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**Article** *in* Fresenius Environmental Bulletin · March 2019



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© by PSP Volume 28 – No. 2A/2019 pages 1610-1615 Fresenius Environmental Bulletin

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## ABSTRACT

Turkish sweetgum (TSG) trees are endemic to Aegean region (Köyceğiz, Fethiye and Dalaman) and to localities between Isparta and Burdur. Once, dense forests of these trees have been diminished to isolated woods in Aegean region. Use of original plant species in urban landscape architecture is increasingly gaining importance worldwide. This study aimed to determine potential areas in Turkey to grow TGS. Monthly maximum and minimum temperatures were interpolated by ordinary kriging (OK) and used with digital elevation values to discretize potential growth areas of TGS across Turkey. The OK performed well in interpolating the monthly means of minimum and maximum temperature. Our results showed that when mean monthly minimum and maximum temperature are used as limiting factor of TSG adaptation, large areas occurred as proper for planting TSG, while use of elevation beside temperature decreased the area substantially. Our results confirmed that TSG can be planted in areas comprised by Black sea, Mediterranean, and central Anatolian regions and that it can survive between elevations of 0 and 800 m (m.t.l) under proper temperature and moisture conditions.

**KEYWORDS:**
Endemic, GIS, Landscape Design, Turkish Sweetgum, Relict, Turkey.

## INTRODUCTION

Turkey is ubiquitous in the World in its richness of plant genetic resources and plant diversity [1]. Approximately 53% of the forests in Turkey are broadleaf, 42% are coniferous, and 5% are mixture of coniferous and broadleaf species [2-3]. Turkey locates at the intersection of phytogeographic regions of Mediterranean, Euro-Siberian, and Irano-Turanian [4-6]. Ninety percent of the forests in Turkey are ‘natural’ in origin and comprises over 450 species of trees and shrubs [7-11]. Three thousand out of the 9,000 plant species are endemic to Turkey [12-15], revealing the obvious wealth of Turkey in plant diversity.

*Liquidambar orientalis* L. is the sole genus in the Hamamelidaceae family [16-17]. It has fossil records back to Tertiary Period. However, it is commonly accepted that it had reached its widest distribution during the Miocene [18-19]. *Liquidambar orientalis* L. is native to southwest of Turkey [20-21]. *L. orientalis* Mill. var. *orientalis* and *L. orientalis* Mill. var. *integriloba* Fiori are the two subspecies of L. orientalis, which exist concomitantly in the same locations. Besides its ecological and biogeographical importance, its balsam “liquid storax” (in Turkish “Günlük” or “Sığla”), a valuable substrate, make this plant economically important as well. In addition its traditional use for more than seven hundred years as an all-purpose drug, particularly as the most effective cure for stomach ulcers by the local people, the liquid storax has been used widely in perfume and cosmetic industries and in modern pharmacy. At the beginning of 20th century, the species was covering a 6321-ha in Turkey. However, currently, its distribution is restricted to only 1337 ha, resulting in approximately 80% decrease [8, 22]. Limited number of reports has been published on the morphology, anatomy, palynology, and phytosociology of this important species [13, 22-26].

Many nations limit import of exotic plants as they prefer use of native plants in landscape architecture, while increased demand on ornamental plants is met by imported exotic plants in Turkey. In this regard, many varieties of *L. orientalis* of Mexico and the USA, produced in European countries especially in Italy, are imported to Turkey and used in urban landscape architecture, which is highly costly in both of supply and maintenance. The native species should be adapted to build sustainable and low-cost landscape architectures. The objective of this study was to find potential growth areas of TGS in Turkey for the purpose of evaluating the possibility of using these native species in urban landscape architecture.

**TABLE 1**
**Information on distribution of Turkish sweetgum (*Liquidambar orientalis*) [34]**

| | Species | |
|---|---|---|
| | *Liquidambar orientalis* Miller var. *orientalis* Miller | *Liquidambar orientalis* Miller var. *integriloba* Fio. |
| **Altitude (m)** | 0-1800 | 0-800 |
| **Endemicity** | Endemic | Not endemic |
| **Habitat** | Flooded plains, Swampy places, River valley near the coast | Flooded plains, Swampy places, River valley near the coast |
| **Distribution in Turkey** | West and Southwestern Anatolia | Southwestern Anatolia |
| **Plant Region** | Mediterranean | Mediterranean |
| **Grid System** | C1, C2 | C1, C2, C3 |

## MATERIALS AND METHODS

In this study, native taxon of Turkish sweet gum (TSG) was used as material. Data of digital elevation model (DEM), obtained from STRM satellite and climate map of Turkey [27] and ARCGIS 10.1 were used as auxiliary material. There are one species and two taxa of TGS in Turkey (Table 1) [28-29]. This species is an important ornamental plant material due to its good-looking crown shape, stem shape, bark texture, leaf orientation, and fruits. *Liquidambar orientalis* is pyramidal when it's young and becomes spherical as it gets older. TGS has a straight stem and can be 30-35 m high and make a diameter of 1.0 m. It flowers between March and April and its fruits are 2-2.5 cm in diameter [30]. Its mature fruits are dark and they fall in October-December depending on their growth conditions. Leaves are dicot, deciduous, petiolate, and compound; often 3 to 5-lobbed, while 7-lobbed in seldom cases. The leaves are 5-7 cm in width and the leaf petioles are 3-6 cm in length. The trees defoliate in October-December depending on elevation [13].

TGS generally grows at altitudes from 180 to 550 m, while it can be found at landforms as high as 900 m. According to Alan and Kaya [31], those growing between 0 and 400 m are called plain sweetgums and those growing over 400 m are called mountain sweetgums. TGS is known to be an important biogeographic agent in Mediterranean region in the Inversion period [13]. Fossil studies reveal that this species had been widespread around temperate and rainy regions of Europe before late ice time and that the TGS had distributed in large areas in Turkey [30, 32] and it is endemic-relic to Anatolia.

The maximum and minimum temperature were interpolated by ordinary kriging (OK). We modeled experimental semivariograms by GS+ (version 7) and used nugget, sill, and range of theoretical semivariograms with OK in geostatistical module of ArcView and built surface maps for minimum and maximum temperatures across Turkey. The rationale behind use of GS+ in semivariogram modeling was that the GS+ is more flexible in semivariogram modeling, while geostatistics module of ArcGIS is better in OK-interpolation, it separates validation and calibration data automatically and it displays the position of the interpolation region in a neighborhood. We used 80% of the climate data (means of monthly maximums and minimums obtained from state meteorological stations) for calibration and 20% for validation in OK-interpolations. We considered minimum of sum of squares and maximum of coefficient of determination (R2) in semivariogram modeling, and minimum of relative sum of squared errors and maximum of correlation coefficient between measured and predicted values of verification data.

We checked the normality of the monthly maximum and minimum temperatures before semivariogram modeling to make sure that data show normal distribution. We considered criteria suggested by [33] in deciding normality of the data. As skewness of all data was below absolute 0.5, we applied no transformation on the data.

We obtained the spatial distribution areas of natural Turkish sweetgum in Turkey from Turkish Plant Data Service [34] and we rectified the maps of each taxon by GIS and digitized its spatial information on the rectified maps. We obtained the information on the elevations and phytogeographical regions from literature (Fig.1) and compared elevation classes obtained for natural TGS by GIS, superposing the data from SRTM and those from DEM. Finally, we rectified the OK-interpolated climate map [35] by GIS, and determined the potential areas where TSG may have been used in urban landscape architecture.

## RESULTS

The relative mean squared error (RMSE) for predictions are below 5 in all the cases (Table 2), suggesting that the OK performed well in interpolating the monthly minimums and maximums across Turkey. However, the r-values suggest that OK was more successful in interpolating minimums compared to maximums.

Fig.1 shows spatial pattern of monthly minimum and maximum temperature along with localities of natural and platted TSG tress based on monthly minimum and maximum temperature and topography. The Fig.1 shows that use of mean

**TABLE 2**
**Parameters for prediction performance of ordinary kriging for long-term monthly maximum and minimum temperature**

| | Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | Jl | Aug | S | O | N | D |
| | Maximum temperature | | | | | | | | | | | |
| $Mean_m$ | 13.69 | 15.61 | 21.02 | 25.78 | 30.09 | 34.05 | 36.39 | 36.09 | 33.29 | 28.43 | 21.67 | 16.12 |
| $Mean_p$ | 13.49 | 15.41 | 20.82 | 25.60 | 29.92 | 33.90 | 36.30 | 35.99 | 33.18 | 28.31 | 21.57 | 15.94 |
| RMSE | 2.05 | 2.16 | 2.13 | 1.96 | 2.028 | 2.13 | 1.97 | 2.002 | 1.88 | 1.77 | 1.65 | 2.07 |
| r | 0.88 | 0.86 | 0.81 | 0.74 | 0.74 | 0.73 | 0.76 | 0.73 | 0.74 | 0.79 | 0.87 | 0.85 |
| | Minimum temperature | | | | | | | | | | | |
| $Mean_m$ | -9.57 | -8.75 | -4.93 | .40 | 4.93 | 9.39 | 12.77 | 12.77 | 7.95 | 2.77 | -2.36 | -6.89 |
| $Mean_p$ | -9.56 | -8.74 | -4.93 | 0.41 | 4.93 | 9.39 | 12.78 | 12.78 | 7.95 | 2.77 | -2.37 | -6.88 |
| RMSE | 3.05 | 3.03 | 2.5 | 1.87 | 1.84 | 1.98 | 2.15 | 2.27 | 2.27 | 2.26 | 2.39 | 2.75 |
| r | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.86 | 0.86 | 0.85 | 0.86 | 0.86 | 0.87 | 0.89 |

$Mean_m$; mean of measured values, $Mean_p$: Mean of predicted values, RMSE: Relative mean squared error, r= correlation coefficient between measured and predicted values of verification data.

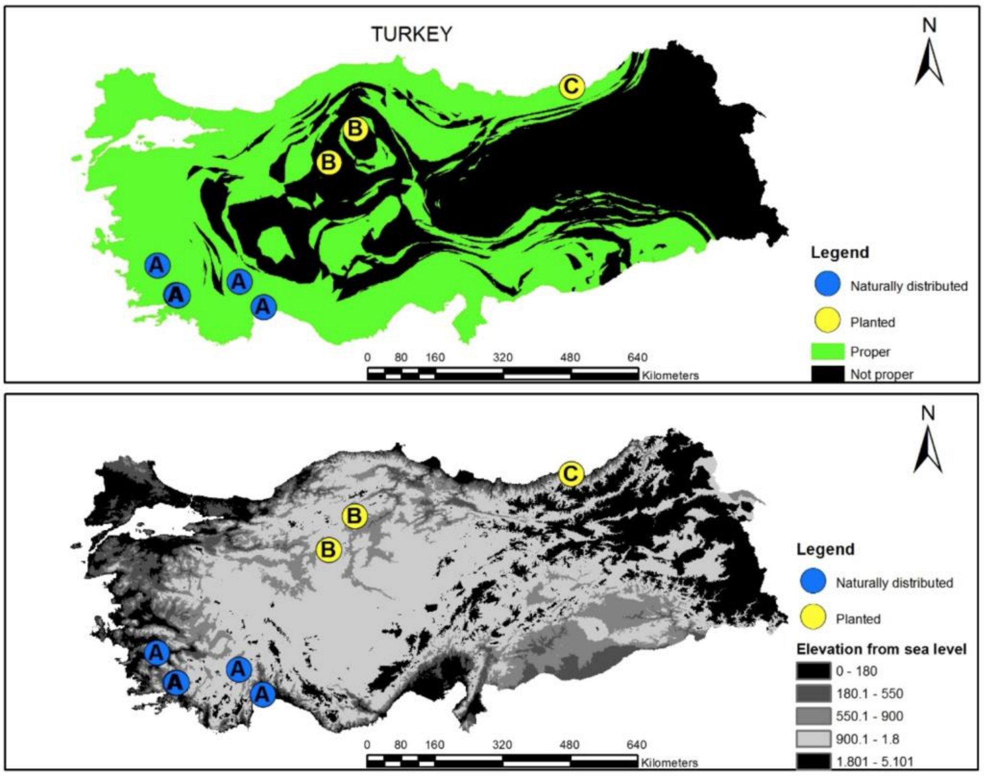


**FIGURE 1**
**Distribution of potential growth areas of Turkish Sweet Gum (TSG) based on monthly minimum and maximum temperatures (above) and elevation besides monthly minimum and maximums (below).**

monthly minimum and maximum temperatures as the only limiting factor of TSG adaptation results in large potential areas for its growth across Turkey. However, when both of climate and elevation are considered, the potential growth area for TSG growth decreases substantially.

## DISCUSSION

Air temperature and total precipitation are the main climate variables mediating plant development and adaptation. Temperatures above and below of critical levels result in death of the plants. The plant development defines orderly progress of plants from germination to death [36]. Development stages in plant indicate intermediated stages such as germination, emergence, leaf appearance, flowering and maturity. All these stages should be completed for a successful plant development.

The maximum and minimum temperature extremes are key determinants of plant adaptation. On the other hand, the extremity of temperature is species-or even taxon-specific. Fig.1 shows naturally distributed and planted areas of TGS trees in Turkey.

When monthly minimum and maximum temperatures considered as only restricting factors, two (those labeled by B) of tree planted regions appeared not proper for plantation of the TSG. However, our observation proves that the planted trees could survive in these regions, suggesting that the maximum and minimum temperatures restricting its growth should be revised.

Elevation is another factor restricting adaptation of TSG. As elevation increases, the temperature decreases gradually, resulting that after a threshold the plant development stops or the plant may die due to extreme temperatures (minimum and maximum temperature), which obscure adaptation of the plants. At high elevations the minimum temperature would be the problem while at low elevations maximum extremes would be. According to Ozturk et al. [13], TSG mainly grows at altitudes from 180 to 550 m, while it can be found rarely at landforms as high as 900 m. Others suggest that TSG exists between the elevations of 0 and 1800 [34]. We observed TSG tress at elevations from 0 to 750 m (mtl) (Fig.1), which contradicts to Ozturk et al. [13].

The "thermal time" is an important determinant of plant development [36]. Therefore, thermal time along with minimum and maximum extremes for growth and development of STG should be determined for its successful plantation and adaptation to changing climate. Total yearly precipitation will not have been a limiting factor in its adaptation to urban landscapes as the plants can be watered when they need. Differences in temperature and in thermal time between its naturally existing location and plated locations may affect the plant morphology as well as aesthetic value on planted landscapes. For example, differences in atmospheric temperature and photosyntetically active radiation may result in leaf form and leaf orientation to change, decreasing aesthetic value of the plants. On the other hand, inadequate thermal time may result in incomplete plant development (i.e. plant cannot flower). Therefore, further research is needed to assess feedbacks of cultured TSG tress to environmental biophysical factors.

The other environmental biophysical factors, such as atmospheric vapor pressure, wind speed and direction, and their interaction with air temperature may be important determinants to be considered in adaptation of TSG in the potential growth regions in Turkey. In this regard, net primary productivity (NPP) may be a good indicator. The response of NPP to climate has already been used to evaluate the feedback of vegetation in response to abrupt climate changes [37]. Babst et al. [38] and Ciais et al. [39] noted that the response of NPP to climate is a good indicator of vegetation growth. Li et al. [16] reported that the mean monthly temperature and precipitation were the principal factors determining NPP and Peng et al. [40] found that air temperature, precipitation, and sunshine percentage had a considerable effect on seasonal variation in NPP. Therefore, NPP can be monitored and used as a surrogate of climate and topography in TSG adaptation studies.

The TSG is an excellent plant for use in urban landscape planning as it mitigates air pollution, balances temperature, saves energy, supplies water vapor, supplies niches for living organisms [41-42], decreases noise [43-44], reduces wind and dust [42, 45-46], and reduces light reflection [47-48]. The natural TSG taxa have a potential to control soil erosion besides its spectacular look. The plant can be used in swamps to dry out the unwanted water due to its high consumption of water and its vivid root system. The cultural form of TSG is used city parks and landscapes across many nations, while it has a limited use in Turkey. Use of TSG in urban landscape design will benefit development of resilient and aesthetic urban landscapes in Turkish cities at low cost.

Besides its aesthetic value, the TSG has an important economic value due its valuable balsam known as "liquid storax". Therefore, TSG may be planted in areas other than urban landscapes for its highly valued substrate. Such plantation may be highly beneficial due to its decreasing erosion and dust, while supporting local people economically.

## CONCLUSIONS

We studied potential growth areas of Turkish sweetgum (TSG) in Turkey, considering mean monthly minimum and maximum values of temperature and elevation from the see level as controlling factors. Ordinary kriging performed well in interpolating mean monthly minimum and maximum temperatures. When only monthly minimum and maximum temperatures were considered, the potential growth area was considerably large, while when elevation was considered as another controlling factor besides temperature, the area decreased substantially. We suggest that further research is needed to determine the conditions of its safe adaptation for the purpose of its use in urban landscapes. Our observations revealed that the temperature extremes and elevation extremes for its adaptation should be revised.

This Economically important endemic species has been faced to extinct in Turkey due to its being used lavishly by local people. Measures should be taken to stop its reduction and to increase its plantation in potential regions with similar climate, soil, and topographic conditions. In this regard, this study is a starting point. We believe that it motivates further studies to increase its distribution across the nation.

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**Received:** 09.10.2018
**Accepted:** 21.11.2018

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