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Future Adaptability of Urban Trees due to the Effects of Climate Change: the Case of Artvin, Turkey

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ABSTRACT

Global climate change began to affect urban and rural landscape planning decisions. The accurate and efficient use of plants that support urban green infrastructure would play an important role in these decisions. The present study aimed to determine the tolerance of domestic and exotic woody plant species planted in public spaces in Artvin province, Turkey to the effects of climate change. Thus, the tolerance of 59 most prevalent trees and shrubs identified in public spaces and natural fields in 12 sampling areas in Artvin province center, Hopa and Ardanuc district centers were surveyed. Findings of the regression model demonstrated that drought, cold hardiness and precipitation had an impact on the adaptability scores of the plants. The differences between the climate conditions in sample areas had an impact on the future adaptation and tolerance of the plants to climate change. This demonstrated that plant species in urban green areas will be affected not only by the global climate change but also by local climate conditions in the short and long term.

Key words: *Artvin, adaptability, climate change, planting design, tolerance, urban trees*

INTRODUCTION

Climate change is defined as any change in climate over time, resulting from natural variations or human activities, which have significant impacts on biodiversity, interactions between the species and ecosystem services by threatening current habitat conditions due to heat and water stress (*EEA 2012; Bellard et al. 2012; Emilson and Sang 2017; Kabisch et al. 2017*). The projected global average temperature rise will be between 1.8 and 4.0°C by 2100 (*Sengur et al. 2015*). The global climate change is expected to lead to significant rises in sea level and to changes in the frequency, intensity and spatial patterns of temperature, precipitation and other meteorological factors (*Depietri and McPhearson 2017; IPCC 2015*), as well as economic downturns (*Reeve and Kingston 2014*).

The main effects of climate change on cities include the urban heat island (UHI) effect, poor air quality and higher ozone concentrations, as well as extreme precipitation (*Bonn et al. 2014; Kabish and Van den Bosch 2017; Taylor 2017*). *Foos and Aenis* (*2017*) stated that the city of Berlin expects higher average temperatures by up to 2.5 °C until 2050, more "hot days" and an increase in days with heavy rain and a rise in rainfall during spring and winter. Increased air temperatures due to climate change could lead to increased heat-related illnesses (*Harlan et al. 2006*) and mortality (*Chen et al. 2014; García-Herrera et al. 2010; Kabisch et al. 2017*).

Urban parks and street trees may play an important role in contributing to human well-being in cities. As a natural contribution to climate change mitigation, they can provide comfortable thermal environments; and thus, may reduce vulnerability to heat stress. Urban parks and green spaces are called 'park cool islands' (PCIs) in the literature (*Kabisch et al. 2017; Spronken-Smith and Oke 1998*). *Bowler et al.* (*2010*) reported that, on average, an urban park could reduce the ambient temperature about 1°C when compared to a non-green site. Urban cooling by green spaces could be significant. In Singapore, mean cooling by vegetation was estimated at 3.07 °C by *Wong and Yu* (*2005*) as the urban heat island effect reached 7 °C (*Chow and Roth 2006; Depietri and McPhearson 2017*). Trees are valuable urban assets, providing numerous ecosystem services (ES), which are necessary for human well-being, such as improved air and water quality, reduction in stormwater runoff, improved thermal comfort, carbon sequestration and storage, prevention of heat-related morbidity and mortality, and recreational opportunities, as well providing habitat for other species (*Chen et al. 2014; Davies and Doick 2017; Kabish and

Van den Bosch 2017).

The selection of appropriate tree species is important for the achievement of high temperature efficiency while limiting maintenance requirements and fulfilling other ecosystem services such as habitat availability and aestheti value (*Emilson and Sang 2017; Rahman et al. 2015*). The current selection of plant material as well as planting design should be adjusted to accommodate the changing climate. A moderate planting design, for example, with tree distance of 7.5 m, in combination with permeable pavement or bare soil extending to the canopy could lead to good cooling and low water stress (*Emilson and Sang 2017; Vico et al. 2014*).

The foreseeable effects of climate change in Turkey demonstrate that the average temperature increase in Turkey will be 1.5-2.5 °C based on the RCP4.5 scenario and 2.5-3.5 °C, based on the RCP8.5 scenario for the 2016-2099 period. Although there is no general increase or decrease prediction in precipitation, it was estimated that the precipitation irregularities would increase (RCP: Representative Concentration Pathway) (*Demircan et al. 2017; Yildirim and Gurkan 2016*). These predicted changes have already been affecting urban and rural landscape planning decisions. The accurate and efficient use of plants that support urban green infrastructure would particularly play an important role in these decisions.

The knowledge on the impact of climate change on trees is thus necessary for tree species selection (*Yang 2009*). It is crucial to determine the tolerance of ornamental plants planted in public spaces to the effects of climate change (such as colder, warmer or more rainy weather conditions) for a sustainable planning. Thus, the present study aimed to investigate the ecological tolerance of woody plant species to climate change in public spaces.

MATERIALS AND METHODS

Study Area and Climate Conditions

The present study was conducted in Artvin province Central, Hopa and Ardanuc districts, Turkey. Artvin province is located in the Eastern Black Sea Region between 40.35 and 41.32 North latitudes and between 41.07 and 42.00 East longitudes with a surface area of 7.436 km^2. It is neighbored by Ardahan province to the east, Rize province to the west, Georgia to the north, Erzurum province to the south and the Black Sea to the northeast. The length of the provincial coastline is 34 km (**Figure 1**).

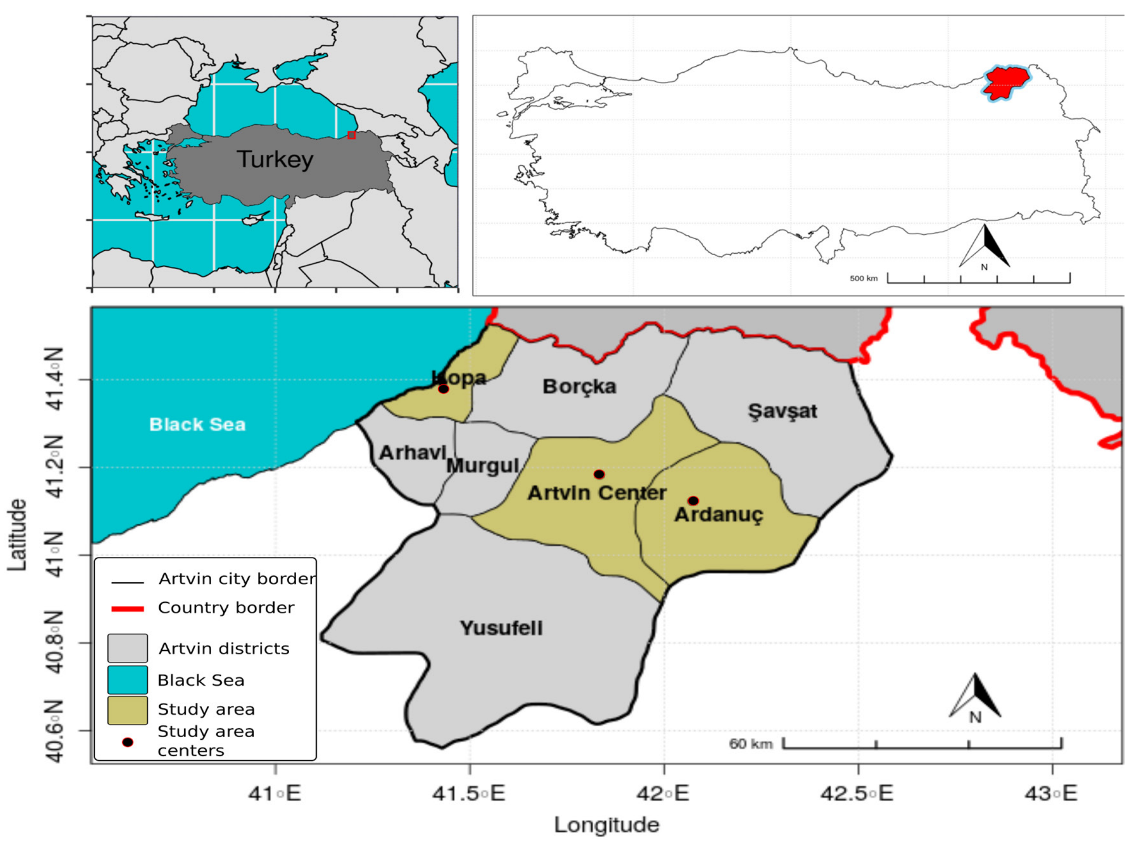

Figure 1. Study area, Artvin, Turkey.

Artvin province has a moist/semi-moist climate with cool winters, warm summers with moderate water deficit and near-sea impact. It has the most variable climate in the Eastern Black Sea region. In the region that includes the coastal areas and the Cankurtaran mountain range, the typical Black Sea climate that includes precipitation in every season is observed. In the area between the Cankurtaran mountains and Borçka and Artvin centers, the Black Sea climate with colder winters and less precipitation is prevalent. The climate in Ardanuc and Yusufeli, and especially in the sections of the Coruh valley, is a partial mix of terrestrial and Mediterranean climate, with hot and arid summers and slightly warmer and less rainy winters. The Coruh River and its basin that runs through Artvin is instrumental in the coexistence of different climate regimes in Artvin. The valley climate typically exhibits the characteristics of Black Sea, Mediterranean and mostly Central Anatolian climates (*ESR 2018)*. This climatic diversity has naturally led to the development of a diverse plant cover and flora.

Analysis of the 1949-2016 Artvin climate (*TSMS 2017a*) and 1981-2016 regional precipitation data (*TSMS 2017b*) demonstrated that the seasonal precipitation has continuously increased and periodical droughts were observed throughout the years. Based on the maps published by Turkish State Meteorological Service (*TSMS 2017c; TSMS 2017d*), Artvin is included in the 8b region (-6.7-9.4 °C) in Plant Hardiness Zone Map and in Zone 4 (the number of days over 30 °C > 14-30) in Plant Heat Zone Map.

Method

In the present study, three public spaces in each central district and one natural field in the immediate vicinity of the central district were determined randomly and the most prevalent trees and shrubs were identified in 12 sample areas. A field survey was conducted in summer 2017 to facilitate the identification of species.

A comprehensive literature review was conducted (*Botanica 1999; Brickell 2003*) and plant database websites (*RHS 2017; TPDS 2017*) were used to determine the ecological requirements and tolerances of the plant species identified in the study area (*i.e.*, temperature tolerance range and moisture requirements).

The tolerance scores of the plant species were compared with the average, highest and minimum values available in long-term meteorological data for Artvin provincial center, Hopa and Ardanuc districts between 1975-2017 (**Table 1**). Thus, tolerances of the plant species in the Eastern Black Sea region to the climate change were determined for each species.

Table 1. Meteorological data for Artvin provincial center, Hopa and Ardanuc districts between 1975 and 2017 (General Directorate of Meteorology, Artvin).

1975-2017	Artvin	Hopa	Ardanuc
Maximum Temperature in a day (°C)	41.6	39.8	45.5
Minimum Temperature in a day (°C)	-11.9	-7.5	-17.8
Total Precipitation Average (mm, yearly)	741.5	2241.9	438.7
Maximum Precipitation in a day (mm)	342.2	734.4	159.3

The dataset included future compatibility tolerances of plant species based on maximum temperature, minimum temperature, maximum precipitation, and drought tolerances of the plant species and climate change scenarios. Thus, a scale between 0 and 3 (0: Non-hardy, 1: Less Tolerant, 2: Moderately Tolerant, 3: Tolerant) was developed and the identified species were scored based on the scale. The scoring system was modified, and the number of parameters were reduced based on a study by *Roloff et al.* (*2009*).

It is known that the growth rings are used to measure the susceptibility and response of the trees to past climate changes and this method could also assist the prediction of the adaptation of the trees to future climate changes (*Roloff et al. 2009*). On the other hand, the review of certain studies on the effects of climate change on soil interactions (*Davidson and Janssens 2006; Kirschbaum 1995*) demonstrated that urban soil actually exhibits a heterogeneous structure under the influence of several variables. Thus, planners and designers should consider soil properties, environmental conditions, human pressures and future climate change scenarios for the future planting areas when selecting adequate plants. In fact, *McPherson et al.* (*2018*) described an approach to identify and analyze the performance of promising but infrequently used tree species (climate-ready trees).

In the present study, the complex correlations between the ecological requirements of the plant and the climatic variables were considered and the climatic parameters that should be considered for more effective selection of urban landscape plants were emphasized. Multiple regression analysis was conducted on the sample district data to determine which climatic factors would be effective on future adaptation of the plant species and to provide an adequate assessment model.

Homogeneity and normal distribution tests were conducted on the variable data. The findings demonstrated that the data were homogeneous and exhibited normal distribution. Unlike *Brouwers et al.* (*2013*), it was decided to analyze all variables together to limit the number of models. Thus, the maximum and minimum temperatures, precipitation and drought variables that limit plant growth were analyzed in conjunction. On the other hand, it is possible for the other factors to change due to changes in climatic variables. The most important factor among these is the variations in soil properties. Thus, since this variable was not analyzed, the effect sizes could not be known and there will be variations in R^2 values.

Plant species were classified in two categories: domestic and exotic plants. Thus, the adaptation scores of plant species could be calculated as follows, based on the model with the highest Adjusted R Square value:

Domestic/Exotic Plant Species Future adaptability Score $= B_{\text{Model Constant}} + (\text{Max. Temp. score} * B_{\text{Max.Temp.}}) + (\text{Min. Temp. score} * B_{\text{Min. Temp.}}) + (\text{Precipitation score} * B_{\text{Precip.}}) + (\text{Drought score} * B_{\text{Drought}})$

In the equation above, the climate parameters for the model obtained with the regression analysis were used, and the parameters not included in the model were removed from the equation. SPSS 19 software was employed in statistical analysis.

RESULTS AND DISCUSSIONS

A total of 59 taxa in 27 families were identified (31 in Hopa district, 35 in Artvin provincial center, 23 in Ardanuc district) (**Table 2**). Comparisons of ecological requirements and hardiness of the plant species were based on long-term mean climate parameters for the districts (**Tables 3, 4 and 5**).

Table 2. Identified plant species in sample areas.

Sample areas		Plant species
Hopa	Sehitler Park	*Callistemon citrinus, Camellia japonica, Chamaerops excelsa, Cupressus macrocarpa* "Goldcrest"*, Eriobotrya japonica, Laurocerasus officinalis, Photinia serrulata, Pinus pinea, Prunus cerasifera* "Atropurpurea"*, Thuja occidentalis*
	Road and refuges	*Catalpa bignonioides, Chamaerops excelsa, Ligustrum japonicum, Nerium oleander, Paulownia tomentosa, Robinia pseudoacacia*
	Meydan park	*Biota orientalis, Cedrus deodara, Chamaecyparis lawsoniana, Cryptomeria japonica, Cupressocyparis X leylandii, Cupressus macrocarpa* "Goldcrest"*, Cupressus sempervirens, Ligustrum japonicum, Magnolia grandiflora, Pinus brutia, Platanus orientalis, Tilia rubra*
	Natural field	*Alnus glutinosa, Buxus sempervirens, Carpinus betulus, Castanea sativa, Fagus orientalis, Rhododendron ponticum, Tilia rubra*
Artvin	Ata Park	*Ligustrum japonicum, Photinia serrulata, Picea pungens* 'Glauca'*, Platanus orientalis, Prunus cerasifera* "Atropurpurea"*, Tilia tomentosa*
	Main Campus of Artvin Coruh University	*Acer campestre, Acer saccharum, Buxus sempervirens, Cotinus coggyria, Cupressus macrocarpa* "Goldcrest"*, Ligustrum japonicum, Malus floribunda, Olea europea, Photinia serrulata, Pinus pinea, Prunus serrulata* "Kanzan"*, Punica granatum, Quercus ilex, Sorbus aucaparia, Taxus baccata, Viburnum tinus*
	University housing and surroundings	*Acer platanoides, Cercis siliquastrum, Cupressocyparis leylandii, Eriobotrya japonica, Morus alba, Nerium oleander, Olea europea, Pinus pinea, Platanus orientalis, Prunus cerasifera* "Atropurpurea"*, Punica granatum, Thuja occidentalis, Tilia tomentosa, Viburnum tinus*
	Natural field	*Acer campestre, Arbutus andrachne, Carpinus orientalis, Cotinus coggyria, Juniperus oxycedrus, Ostrya carpinifolia, Paliurus spina-christi, Pinus sylvestris, Punica granatum, Quercus petraea, Rhus coriaria*
Ardanuc	Public space (Ziraat Bank Garden)	*Cedrus deodara, Nerium oleander, Pinus pinea, Punica granatum, Pyracantha coccinea*
	Beylikduzu Park	*Biota orientalis, Picea abies, Pinus pinea, Pinus sylvestris, Tilia rubra, Tilia tomentosa*
	Road and refuges	*Biota orientalis, Cedrus deodara, Cupressus macrocarpa* "Goldcrest"*, Cupressus sempervirens, Juglans regia, Platanus orientalis, Robinia pseudoacacia, Tilia rubra, Tilia tomentosa*
	Natural field	*Acer campestre, Carpinus orientalis, Cotinus coggyria, Juglans regia, Juniperus oxycedrus, Paliurus spina-christi, Pinus sylvestris, Quercus petraea, Rhus coriaria, Salix alba*

Hopa District

Of the 31 species identified in the sample area in Hopa district, 13 were domestic and 18 were exotic species. *Buxus sempervirens, Fagus orientalis, Laurocerasus officinalis, Pinus brutia and Rhododendron ponticum were moderately tolerant domestic species. Camellia japonica, Chamaecyparis lawsoniana* and *Magnolia grandiflora* were less tolerant (**Table 3**). *Chamaerops excelsa, Cryptomeria japonica, Cupressocyparis x leylandii, Cupressus macrocarpa "*Goldcrest*", Eriobotrya japonica, Photinia serrulata* and *Thuja occidentalis* were moderately tolerant exotic species that would be exposed to climate change risks. In Hopa district, sea winds, sudden temperature changes, extreme sunlight, and the increase in the number of arid days would constitute a risk for these plants.

Artvin Provincial Center

Of the 35 identified plant species in the sample areas in Artvin central district, 23 were domestic and 12 were exotic. *Acer platanoides, Arbutus andrachne, Buxus sempervirens, Nerium oleander, Olea europea, Pinus pinea, Platanus orientalis, Punica granatum* and *Rhus coriaria* domesctic species were moderately tolerant to sudden temperature changes, the increase in the number of days with frost and increase in the number of arid days. Exotic species *Acer saccharum, Cupressocyparis x leylandii, Cupressus macrocarpa "*Goldcrest*", Eriobotrya japonica, Malus floribunda, Photinia serrulata, Picea pungens "*Glauca*", Prunus serrulata* "Kanzan" and *Thuja occidentalis* were moderately tolerant species (**Table 4**).

On the other hand, indigenous *Sorbus aucaparia* and *Taxus baccata* species were most vulnerable to future climate changes. They will not exhibit any tolerance if the area is not adequately maintained based on the environmental conditions (e.g., sheltered, shaded, irrigated areas, etc.).

Ardanuc District

Seventeen of the 23 plant species identified in the sample areas in Ardanuc 17 were domestic and six were exotic plants. It was observed that the species planted in the area were mostly resistant to local ecological conditions. However, future sudden temperature changes, increase in the number of days with frost in the winter and long arid summer days would be risky for certain species.

Thus, the exotic species *Cedrus deodara, Cupressus macrocarpa "*Goldcrest" and *Picea abies* could be at risk. Among the domestic species, *Cupressus sempervirens, Nerium oleander, Pinus pinea, Platanus orientalis, Punica granatum, Rhus coriaria* and *Tilia rubra* could be at risk. Especially in case of long summer droughts,

Table 3. Individual tolerance grades of the plant species identified in Hopa district based on the climate data (tolerant species are not included in the table)..

Plant name	Family	Max. Temp. (39.8 °C)	Min. Temp. (-7.5 °C)	Precipitation (Max. Precip.: 734.4 mm)	Drought (zone 4)	Future adaptability grade
Buxus sempervirens	*Buxaceae*	2	3	3	2	2
Camellia japonica	*Theaceae*	2	2	2	0	1
Chamaecyparis lawsoniana	*Cupressaceae*	2	3	3	2	1
Chamaerops excelsa	*Palmaceae*	3	3	1	3	2
Cryptomeria japonica	*Cupressaceae*	2	3	3	1	2
Cupressocyparis x leylandii	*Cupressaceae*	3	3	2	2	2
Cupressus macrocarpa "Goldcrest"	*Cupressaceae*	3	2	2	2	2
Eriobotrya japonica	*Rosaceae*	2	3	2	2	2
Fagus orientalis	*Fagaceae*	3	3	3	2	2
Laurocerasus officinalis	*Rosaceae*	3	3	3	2	2
Magnolia grandiflora	*Magnoliaceae*	3	3	2	1	1
Photinia serrulata	*Rosaceae*	3	3	2	2	2
Pinus brutia	*Pinaceae*	3	3	1	3	2
Rhododendron ponticum	*Ericaceae*	3	3	3	1	2
Thuja occidentalis	*Cupressaceae*	3	3	3	2	2

species that cannot acquire sufficient moisture might be adversely affected (**Table 5**). Similarly, the species that are susceptible to cold are likely to be damaged by long periods of frost during the winter. Exceptionally, the species planted in sheltered areas may have the chance to withstand the adverse effects of future climate changes.

Table 4. Individual tolerance grades of the plant species identified in Artvin central district based on the climate data (tolerant species are not included in the table).

Plant name	Family	Max. Temp. (41.6 °C)	Min. Temp. (-11.9°C)	Precipitation (Max. Precip.: 342.2 mm)	Drought (zone 4)	Future adaptability grade
Acer platanoides	*Aceraceae*	2	3	3	2	2
Acer saccharum	*Aceraceae*	1	3	3	2	2
Arbutus andrachne	*Ericaceae*	3	1	2	3	2
Buxus sempervirens	*Buxaceae*	2	3	2	2	2
Cupressocyparis x leylandii	*Cupressaceae*	2	3	3	2	2
Cupressus macrocarpa "Goldcrest"	*Cupressaceae*	3	2	2	2	2
Eriobotrya japonica	*Rosaceae*	2	2	2	2	2
Malus floribunda	*Rosaceae*	3	3	2	2	2
Nerium oleander	*Apocynaceae*	3	1	2	3	2
Olea europea	*Oleaceae*	3	2	3	3	2
Photinia serrulata	*Rosaceae*	2	2	2	3	2
Picea pungens "Glauca"	*Pinaceae*	1	3	2	2	2
Pinus pinea	*Pinaceae*	3	2	3	3	2
Platanus orientalis	*Platanaceae*	3	3	2	2	2
Prunus serrulata "Kanzan"	*Rosaceae*	2	3	2	2	2
Punica granatum	*Lythraceae*	3	1	3	3	2
Rhus coriaria	*Anacardiaceae*	3	1	3	3	2
Sorbus aucuparia	*Rosaceae*	2	3	2	1	1
Taxus baccata	*Taxaceae*	1	3	2	1	1
Thuja occidentalis	*Cupressaceae*	2	3	2	1	2

Table 5. Individual tolerance grades of the plant species identified in Ardanuc district based on the climate data (tolerant species are not included in the table).

Plant name	Family	Max. Temp. (45.5 °C)	Min. Temp. (-17.8°C)	Precipitation (Max. Precip.: 159.3 mm)	Drought (zone 4)	Future adaptability grade
Cedrus deodora	*Pinaceae*	3	2	2	3	2
Cupressus macrocarpa "Goldcrest"	*Cupressaceae*	2	1	2	2	1
Cupressus sempervirens	*Cupressaceae*	3	1	3	3	2
Nerium oleander	*Apocynaceae*	3	1	2	3	1
Picea abies	*Pinaceae*	2	3	2	1	1
Pinus pinea	*Pinaceae*	3	1	3	3	2
Platanus orientalis	*Platanaceae*	3	3	2	2	2
Punica granatum	*Lythraceae*	3	1	3	3	2
Rhus coriaria	*Anacardiaceae*	3	1	3	3	2
Tilia rubra	*Tiliaceae*	2	3	1	3	2

Relationships between Climate Data and Plant Adaptability

Based on the study findings, it can be argued that the plant species in public spaces may moderately tolerate the effects of possible climate change (**Figure 2**). It was estimated that certain trees and shrubs may adapt to the climate conditions in Hopa; however, the same species may be at risk in Artvin central and Ardanuc districts. For example, *Cedrus deodara, Cupressus sempervirens, Nerium oleander, Pinus pinea, Platanus orientalis* and *Tilia rubra* species could adopt in Hopa, while these would exhibit moderate tolerance in Ardanuc and Artvin Center districts.

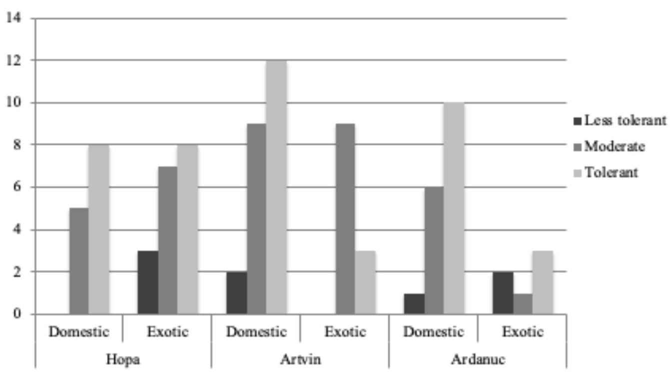

Figure 2. Adaptation score distributions of plant species in sample areas.

The results of the regression analysis demonstrated that all climate characteristics (max temperature, min temperature, precipitation, drought) affected the adaptability of the exotic plant species in Hopa sample area (R^2= 0.677). Maximum temperature, precipitation, and drought were relatively effective on future adaptability of domestic plant species (R^2= 0.291) (**Table 6**). Although Hopa has a milder climate when compared to the other districts due to its coastal location, and it provides adequate conditions for the survival of these plants, the extreme climate changes experienced in recent years actually pose a threat to future adaptability.

Drought (R^2= 0.482) was effective on adaptability of exotic species in the Artvin central sample area, while minimum temperature and drought (R^2= 0.886) were both important factors for domestic species (**Table 7**). One of the reasons of this fact was the possible future increases in summer aridity and frost in Artvin center.

In Ardanuc sample area, maximum temperature was effective on future adaptability of exotic species (R^2= 0.806), while it was determined that minimum temperature and precipitation (R^2= 0.723) were effective on domestic species (**Table 8**). In Ardanuc, which is located far from the coast when compared to other districts, the decrease in precipitation and sudden temperature increases that would be experienced especially during summer would adversely affect the plant species.

Table 6. Regression analysis of plant species in Hopa district*.

Species	Model	B	t	Sig.	F	Adjusted R^2
Exotic 1	(Constant)	.388	.770	.299	9.897	.677
	Max. temperature	.186	.575	.576		
	Min. temperature	-.277	.485	-.719		
	Precipitation	.260	.170	1.453		
	Drought	.682	.002	3.944		
Domestic 1	(Constant)	-1.727	.337	-1.014	2.641	.291
	Max. temperature	.636	.191	1.414		
	Precipitation	.455	.091	1.890		
	Drought	.545	.050	2.268		

**Enter* model used

Table 7. Regression analysis of plant species in Artvin central district*.

Species	Model	B	t	Sig.	F	Adjusted R^2
Exotic 1	(Constant)	1.059	2.882	.016	11.25	.482
	Drought	.529	3.354	.007		
	(Constant)	.294	.720	.479		
Domestic 1	Drought	.794	5.380	.000	28.94	.559
	(Constant)	-1.500	-4.847	.000		
2	Drought	1.000	12.569	.000	86.522	.886
	Min. temperature	.500	7.822	.000		

**Stepwise* model used

Table 8. Regression analysis of plant species in Ardanuc district*.

Species		Model	B	t	Sig.	F	Adjusted R^2
Exotic	1	(Constant)	-2.500	-2.462	.070	21.778	.806
		Max. temperature	1.750	4.667	.010		
		(Constant)	1.452	4.660	.000		
Domestic	1	Min. temperature	.470	3.709	.002	13.759	.444
		(Constant)	-.287	-.591	.564		
	2	Min. temperature	.592	6.269	.000	21.854	.723
		Precipitation	.563	4.012	.001		

**Stepwise* model used

The differences in climate conditions in sample areas have an impact on future adaptability of the plants and their tolerance to climate change. This suggested that plant species in urban green areas would be affected not only by global climate change but also by short and long term changes in regional climate conditions. *Roloff et al.* (*2009*) emphasized the significance of drought tolerance and cold hardiness on future survival of trees in climate change. As a result of the present study, it became clear that drought and cold hardiness were effective parameters.

The use of urban forests and green zones by local governments and municipalities is an important urban planning element to improve the quality of life of the citizens (*Varras et al. 2016*). Urban trees provide ecological, aesthetic, economic and psychological facilities (*Coutts et al. 2016; Li et al. 2018*). However, trees in urban areas are exposed to a large number of pollutants and higher temperatures (*Gregg 2003*), which may lead to positive or negative effects on tree quality when compared to rural areas. For example, due to the urban heat island effect, temperatures in urban areas are 3.5 – 4.5 °C higher when compared to rural areas (*Forrell et al. 2015; Nitschke et al. 2017)*. Thus, determination of the vulnerability of urban trees and even other plant species is important for the sustainability of urban green infrastructure and biodiversity.

Generally, heat stress could be defined as a rapid increase of 10-15°C over the normal ambient temperatures (*Lipiec et al. 2013*). Rapid increases and sudden drops in the air temperature would adversely affect the temperature and water retention capacity of the soil. The climate change would have various effects on plant health. For example, warmer temperatures could increase the evapotranspiration demand and drought stress, the vulnerability of the trees to certain diseases, that could result in harmful consequences (*Tubby and Webber 2010*). Extreme weather events are likely to increase in the future, exposing trees to intense winds, as well as flooding, storm surges and heavy snow and ice loads (*McPherson et al. 2018; Yang 2009*). Certain ornamental plants could adapt to climate change-induced extreme temperatures (an increase in the number of arid days) and rainy periods, but they may lose their flowers, fruits and foliage properties (e.g., *Paulownia tomentosa*).

Another effect of climate change, warmer winters and higher summer temperatures may favor certain exotic ornamental plants. The use of domestic plants in urban areas may be reduced. Certain studies on future climate change scenarios emphasized the vulnerability of plant species to climate change and it was reported that planting drought and heat-resistant species would be a better approach in urban areas (*Nitschke et al. 2017*). Thus, although we support the use of indigenous plant species due to their ecological, economic and functional benefits, it is of strategic importance to select the right species for future adaptability. Furthermore, the unique characteristics of each plant species and their response to local area conditions and various stress factors are also highly variable (*Fahey et al. 2013; McPherson et al. 2018*), which makes it difficult to select the adequate species.

The ecological environment of indigenous plant species is exposed to lower stress levels when compared to urban areas. However, the effects of climate change will be observed on a broader scale; for example, certain plants in lower altitudes will have to migrate to higher altitudes over time. Certain species such as *Pinus sylvestris*, which was identified in the present study, may migrate to higher and more humid and cool altitudes . On the other hand, certain Mediterranean plants (e.g., *Arbuts andrachne, Rhus coriaria, Olea europea* and *Pinus pinea*) in the relatively mild and hot Coruh basin would be under the risk of environmental effects that would be facilitated with the construction of the dams on the Coruh river and the effects provisioned in global climate change scenarios.

Sudden temperature changes that may be experienced in the future and the resistance of plants to precipitation anomalies may vary based on the characteristics of the planting site. Certain plants may tolerate warm and cold conditions based on the planting site (e.g., exposure, sheltered areas such as shade of a building, etc.). However, maintenance would be crucial to maintain this resilience. This could lead to expensive maintenance costs.

CONCLUSIONS AND RECOMMENDATIONS

According to the climate change scenarios, although periodic increases are not projected in the temperatures in Turkey, periodical rises and decreases and abnormalities in regional precipitation have been predicted. Thus, the present study, which was conducted in Artvin province provided the researchers with the opportunity to predict the vulnerabilities of plant species in and around the urban green areas against the effects of the possible climate change. It was determined that drought tolerance, minimum-maximum temperatures and precipitation variables were influential on future adaptability of plant species based on the data collected in sample areas. However, in addition to the climate parameters, it is important to consider other environmental and ecological elements (e.g., soil properties, local conditions, pathogens, individual properties of the plant) for future adaptability of plant species when making planting decisions.

It was observed that mostly aesthetic and functional plant properties were emphasized in landscape design decisions in urban open green spaces. However, the adaptability of these ornamental plants to future climate changes has not been considered sufficiently in planning. The planting decisions have usually been made based on market conditions in Turkey, and application preferences have generally been set by ornamental plant market trends. Thus, the present study aimed to provide guidelines for future decision-maker and designer strategies.

Rapid transition between the seasons and months that are drier and colder than seasonal norms could have negative effects on the development of plant species. Thus, domestic or exotic plants should be selected based on tolerance and adaptability of the plants to changing climatic conditions during the design phase. Climate change should be considered as a decisive parameter in environmental impact assessments, environmental protection and sustainable planning. Trees in urban green spaces, especially those under extensive human pressure, could remain healthy against the risks of upcoming climate change and contribute to urban biodiversity with the utilization of correct planning approaches that anticipate the future.

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