Lake Avlan Drainage Effects on Radial Tree Growth at Microecological Level

Neşat Erkan *

Lake Avlan is a natural lake located in the mountainous areas in southwestern Turkey. The lake was drained towards the end of the 1970s. However, some serious socioeconomic impacts were felt in the region surrounding the lake basin. Because the increasing ecological problems were realized within 20 years, the lake was restored towards the end of the 1990s. The present study considers the effects of lake drying on the radial growth rate of cedar and juniper forests on the slopes adjacent to the lake basin, during the drained period. Dendrochronological methods were used in two stands, one from cedar and the other from juniper forests. Results showed that mean index values derived from annual growth rate for the drained period were 15% and 14% less than that of the average of pre- and post-drying periods of the lake for cedar and juniper sites, respectively. Microecological change, namely decreasing air humidity, due to drying the lake may be the main reason of differentiation in the index values. Natural lakes, like Avlan, on mountainous areas are an important component of forest ecosystems and should not be overlooked by natural resource planners in such regions.

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Contact information: Bursa Technical University, Faculty of Forestry, Mimar Sinan Mahallesi, Mimar Sinan Bulvari, Eflak Caddesi, No. 177, 16310 Yıldırım, Bursa, Turkey;
** Corresponding author: nesat.erkan@yahoo.com*

INTRODUCTION

Any environmental problem caused by natural lake drainage is a wake-up call to rethink the natural resources' management activities. Indeed, many lessons have been learned about the importance of management of water resources in terms of social, economic, and environmental dimensions (Alborzi *et al.* 2018). Over the last few decades, areas of intensively used agricultural lands have expanded rapidly against forest and natural ecosystems (Falkenmark and Rockström 2004). Lake areas are one such ecosystem that have been exploited for this purpose. For instance, many natural lakes were dried within the past several decades in Anatolia for different purposes, *i.e.*, gaining agricultural lands, urbanization, fighting diseases, flood control, and irrigation (Neyişci 1997; Korkmaz 2008; Bingöl and Korkmaz 2013; Kum and Sönmez 2016).

Small natural lakes, especially in high mountainous areas, are the driving factor in ecosystems with characteristic plant and animal communities. They have potential implications for the social and cultural livelihoods of surrounding human communities. Drainage or drying of such lakes is usually performed for consolidation purposes by authorities based on demand of local people to obtain land mainly for agriculture. Such interference with natural processes, which seems to be advantageous in the short-term, is bound to cause significant negative environmental impacts in the longer term. Negative environmental impacts can include the disappearance of endemic plant species, subsequent damage to wildlife, and loss of biodiversity, which in turn result in the decrease and deterioration of agricultural production. Although the draining of Lake Avlan had such noticeable effects down the line on ecosystems and livelihoods of people, its short-term impacts on the nearby forest ecosystems have not yet been studied and evaluated. Therefore, it was expected that this study would be an effort to fill the gaps along this line. Dendrochronology (tree-ring dating) is one important technique that can be employed for such studies, as it allows instantly observing and measuring the Microecological effects on plant communities surrounding dried lakes (Fritts and Swetnam 1989; Stokes and Smiley 1996).

Lake Avlan (located near Elmali, Antalya, Turkey) represents an interesting case, as it was first dried in 1978 and 19 years later in 1997 it started to collect water again. During the 1980s, the farmers living in the Lake Avlan basin complained about the quality deterioration and decline in their agricultural crops, mainly apple fruits (AGÇTP, 1997; Çiçekci *et al.* 2014). It is reported that in addition to Lake Avlan, around 10 additional lakes were dried in the region between the 1960s and 1970s, but their short- and long-term effects on the natural ecosystems are not known and need to be studied (AGÇTP, 1997). A research study conducted using a method of face-to-face interviews with local farmers refers to some additional changes due to the drying of Lake Avlan such as tree deaths in forests, decreased populations of birds, and increased frost damages (Kum and Sönmez 2016). These anomalous conditions were probably associated with an expected break in the normal sequence of micro-climate changes at the catchment level. Yet, it was apparent that achieving an accurate evaluation would only be possible through use of quantitative methods.

Trees respond to changes in environmental factors by their growth behavior (Fritts *et al.* 1965; Tardif and Bergeron 1997). For example, tree-ring width is known to vary according to environmental stresses (Fritts and Swetnam 1989; Stokes and Smiley 1996; Touchan *et al.* 2007). Analyzing the relationships between changes in environmental factors and radial tree growth rate may be a useful approach to explain the effect of changes in microecology (primarily air-humidity) caused by the drying of Lake Avlan. To the author's knowledge, no previous studies have examined the effects of drying of natural lakes located in highlands on radial tree growth rate by using tree-ring analyses.

Cedar (*Cedrus libani* A. Rich.), juniper (*Juniperus excelsa*), and oak (*Quercus coccifera*) are the main naturally distributed tree species forming pure and mixed forests in the Lake Avlan catchment area (Başaran *et al.* 2007). Especially cedar and juniper can grow on relatively poor soil conditions, but they are considerably affected by climatic changes (Touchan *et al.* 2003; Özkan *et al.* 2010; Güney *et al.* 2020).

With this study, the author aimed to determine and measure the microecological effects of the lake drainage on the nearby cedar and juniper forest growth through the dendrochronological technique. The author expects that the results of this study will be useful for policy makers and land managers dealing with lakes and wetlands and for the management of such ecosystems at the national and international levels.

EXPERIMENTAL

Lake Avlan is located (36°35′02.57” N; 29°56′48.63” E) about 75 km southwest of the City of Antalya and close (16.6 km) to the town of Elmali (Turkey). The lake is located at 1035 m elevation in a closed basin, surrounded by high mountains (2400+ meters above sea level (MASL)) on all sides. It has an 8.55 km^2 surface area. There are relatively large and productive agricultural areas surrounding the lake, especially on the northeast side (Fig. 1). The lake is mainly fed by rain and snow waters falling into the catchment area.

Fig. 1. Lake Avlan and locations of the study sites (Google Earth image taken 2020)

According to data provided from the Elmali Weather Station for the period of 54 years (from 1960 to 2014), the mean annual precipitation has ranged from 288 to 777 mm yr^{-1} and occurs mainly during the fall, winter, and spring in the study area. Summers are quite dry with mean total precipitation of 53 mm yr^{-1} during the July to September period. Mean annual temperature is 13.04 °C, with ranges from 11.08 °C to 15.03 °C. July is the warmest month with a mean temperature of 24.32 °C, whereas January is the coldest month with a mean temperature of 2.33 °C. Meteorological data were provided by Turkish General Directorate of Meteorology (TGDM) (TGDM 2015) for the Elmali Weather Station located 16.6 km far from Lake Avlan in the northeast direction.

The author sampled trees on two sites both located on the west side of the Lake Avlan and having southeast facing slopes. One of the sites was for cedar forest (*Cedrus libani* A. Rich.; 36°34′25.43” N; 29°56′00.20” E, and 1131 m elevation) and the other was for juniper (*Juniperus excelsa*; 36°35′09.79” N; 29°55′27.27” E and 1068 m elevation). While selecting the location of the sites, the author tried to avoid any possible groundwater effect due to the presence of water in the lake.

The sampled cedar and juniper trees were selected from natural stands, representing typical sites for the concerned species in the lake catchment. The catchment has mainly three natural tree species: *Cedrus libani*, *Juniperus excelsa*, and *Quercus coccifera.* The catchment also has four forest types at association level, *i.e.*, *Juniperus excelsa-Cedrus libani* forest, *Astragalus oxytropifolius-Cedrus libani* forest, *Quercus coccifera-Cedrus libani* forest, and *Juniperus excelsa-Quercus coccifera* shrubs (Başaran *et al.* 2007).

Sampling and Data Analyses

The dendrochronological technique was used to determine the effects of drying Lake Avlan on microecology and radial growth rate of tree species. Tree-ring master chronology was developed for each site (species) using 13 individual tree-ring chronologies for cedar and 15 for the juniper site. Rings were sampled by coring living trees and using PRESSLER increment borers (Forestry Suppliers Inc., Jackson, MS, USA) (two cores per tree) on two opposite sides of stems. The core samples were fine-sanded and cross-dated using dendrochronological techniques (Stokes and Smiley 1996). Widths of the individual annual rings on 56 cores from the 28 sampled trees were measured at the precision level of 0.01 mm using a PREISSER DIGI-MET (EBAY Inc., Islandia, New York, USA) measurement machine. The author developed 28 series by averaging the two series of each tree. Standardization was applied in each series to remove the non-climatic trends, tree size, and age-related effects as well as the other effects of stand dynamics (Fritts and Swetnam 1989; Stokes and Smiley 1996; TTC, 1999). To carry out the standardization process, regression analyses were applied to the tree growth data, and each of the 28 series of tree-ring width measurements was fit using a polynomial regression model. Each year's annual ring width was divided by the fitted regression curve value of the related year to calculate an index value with a mean of 1 (Eq. 1). Then, an indexed mean chronology of radial growth was developed for each tree,

$$I_{\mathrm{t}} = \frac{W_{\mathrm{t}}}{Y_{\mathrm{t}}} \tag{1}$$

where I_t is the radial growth index value for the year t (dimensionless), W_t is the measured tree-ring width (0.01 mm) for the year t, and Y_t is the regression curve value of the year t.

Master chronologies were developed for each site by combining the indexed series of rings obtained for individual tree base (Cook 1985; Fritts and Swetnam 1989; Stokes and Smiley 1996). One-way ANOVA was performed to test the effect of three periods (pre-, during, and post-drying periods) on radial growth. Correlation analysis was adopted between the mean radial growth series calculated for cedar and juniper to test the association of these two species with their responses to environmental influences. Lastly, SPSS software v. 22.0® (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

RESULTS AND DISCUSSION

To understand whether the radial growth rates of cedar and juniper trees exhibited associations with the dry/wet periods of Lake Avlan, the author used tree-ring analyses for the time span covering the pre-, during, and post-drying periods. The longest time span for the chronologies was 71 years for cedar and 66 years for juniper sites. However, the author used the period of 1960 to 2016 (56 years) for both sites to ensure data reliability due to high variation in annual tree-ring width in early ages. In fact, the rate of growth response to climate conditions may vary depending on the sensitivity of tree species to climate (Touchan *et al.* 2003; Elliott *et al.* 2015). However, the results of this study showed very strong correlation ($r = 0.88$; $P < 0.001$) between the two sites (and two species) for the average annual tree-ring widths that were calculated as arithmetic mean of all series of individual trees in their relevant sites (Fig. 2). This implies that both tree species exhibited more or less similar radial growth response to environmental factors, mainly to climatic ones, which is essential for cross-dating (Stokes and Smiley 1996; Touchan *et al.* 2007).

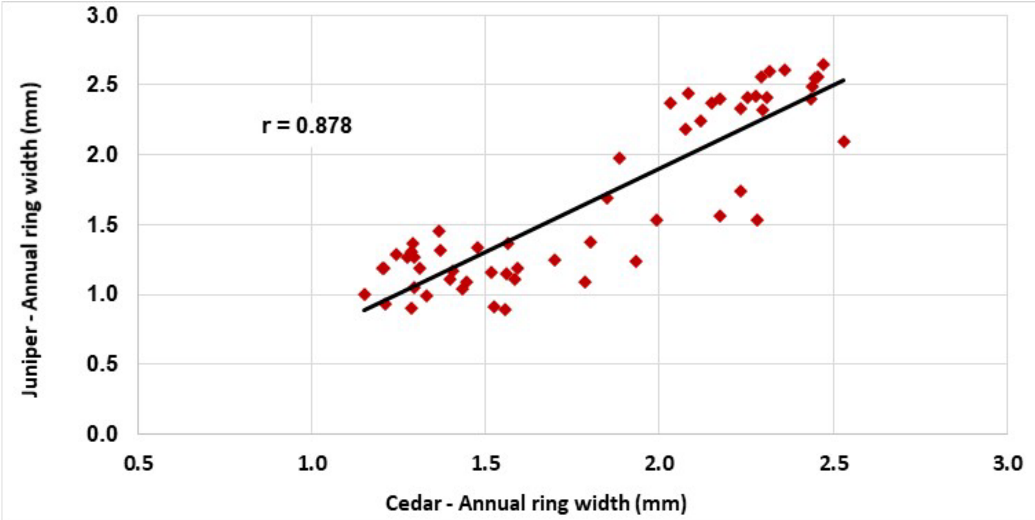

Fig. 2. Relationship between average growth rates of two species (cedar and juniper)

The author developed master chronologies for the two (cedar and juniper) sites by combining the indexed series of individual trees (Fig. 3). As shown in Fig. 3, indexed values of the annual radial growth rate display a random pattern above and below the overall mean line, consistent with the long-term climate-driven patterns for the periods outside of the dry period. However, throughout the dry period, the indexed series pattern persistently tended to be lower than the overall mean line for both species

Analysis of variance (ANOVA) results showed that the mean of index values calculated for the dried period was significantly lower ($P < 0.05$) than those of the periods of pre- and post-drying of the lake for both test sites (Table 1). The mean index value for the dry period was calculated as 0.88, which was 15% less than the mean index values of pre- and post-drying periods of the lake for the cedar site. Corresponding values for the juniper site were calculated as 0.89 and 14%.

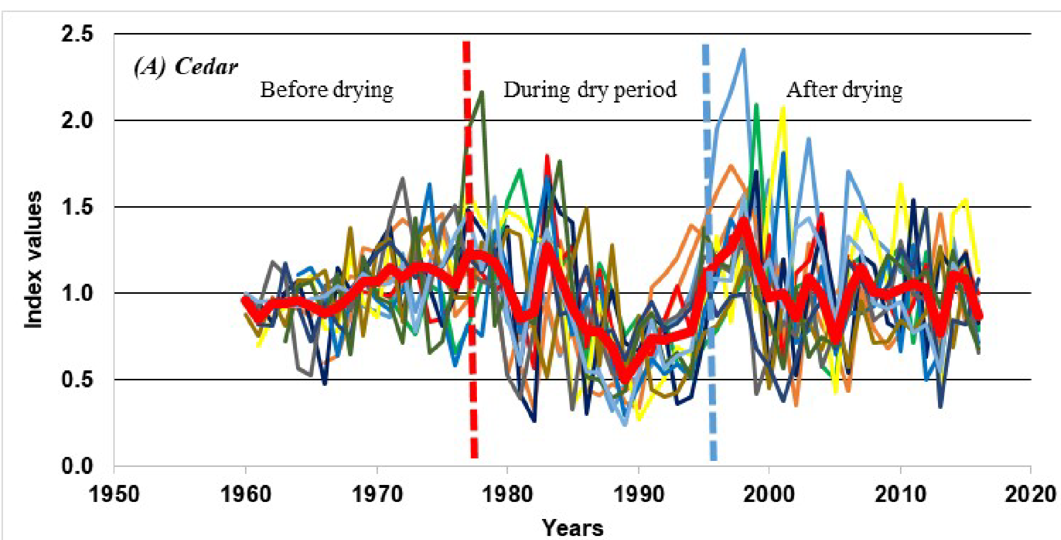

Fig. 3A. Master chronologies for cedar (A) and juniper (B) showing the periods of pre-, during, and post-drying of Lake Avlan. Thin lines show tree-ring index series for individual trees and the thick line shows master chronologies for the related tree species. The horizontal line with the index value of 1.0 indicates the overall series mean value.

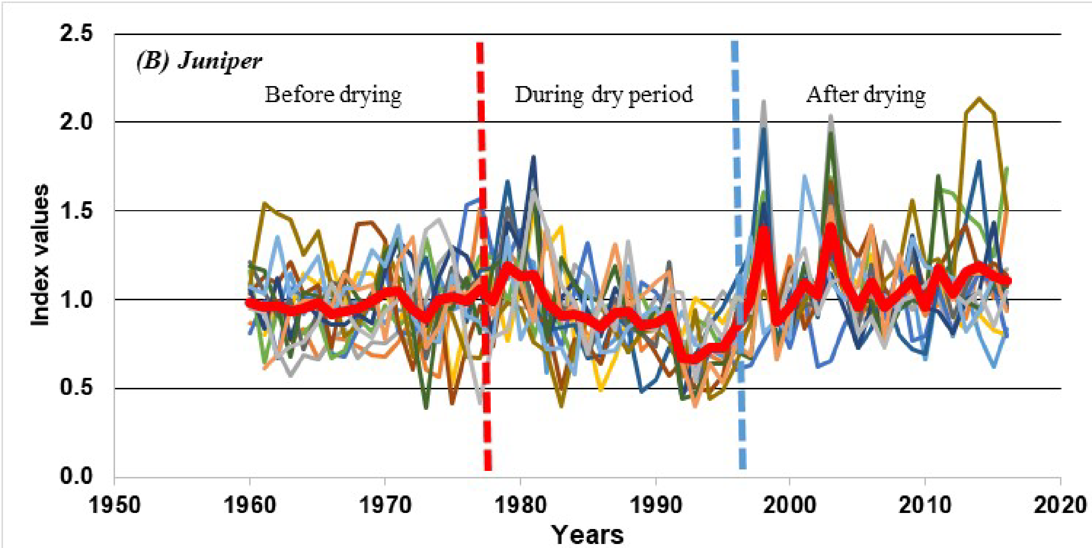

Fig. 3B. Master chronologies for cedar (A) and juniper (B) showing the periods of pre-, during, and post-drying of Lake Avlan. Thin lines show tree-ring index series for individual trees and the thick line shows master chronologies for the related tree species. The horizontal line with the index value of 1.0 indicates the overall series mean value.

Table 1. Result of ANOVA for the Impact of Lake Avlan Presence on Radial Tree Growth on Two Test Sites (Index Values Were Calculated Using Eq. 1)

		Index Values (Mean ± SE)		
Sites	**N**	**Before (1960 to 1978)**	**During (1979 to 1996)**	**After (1997 to 2016)**
Cedar	13	1.04 ± 0.026 a	0.88 ± 0.051 b	1.03 ± 0.035 a
Juniper	15	0.98 ± 0.010 a	0.89 ± 0.035 b	1.09 ± 0.031 c
Different letters in the same row represent significant difference at α = 0.05; N: number of measured trees; SE: standard error; Before, During, and After: represent the periods of pre-, during, and post-drying the lake				

Analysis of dendrochronological records presented so far indicates that there are strong relationships between the tree growth rate and drainage history of Lake Avlan. The question is, "what is the most likely climate variable that leads to such relationships?"

Air humidity, among others, appears to be one of the leading climate variables that affect plant growth at the microecological level in this study area. For instance, Güney *et al.* (2020) found close relationship between air humidity and daily stem radial increment for *C. libani*. Similarly, Ehrenberger *et al.* (2012) reported the effects of microclimate on tree-water relationships. Specifically, evaporation from a lake surface is assumed to be one of the sources of moisture in the atmosphere of the surrounding area. As the water level of a lake declines (and eventually the lake dries up) evaporation from surface water also declines, a consequence of which is a lower contribution to free air humidity that is crucial for the forest ecosystems. For instance, Henderson-Sellers *et al.* (2002) reported that evaporation of water directly from lakes and other areas with open water surfaces contribute between 20% and 40% to the total evaporation flux in the atmosphere. Considering the vegetation cover and the other climate agents, this rate is expected to be higher in the Mediterranean region, where this particular study was conducted in. In addition, Leuschner (2002) investigated the long-term effects of air humidity on the growth rate of eight plant species on natural forest floor. Leuschner found out that the plants were significantly and positively influenced by air humidity, independent from soil moisture status, in terms of their above and belowground dry matter production. Similarly, Leuschner and Lendzion (2009) found the air humidity, in addition to the soil moisture and concentration of exchangeable Ca and K, as the most important abiotic factors affecting the total herb cover. Moreover, several other experimental studies showed that air humidity is an effective climate variable on the whole physiology, anatomy, and nutrition of a tree (Lendzion and Leuschner 2008; Kupper *et al.* 2011).

Effective soil moisture content, which is defined as the amount of available subsurface water, is another important limiting factor at microecological level on the radial growth of trees (Stokes and Smiley 1996). It is clear that the level of air humidity rate affects the soil moisture by controlling the evapotranspiration level from the soil surface. For example, in the Mediterranean region, in mid-July, soil moisture drops below the critical value and results in drier and warmer summers in contrast with what happens in Middle and Northern Europe with higher air humidity (Heck *et al.* 2001). In this respect, Başaran *et al.* (2007) indicate that according to the Thornthwaite water balance diagram, it is highly probable that water deficiency in terms of soil moisture in the basin of Lake Avlan occurs even more severely, starting at the early months of the growing season during the dry periods of the lake.

In contrast, Kum and Sönmez (2016) also obtained meteorological data from Elmali (*i.e.*, the same weather station as utilized in this study, 16.6 km far from Lake Avlan in northeast direction) and studied the relationships between meteorological data and the pre-drying, during, and post-drying periods of Lake Avlan. These authors reported no cause and effect relations between drying of the lake and the overall climate records of the Elmali region. These authors also concluded that eco-social and eco-environmental changes in the livelihood of people during the dry period were related directly to the drainage of Lake Avlan, not to overall climatic changes in the Elmali region. Indeed, the climate emerges as a result of atmospheric events that are effective at the regional level in larger areas and should not be expected to change by the lake, which has a limited effect in local area (Stokes and Smiley, 1996).

Based on all the above results and discussion, it is possible that the decrease in tree radial growth during the dry period of Lake Avlan may have been brought on by air humidity reduction at the microecological level in the study area rather than by overall climate change in the Elmali region. Based on the results of analysis of variance given in Table 1 and findings of previously conducted studies in the study area, it can be concluded that the drying of Lake Avlan also had an impact on the forest ecosystem at the microecological level by reducing the tree growth rate in the lake catchment. In other words, lesser air humidity due to the drainage of the lake might have led to lesser radial growth rate in trees in the forest.

CONCLUSIONS

1. Dendrochronology is one of the accurate methods used for the examination of ecological and environmental events in an area where trees grow and tree samples are available. It is also quite beneficial for accurate and appropriate decision making on natural resource management. Therefore, tree-ring records could be considered as a type of indirect archive of data about environmental factors to which the plants respond.

2. Natural lakes on high mountainous areas are one of the important parts of ecosystems, and they are quite sensitive to any disturbances. For instance, the drying of Lake Avlan by human interference had considerable reduction on the radial growth of trees surrounding the lake basin. The study indicates that lakes in similar areas have multilateral impacts on forests, as well as agricultural ecosystems, at various biological and social dimensions.
3. Natural resource planners must be aware that mountainous ecosystems in high elevations are highly fragile, and they must take every possible measure to avoid interfering in the natural status of lakes and surrounding ecosystems in such areas.

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Conflicts of Interest

The author declares no conflict of interest.

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