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IMPACTS OF CLIMATE CHANGE ON ORIENTAL SPRUCE (*PICEA ORIENTALIS*) ECOSYSTEMS IN THE EASTERN BLACK SEA REGION OF TURKEY

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Abstract

Climate change has recently gained increased attention from the global scientific community due to its widespread and accelerating impacts on ecosystems. The Eastern Black Sea Region of Turkey is expected to be significantly affected by these changes, as projected by the RegCM3 regional climate model.

*Oriental spruce (*Picea orientalis*), an ecologically and economically important tree species endemic to this region, is highly sensitive to climatic shifts. Recent observations indicate that global warming has contributed to severe bark beetle outbreaks, resulting in the death of over 200,000 trees.*

This study evaluates the current status and future vulnerability of Oriental spruce ecosystems using field observations and existing literature on regional climate projections. According to Dalfes et al. (2007), regional temperatures are expected to rise by 2–4 °C over the next century. Precipitation is projected to increase by 200–300 mm in the eastern part of the region, while no significant change is expected in the western areas.

Temperature increases, particularly in the western zone, are likely to intensify drought stress, elevate bark beetle infestations, and increase wildfire risk. A potential upward altitudinal shift of 400–800 meters in the spruce distribution zone is anticipated, along with a general upward movement of the treeline across both eastern and western parts of the region.

These findings highlight the urgent need for adaptive forest management and conservation strategies to mitigate the projected impacts of climate change on Oriental spruce ecosystems.

Keywords: *Climate change; oriental spruce (*Picea orientalis*); Eastern Black Sea region; forest ecosystems; bark beetle; Turkey*

INTRODUCTION

Global warming has been receiving increasing attention from both the public and scientific communities in Turkey and worldwide. Weather anomalies, extreme temperatures, frequent flooding events, sea-level rise, and glacial melting represent key phenomena that the scientific community strongly associates with ongoing climate warming (IPCC, 2007).

The period from 1995 to 2006 included eleven of the twelve warmest years in the instrumental record of global surface temperature

since 1850. Oceanographic observations since 1961 indicate that the average temperature of the global ocean has increased to depths of at least 3000 m, with the ocean absorbing over 80% of the additional heat introduced into the climate system. This thermal expansion of seawater contributes significantly to sea-level rise (IPCC, 2007).

Atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly due to human activities since 1750, now substantially exceeding pre-industrial

levels documented through ice core records spanning millennia. The rise in atmospheric CO₂ primarily results from fossil fuel combustion and land-use changes, while increased methane and nitrous oxide concentrations are largely attributable to agricultural practices (IPCC, 2007).

The global atmospheric CO₂ concentration has risen from approximately 280 ppm in pre-industrial times to 379 ppm by 2005. This current level dramatically exceeds the natural range of 180-300 ppm observed over the past 650,000 years in ice core records. Notably, the annual growth rate of atmospheric CO₂ was higher during the recent decade (1995-2005 average: 1.9 ppm/year) compared to the long-term average since continuous monitoring began (1960-2005 average: 1.4 ppm/year), despite interannual variability (IPCC, 2007).

These documented changes provide compelling evidence that climate warming is occurring, predominantly driven by fossil fuel consumption. However, research examining how global warming will specifically affect Turkey's climate and ecosystems remains limited. Analysis of meteorological data from 1951-2004 by Dalfes et al. (2007) revealed significant decreases in winter precipitation across western Turkey over recent decades, while autumn precipitation increased at stations primarily in northern central Anatolia. Their most prominent finding was the widespread increase in summer temperatures throughout the country. Using the RegCM3 climate model, Dalfes et al. (2007) projected temperature increases of 4-6°C in western Turkey and 2-4°C in eastern regions for future climate scenarios. Precipitation projections generally indicated decreases along Aegean and Mediterranean coasts, with increases anticipated along the Black Sea coast.

Picea orientalis represents an ecologically significant conifer species endemic to the eastern Black Sea region of Turkey. As spruce genera typically dominate boreal ecosystems characterized by cold winters and cool summers, these spruce-dominated ecosystems are likely to be among the first to manifest detectable responses to climate change. This investigation utilizes current scientific literature and field observations to evaluate this hypothesis systematically.

MATERIALS AND METHODS

The genus *Picea* comprises 35 species across the Northern Hemisphere, with *Picea orientalis* representing the only naturally occurring species in Turkey. Oriental spruce forests cover approximately 297,396 hectares of Turkey's forested areas (Anonymous, 2006). This species demonstrates preference for humid climates, areas experiencing summer fog events, and north-facing slopes where precipitation is limited. It forms mixed stands with several species including *Pinus sylvestris*, *Abies nordmanniana*, *Fagus sylvatica*, and *Quercus* species. *Picea orientalis* becomes the dominant canopy species in mixed stands at elevations around 1000 meters, maintaining dominance up to 2400 meters, and frequently forms pure stands within this elevational range (Anonymous, 2001).

Climatic conditions within the species' distribution range feature mean annual temperatures of 5-10°C, though extreme temperatures can reach -20°C in winter and 30°C in summer. Mean temperatures during the growing season range between 10-20°C (Tüfekçioğlu, 2008). Annual precipitation across the species' distribution varies substantially from 700-3000 mm.

Fog precipitation plays a crucial role in the distribution and persistence of spruce ecosystems within these warm temperate regions. Despite its importance, no scientific studies have quantified fog water input to these ecosystems in the region. For comparison, an 18-week investigation in a *Picea sitchensis*/*Tsuga heterophylla* stand in Oregon recorded 290 mm of fog drip alongside 640 mm of rainfall (Kimmins, 1997). Additionally, fog provides shading from direct solar radiation while fog drip cools needle surfaces. We hypothesize these mechanisms represent key factors enabling spruce ecosystem persistence in this humid temperate region.

This study employs comprehensive literature review and systematic field observations to address our research questions regarding climate change impacts on Oriental spruce ecosystems.

RESULTS AND DISCUSSION

Global Climate Change and Spruce Ecosystems

Spruce ecosystems predominantly occur within the boreal zone, characterized by short, moderately warm, moist summers and prolonged, cold, dry winters, with mean annual temperatures ranging from -5 to 3°C (Perry, 1994). The boreal forest spans over 1.2 billion hectares across North America and Eurasia, representing the largest terrestrial carbon reservoir (30-35% of global terrestrial carbon), primarily stored in organic soils of the forest floor (Soja et al., 2007). Spruce forests also extend into high-elevation areas of temperate regions.

Scientific consensus acknowledges increasing global mean temperatures, with the most pronounced warming occurring in northern high-latitude and high-elevation regions where spruce forests predominantly exist (Soja et al., 2007; Tüfekçioğlu, 2008). Predicted ecological indicators of climate change in these regions include: (1) intensified fire regimes (increased frequency, severity, burned area, and extended fire seasons); (2) enhanced insect infestations (greater frequency, duration, and spatial extent); (3) treeline altitudinal shifts; and (4) stand- and landscape-level alterations in forest composition (age structure, and species composition) (Soja et al., 2007).

Fire represents the primary ecological driver influencing structure, age distribution, and species composition in spruce forests, playing a vital role in maintaining biodiversity. Research conducted across North American and Russian boreal forests demonstrates increased fire frequency that is projected to accelerate with continued climate change (Soja et al., 2007).

Bark beetle outbreaks have emerged as a significant threat to spruce ecosystems worldwide. Enhanced bark beetle activity has been directly linked to climate warming, as elevated temperatures enable completion of the insect life cycle in one year rather than two, dramatically increasing population growth (Berg et al., 2006; Weissbacher, 2004). In Germany, bark beetles caused extensive mortality across 3,700 hectares of spruce forest in Bavaria National Park, primarily driven by elevated temperatures, windthrow events, and drought stress

(Heurich et al., 2001; Nusslein et al., 2000).

Climate change-induced treeline shifts have been documented globally (Soja et al., 2007). Altitudinal treeline advances have been recorded across the southern Urals, Altai, Sayan, and Kuznetsky Alatau mountain ranges. In the southern Urals, the forest treeline ascended 20-40 meters, reducing adjacent tundra area by approximately half.

Climate-mediated growth responses in spruce forests demonstrate complex patterns. Contrary to expectations, increased productivity at treeline due to warming may not be straightforward. Lloyd and Fastie (2002) examined tree growth responses at boreal forest margins to 20th-century climate variability, finding regional differences in climate sensitivity. Post-1950, warmer temperatures correlated with growth declines except in the most humid regions, indicating drought stress may accompany warming in many boreal forests (Soja et al., 2007).

Complementary research by Barber et al. (2000, 2004) documented negative growth responses in Alaskan *Picea glauca* to drought conditions. Dendrochronological and $\delta^{13}\text{C}$ isotope analyses near Fairbanks revealed moisture-stress-mediated effects during warmer decades, consistent with model predictions.

Climate Change Impacts on Turkey's Spruce Ecosystems

Turkey is projected to experience significant climate change impacts (UNDP Turkey, 2007). Analysis of 18 meteorological stations (1939-1989) identified a 0.63°C increase in Turkey's mean annual temperature (Asan, 1995). Regional analysis of Eastern Black Sea stations (1951-2004) by Dalfes et al. (2007) showed increased winter and spring precipitation in Artvin, decreased spring precipitation in Trabzon, and surprisingly, decreased mean annual temperature in Artvin. Regional climate modeling using RegCM3 projects temperature increases of $2-4^{\circ}\text{C}$ in the region during the coming century (Dalfes et al., 2007). Precipitation scenarios indicate increases of 200-300 mm in the eastern Black Sea region, while western areas show no substantial precipitation changes.

These projected changes may cause upward

shifts of 400-800 meters in the spruce distribution belt in western regions. Eastern areas will likely experience treeline ascent without significant lower-elevation boundary changes due to compensatory precipitation increases. Consequently, spruce forest area may decrease in western regions while expanding in eastern areas.

Temperature increases will likely induce physiological stress in spruce trees, potentially increasing susceptibility to bark beetle attacks. Approximately 100,000 spruce trees experienced mortality from bark beetle outbreaks in Hatilla National Park, Artvin (Tüfekçioğlu et al., 2005). Dendroecological analysis of 200 tree-ring samples (100 live, 100 dead) revealed that beetle-killed trees exhibited greater mean annual diameter increment over two decades, suggesting these rapidly growing trees experienced significant stress in their final decade.

Fire may emerge as a novel threat in western regions under projected climate change. Currently, fire represents an insignificant disturbance agent in Oriental spruce ecosystems due to humid summer conditions. However, fire plays a crucial ecological role in maintaining structure, diversity, and health in boreal spruce ecosystems globally (Soja et al., 2007).

Climate change will likely trigger drought-induced mortality and growth reduction in Oriental spruce ecosystems. Similar drought-mediated growth declines have been documented in Alaskan spruce forests (Barber et al., 2000). Mortality events in low-elevation spruce and pine forests during dry years have already been observed in the Black Sea region (Tüfekçioğlu

et al., 2005).

Climate change will fundamentally alter the structure, stability, and biodiversity of Oriental spruce ecosystems. Fire-mediated secondary succession may become established in western regions, while insect outbreak-driven succession events will likely increase in frequency. Such changes may increase plant diversity through replacement of shade-tolerant *Picea orientalis* with shade-intolerant species, which typically support richer understory communities (Kiliç & Kutbay, 2004). Conversely, treeline advance and replacement of alpine grasslands by spruce forest would likely decrease plant diversity at high elevations.

CONCLUSIONS

Climate change will significantly influence distribution, diversity, structure and stability of the oriental spruce ecosystems. According to RegCM3 regional climate model, the temperatures will increase 2-4 °C in the region in the next century. Future climate scenarios predict 200-300 mm increases in precipitation in the eastern part of the region while the western part won't have any increase in precipitation in the next century. Temperature increases in the western part of the region will put more stress on spruce trees and will probably increase bark beetle attacks. Also, fire could become an important threat in the western part of the region. It is possible to observe 400-800 m upward shift in the spruce belt in the western part. Treeline of spruce and scotch pine stands will probably move upward both in western and eastern part of the region.

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