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Results of a paired catchment analysis of forest thinning in Turkey in relation to forest management options

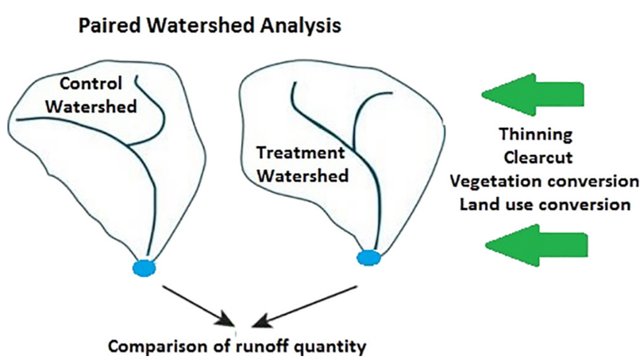
Ibrahim Yurtseven *, Yusuf Serengil, Ferhat Gökbulak, Kamil Şengönül, Süleyman Ozhan, Umit Kılıç, Betül Uygur, Mehmet Said Ozçelik

Istanbul University, Faculty of Forestry, Department of Watershed Management, 34473 Sariyer, Istanbul, Turkey

HIGHLIGHTS

- Climate change management of water-related forest ecosystem services is essential.
- A paired experimental watershed study was conducted over different time periods.
- Two different cutting treatments were applied and the impact on runoff was analyzed.
- Results were linked to global studies on clearcutting, thinning and vegetation change.
- Better water yield depends on precipitation, climate conditions and cutting treatments.

GRAPHICAL ABSTRACT



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ABSTRACT

Adaptation to climate change has become a more serious concern as IPCC assessment reports estimate a rise of up to 2 °C in average global temperatures by the end of the century. Several recently published studies have underlined the importance of forest management in mitigating the impacts of climate change and in supporting the adaptation capacity of the ecosystem. This study focuses on the role of water-related forest services in this adaptation process. The effects of forestry practices on streamflow can best be determined by paired watershed analysis. The impact of two cutting treatments on runoff was analyzed by a paired experimental watershed study in the Belgrade Forest and the results were evaluated in relation to similar experiments conducted around the world. Forest thinning treatments at 11% and 18% were carried out in a mature oak-beech forest ecosystem over different time periods. Although the thinning increased the runoff statistically, the amount of surplus water remained <5% of the annual water yield. Evidently, the hydrologic response of the watersheds was low due to the reduced intensity of the timber harvest. Finally, the results were combined with those of global studies on thinning, clearcutting and species conversion with the aim of formulating management options for adaptation.

1. Introduction

Ecosystems across the world are under the increasing pressure of anthropogenic stressors (Sicard et al., 2016). This raises concerns for the sustainable provision of some ecosystem services including water

* Corresponding author.
E-mail address: ibrahimy@istanbul.edu.tr (I. Yurtseven).

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production. Climate change is a major threat having potentially serious impacts on the quality, regime and yield of water (Hesse et al., 2015). Furthermore, land-use change or inappropriate land use practices may exacerbate these effects (Pamukcu et al., 2014).

Forests have a well-recognized place in the science and policies related to climate change mitigation, while their place in climate adaptation still needs to be developed. In this respect, better management strategies may boost the capacity of forests further, especially in water-related adaptation issues.

A growing forest not only removes net carbon from the atmosphere, but also provides services (e.g., providing water, purifying the air, regulating the microclimate) that support adaptation. In other words, the carbon removal by the forests is strongly linked (in a positive or negative direction) to the ecosystem services, especially those of water production. Considering that even the most optimistic IPCC AR5 scenario (RCP 2.6) predicts a 1.5–2 °C temperature rise globally by the end of the century (IPCC, 2013), a better understanding is needed of ways in which forests can be made more resilient to climate change while still providing ecosystem services.

The Mediterranean basin that comprises Turkey and a large part of southern Europe lies within one of the most vulnerable regions in terms of climate change (Lionello et al., 2014), making this area susceptible to drought, desertification, water shortage, and floods. In Turkey, the mean annual precipitation drops to 200 mm in semiarid central Anatolia (Asouti and Hather, 2001), while it exceeds 2000 mm in the Black Sea coastal region (Bozkurt and Sen, 2011). Thus, the great variation in the distribution of precipitation across the country in combination with current land use-based problems (desertification, erosion, etc.) may result in a number of water-related concerns in the coming decades.

Adaptive forest management strategies have been proposed to support the climate change adaptation capacity of the forests (Linder, 2000; De Dios et al., 2007) and create more resilient ecosystems (Biggs et al., 2012). Resilience enables a forest to withstand or absorb external pressures and, over time, return to its pre-disturbance state (Rammer and Seidl, 2015). Because of their generally reduced biodiversity, plantations and modified natural forests will face greater disturbances and risk of large-scale losses due to climate change than primary forests (Pawson et al., 2013). Therefore, the resilience of a forest ecosystem is related to its biodiversity, structure, and management. Adequate management approaches must support ecosystem resiliency as well as provision of ecosystem services.

According to Sanz and del Jalón (2005), streamflow parameters can be used to evaluate the response of ecosystems to forestry treatments or disturbances. The aim of this research was to focus on the impacts of selected forestry treatments and investigate their effects on the forest hydrology and closely related adaptation capacities. Hydrology as is a crucial element in the adaptation of ecosystems to changing climatic conditions (Mackey et al., 2008). Precipitation conditions are major determinants of the adaptation capacity of ecosystems. The amount and seasonality of the precipitation are key factors influencing water deficiency in the soil and flood risk (Robichaud, 2016). The overall water cycle in an ecosystem also influences the streamflow pattern, which is vital for riparian habitats (Xiang et al., 2016).

Hydrology is also linked to ecosystem water production. Therefore, forest management operations potentially influence not only the water cycle, but also the water production of the forests, which is an important factor for the local inhabitants. Forestry treatments may also support adaptation by regulating water reduction. Water as a critical issue is more visible in urbanized areas where water demand rises with population growth, resulting in an insufficient supply of available fresh water. Urbanization and urban sprawl are recognized as serious threats to forested watershed functionality and health (Serengil et al., 2012). The low and high flow conditions of streams are especially critical at the point where urban areas and forests converge (Roy et al., 2005). Changes in the seasonal flow pattern may lead to degradation of stream habitats (Belmar et al., 2013), increased frequency of floods (Ouarda et al., 2006), and prolonged low flows (Laaha and Bloschl, 2006).

Forest management is a significant tool for facilitating forest adaptation to climate change and generating ecosystem services. Adaptive forest management has been suggested in order to establish a more flexible approach (Stankey et al., 2005), but there is a need for more understanding of and reliable data on the impacts of sequential management applications. This is problematic, as forest hydrology research around the world is limited because these studies require extensive time, funding and effort.

In brief, adaptive resource planning should be applied in order to achieve the highest possible adaptation level under changing social, economic and ecological conditions. The concept of resource management has been developed to improve management and planning approaches according to the results of collected and analyzed data. In this study, the objective was to evaluate the impact of forestry treatments on streamflow, and by integrating the findings with worldwide hydrological studies, to develop forest management policies that will enhance adaptation capacities.

2. Material and methods

2.1. Study area

The paired watershed methodology is a well-established research approach for analyzing the impacts of various treatments on streamflow by eliminating the influence of variations in climatic conditions (Gökbulak et al., 2016; Serengil et al., 2007; Ssegane et al., 2015). The Ortadere paired experimental watersheds (W-I and W-IV) located in the Kurtkemeri forestry district of the Belgrade Forest have been instrumented and studied for long-term ecological research since 1977 (Fig. 1). The Ortadere experimental watersheds are approximately 3 km south of the Black Sea and 10 km north of the Bosphorus. Precipitation, runoff, and water quality have been monitored continuously since 1978.

The experimental watersheds are covered with native deciduous tree species including oak (*Quercus petraea* L., *Quercus frainetto* Ten.), beech (*Fagus orientalis* L.), hornbeam (*Carpinus betulus* L.), chestnut (*Castanea sativa* M.), alder (*Alnus glutinosa* L.) and rowan (*Sorbus torminalis* L.). Watershed-I (W-I), with an area of 71.9 ha, was kept as the control, while Watershed-IV (W-IV), with an area of 77.5 ha, was used as the treatment watershed. The average crown closure is about 95–100% within both watersheds and the average slopes of the paired watersheds are respectively 10% and 14%. According to Özhan (1977), soils in the watershed are Vertic Xerochrept mainly derived from Neogene loam and gravel deposits. The soil texture of the surface horizon is loamy clay with high erodibility potential and medium permeability. The average depth of the mull-type forest floor is 5 cm, with high detention and retention capacity, providing a buffering effect against overland flows (Balcı et al., 1993). Thus, the streamflow in this forest ecosystem produces hydrographs. The topsoil in the watersheds is approximately 30 cm deep and consists of 3.2% organic matter, whereas this value is 4.9% in the Belgrade Forest where the experimental watersheds are located (Özhan, 1977). Both watersheds were instrumented with V-notch weirs equipped with automatic flow recorders.

According to the Thornthwaite classification system, the climate of the watersheds is humid, mesothermal and oceanic with a moderate water deficit in summer (Balcı et al., 1986). The mean annual precipitation is 1050 mm with a large portion generally falling from October to March. The average temperature is 12.8 °C. The share of snowfall in the annual water yield represents <3% and thus, is not a significant component of the water budget. The streamflow reaches peak values between January and March, depending on the interannual precipitation pattern.

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