	170	26.35	0.39	0.10
Malawi	Malawi, Tanzania, Mozambique	29600	290	9.09	0.30	0.10
Kivu	DR Congo, Rwanda	2693	240	27.79	0.14	0.06
Tanganyika	Zambia, Tanzania, Burundi, DR Congo	32900	580	22.20	0.14	0.04
Edward	DR Congo, Uganda	2150	34	68.95	5.60	1.43
Mweru	Zambia, DR Congo	2700	8	155.60	25.70	7.20
Nasser/Nubia	Egypt, Sudan	5248	25	57.16	27.50	7.14

Excepting Lake Van all information regarding the other lakes is quoted from Kolding and van Zwieten (2012). Data on area and average depth of Lake Van are from Degens et al. (1984). Amount of landing from Lake Van is the average of landings from last five years (2010-2014)

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