Eur J Forest Res (2017) 136:653–664
DOI 10.1007/s10342-017-1062-3

ORIGINAL PAPER

Response of selected water chemical quality parameters to slight thinning in a mature oak–beech forest ecosystem under sub-humid climate conditions

Ibrahim Yurtseven[1] · Ferhat Gökbulak[1] · Yusuf Serengil[1] · Betül Uygur Erdoğan[1] · Mehmet Said Özçelik[1] · Kamil Şengönül[1] · Süleyman Özhan[1]

Received: 5 May 2017 / Revised: 8 June 2017 / Accepted: 4 July 2017 / Published online: 8 July 2017
© Springer-Verlag GmbH Germany 2017

Abstract The objective of this study was to determine the effect of 18% thinning on streamflow nutrient flux from a mature oak–beech forest ecosystem by paired watershed approach. Two experimental watersheds including control (W-I) and treatment (W-IV) watersheds were used in the study. The experimental watersheds were monitored about 6 years from 2006 to 2011 for the calibration period and 4 years from 2012 to 2015 for the treatment period. The forest in the treatment watershed was thinned between October and December in 2011, and the forest in the control watershed was left untreated. Water grab samples were collected from the streams in the watersheds on weekly basis during both the calibration and treatment periods and analyzed for calcium (Ca^{2+}), magnesium (Mg^{2+}), Kjeldahl nitrogen (KN), sodium (Na^{+}), potassium (K^{+}), iron (Fe^{3+}), aluminum (Al^{3+}), ammonium nitrogen (NH_4^{+}-N), and sulfate (SO_4^{2-}). The simple linear regression equations were developed between mean monthly nutrient fluxes of two watersheds in the calibration period with significantly high correlation coefficients, and they were used to estimate nutrient fluxes from the treatment watershed during the treatment period as if thinning had not been applied. The changes in the monthly nutrient fluxes were estimated as the differences between measured and values calculated with the linear regression equations. Results showed that removal of 18% standing timber volume did not significantly change nutrient exports except for KN and Na^{+} from the treatment watershed.

Keywords Nutrient outflux · Stream water quality · Paired experimental watersheds · Oak–beech forest ecosystems · Thinning

Introduction

Forestlands provide freshwater with best quality compared to other land uses (Sun et al. 2004; Neary et al. 2009; Boggs et al. 2016) but consume great amount of water through transpiration and interception. Additionally, most of the rivers around the world derive their waters from forested uplands, and residents of many cities and towns depend on these forested watersheds for their domestic water supplies (Ryan and Glasser 2000; Feller 2005). Forested watersheds also provide several services including nutrient cycling, wildlife habitat, recreation, climate regulation, forage for grazing animals, timber production, and soil and water conservation (Martin et al. 2000). Therefore, freshwater-supplying forested watersheds require special attention for their management. Silvicultural activities are applied in these forest ecosystems with several purposes such as regeneration of existing forest vegetation, reforestation, plantation, clearcutting, vegetation cover change, thinning. Among these activities, timber harvesting is also used as a tool to increase water yield from forested watersheds. In general, results showed that streamflow can be increased by intensive timber harvesting that reduces the forest canopy interception and transpiration and increases the proportion of precipitation reaching soil surface (Bosch and Hewlett 1982; Keppeler and Ziemer 1990; Stednick 1996; Lane and Mackay 2001; Özyuvacı et al. 2004;

Communicated by Agustín Merino.

✉ Ferhat Gökbulak
fgokbulak@istanbul.edu.tr

[1] Department of Watershed Management, Faculty of Forestry, Istanbul University, 34473 Bahçeköy, Istanbul, Turkey

Hubbart et al. 2007; Dung et al. 2012; Suryatmojo et al. 2013; Gökbulak et al. 2016). Intensive forest harvesting like clearcut has also the potential to alter chemical characteristics of streams draining forested watersheds. Concentrations of some chemical water quality parameters are increased due to decreased nutrient uptake by plants, increased water outflows, and soil temperatures resulting in higher rates of N-mineralization and nitrification, and nutrient leaching through soil to stream waters (Dahlgren 1998; Wynn et al. 2000; Wang et al. 2006). While forest harvest activities can cause increases in the water yield, they can also have an adverse effect on water quality in the forested watersheds due to nutrient losses, erosion, and leaching (Dahlgren 1998; Swank et al. 1989). In fact, Gökbulak et al. (2008) showed that there were significantly high correlations between streamflow and nutrient and suspended solid losses in a forested watershed. That is, nutrient and sediment losses can increase and be detrimental to quality of potable stream water if streamflow increases due to intensive timber harvesting. For instance, Burns and Murdoch (2005) reported that NO_3^- concentration increased more than 1400 $\mu mol l^{-1}$ after clearcut. High nitrate concentrations can deteriorate water quality in the streams and, hence, cause mortality of the aquatic lives like brook trout (Baldigo et al. 2005). Similarly, Tremblay et al. (2009) measured great increase up to 6000% in the NO_3^- concentration after timber harvest in their study carried out in Canada. While the streamwaters of the forested watersheds are available without filtration, as in Portland, Oregon (Neary et al. 2009), the chemical quality of the streamwater can be deteriorated due to eutrophication caused by excessive nitrogen and phosphorus export as a result of intensive timber harvest (Gravelle et al. 2009). A number of studies carried out around the world showed that nutrient flux generally increased after clearcut compared to partial cut but magnitude showed variability due to diversity of climate, vegetation, topography, soil, and harvest and logging strategies and techniques among the study sites. Swank et al. (2001) found small increases in nutrient fluxes after clearcut but largest increases occurred three years after clearcut, while Dahlgren (1998) and Wynn et al. (2000) reported higher nutrient losses from the clearcut watersheds compared to the untouched control watersheds and losses increased especially during the high streamflows following storm events. Burns and Murdoch (2005) found fivefold increase in the concentration of NO_3^- from 20 to 100 $\mu mol l^{-1}$ just three months after clearcut treatment. Similar increases in nutrient outflow after clearcut were also reported in other studies (Reuss et al. 1997; Arthur et al. 1998; Martin et al. 2000; Ensign and Mallin 2001; Boggs et al. 2016).

In contrast to clearcut, harvests with low-intensity timber removals such as selective cutting, partial harvest, and thinning result in slight changes in the concentrations of nutrients in the streamwater. In fact, Siemion et al. (2011) studied effect of harvest intensity on streamwater chemistry and found that greater changes occurred in the streamwater chemistry when biomass harvest was greater than 40% and recovery period for the streamwater chemistry was shorter for the forest received low-intensity timber harvest than that subjected to high-intensity timber removal. On the other hand, some studies compared the effects of clearcut with those of partial cut on nutrient outflow but the results from these studies were not consistent. For example, Messina et al. (1997) found that clearcut and partial harvest had similar effects on the NH_4-N, NO_3-N, PO_4-P concentrations in the streamwater, while Martin et al. (2000), Baldigo et al. (2005), Gravelle et al. (2009), and Tremblay et al. (2009) found statistically significant increases in the concentrations of some streamwater chemical parameters after both clearcut and partial cut treatments. Similarly, Clinton (2011) found great increases in the stream nitrate concentration in the site with no-buffer (clearcut site) zone, whereas the sites with 10- and 30-m-wide buffer zones did not have increases in the stream chemical parameters. Similar studies from different regions also showed that thinning or shelter wood cutting influenced nutrient discharge in various magnitudes. Bäumler and Zech (1998) tested the impact of a 40% thinning on streamwater chemistry, and they found increases in the ion concentrations and solution loads, especially NH_4^+, in the streamflow discharge. Serengil et al. (2007a) also found significant increases for Cl^-, Ca^{2+}, Mg^{2+}, and K^+ loads but not for total nitrogen and PO_4-P loads in the streamwater after 11% thinning. Wang et al. (2006) observed significant increases in the NO_3^-, NH_4^+, Mg^{2+}, Ca^{2+}, K^+, and Al_{to} concentrations in the streamwater, and their concentrations peaked between 1 and 6 months after 33% timber harvest.

Thinning is a common silvicultural treatment in Turkish forestry including freshwater-producing forested watersheds, but there are limited studies regarding effect of timber harvest on streamwater quality (Serengil et al. 2007a). The study site lies between sub-humid Southern Europe and semiarid Middle East with various forest ecosystems and rich plant species. The study site also includes seven dams constructed during fifteenth century and supplies some freshwater to Istanbul City for domestic use. Since water is a limited resource in the region, freshwater demand of residents in the city has been met from the forested watersheds located in the neighboring cities. That is why, it is important to investigate effects of forestry operations on water quantity and quality in this region and the results of this study can be utilized by forest managers for the management of other forested watersheds. Therefore, main objective of this study was to examine the

impact of 18% thinning on streamwater chemical quality in Ortadere experimental watersheds in Belgrad Forest of Istanbul.

Materials and methods

Study area

Two experimental watersheds located in Belgrad Forest of Istanbul were used in this study (41°13′00″– 41°14′13″ N, 28°54′25″-28°56′37″ E) (Fig. 1). The watersheds have similar ecological conditions such as vegetation, soil, and climate, and the distance between the control (W-I) and treatment (W-IV) watersheds is approximately 1.4 km. The treatment watershed is 77.50 ha with an average slope of 14% and a slope length of 395 m, while the control watershed is 71.90 ha with a mean slope of 10% and a slope length of 362.50 m. The elevations range from 97 to 190 m in the treatment watershed and from 99 to 170 m in the control watershed. The treatment and control watersheds have drainage densities of 3.80 and 3.60 km km^{-2}, respectively, with second-order streams that flow into a dam supplying very little portion of drinking water for Istanbul City. The main stream channels have a slope of 3% in the control watershed and 5% in the treatment watershed (Fig. 1). The thickness of forest floor and crown closure were similar between the watersheds and varied from 4 to 6 cm and from 74 to 100%, respectively (Özhan 1977). Parent materials in the site are mainly carboniferous clay schists and Neogene loamy, gravelly deposits. The site has moderate to deep soil depth with good hydraulic conductivity and organic matter content greater than 3% (Özhan et al. 2010). The soil type in the watersheds is Vertic Xerochrept (USDA 1996) with sand clay loam and sandy loam soil textures. The watersheds have almost identical road densities, and they are 12.36 m ha^{-1} for the W-IV and 12.93 m ha^{-1} for the W-I. Mean annual precipitation in the study site is about 1129 mm, and mostly falls from October to April. Snowfall is rare in the site, and snow cover stays on the ground less than a week when it falls. Mean annual temperature was about 12.3 °C and varied between 21.7 °C in August and 4.2 °C in February (Özhan et al. 2008). The study site has a sub-humid Mediterranean climate type characterized with mild-wet winters and hot-dry summers.

Dominant vegetation is composed of approximately 60–70-year-old oak [*Quercus petraea* (Mattuschka) Liebl. and *Q. frainetto* Ten.] and beech (*Fagus orientalis* Lipsky)

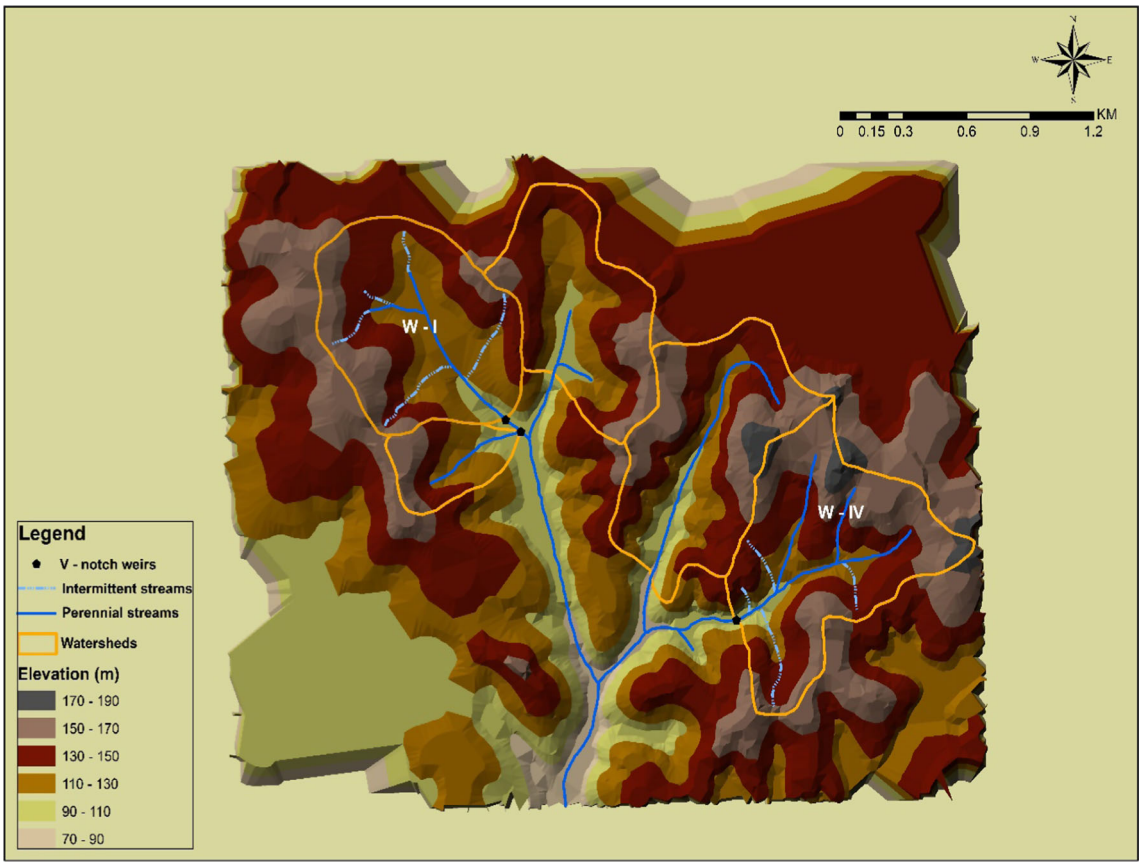


Fig. 1 Topographic map of the control (W-I) and the treatment (W-IV) watersheds

tree species with low proportions of other tree species such as *Q. cerris* L., *Populus tremula* L., *Alnus glutinosa* L., *Carpinus betulus* L., *Acer trautvetteri* Med., *Acer campestre* L., *Castanea sativa* Mill., *Ulmus campestris* L., and *Sorbus torminalis* Crantz. in the overstory. Understory vegetation consists of some shrubs such as *Erica arborea* L., *Erica verticillata* Forssk., *Cistus creticus* L, *Cistus salviifolius* L., *Cistus villosus* L., *Rubus* spp., and *Spartium junceum* L. and some herbaceous plant (Yaltırık 1966).

Treatment

Two neighboring watersheds (W-I and W-IV) were selected due to comparability of their size, vegetation, soil, topography, elevation, slope, geology, and aspect, and paired watershed approach was used to evaluate impact of 18% thinning on streamwater chemical quality. The paired watershed experimental design is a widely used method by researchers to investigate impacts of forest management on water yield and water quality in the forested watersheds and requires at least one reference watershed and one treatment watershed (Boggs et al. 2016). Data collection in this experimental design covers two terms called calibration period (before timber harvest) and treatment period (after timber harvest). Furthermore, in order to use paired watershed methodology, a significant relationship must exist between watershed pairs with high correlation coefficients (Swank et al. 2001). The experimental watersheds were monitored for streamwater nutrient outflow from January 2006 to October 2011 for a calibration period. Prior to thinning treatment in W-IV, standing timber volumes were 355.49 m^3 ha^{-1} in the treatment watershed and 328.18 m^3 ha^{-1} in the control watershed. Timber harvest was carried out farther away from the main stream and tributaries from October to December in 2011 in the treatment watershed (W-IV). Merchantable parts of the hand felling trees were taken out from the treatment watershed by using existing forest road network and keeping forest floor disturbance at minimum level. Logging residues including branches smaller than 1 cm diameter, foliage, and tree tops were left on the site.

After removing 18% of the standing timber volume from the W-IV and leaving the W-I untouched as a reference area, the W-I and W-IV were monitored for the nutrient outflow from January 2012 to December 2015 for the treatment period.

In order to estimate average monthly nutrient outflow, streamflows were also monitored in the control and treatment watersheds for both the calibration and treatment periods. Stream stages were recorded with 10-min intervals in 90° and 120° concrete sharp-crested V-notch weirs constructed at the outlets of the W-I and W-IV and equipped with automatic water stage height recording systems. Stream discharges were estimated as cubic meter per second by using the following formula:

$$Q = C \times H^n,$$

where Q is the runoff (m^3 s^{-1}), H is the depth of the water column above the bottom of the V-notch in meter, n is a coefficient taken as 2.48, and C is a constant and changes in relation to the angle of the notch and unit of the measurement (Özhan et al. 2010). Precipitation was measured with an automatic tipping bucket-type rain gauge installed near the watersheds. Water grab samples were collected from the streams in the watersheds with 2-L polyethylene bottles on weekly basis just above the weirs at the beginning of January 2005. The water samples were analyzed usually at the same day of collection for Fe^{3+}, Al^{3+}, KN, NH_4^+-N, Ca^{2+}, Mg^{2+}, K^+, Na^+, and SO_4^{2-}. The samples were analyzed according to the standard methods of American Public Health Association, American Water Works Association, and Water Environment Federation (APHA–AWWA–WEF) (1998). Concentrations of Fe^{3+}, Al^{3+}, and SO_4^{2-} were measured by using UV visible spectrophotometer; KN, Ca^{2+}, and Mg^{2+} were determined with titration method; and NH_4^+-N, K^+, and Na^+ were measured with ion-selective electrode method (APHA–AWWA–WEF 1998). The concentrations of the water quality parameters were firstly measured in mg l^{-1} on weekly basis and then converted to monthly values. The monthly values of water quality parameters were multiplied by mean monthly discharge volume to calculate ion outflows as kg ha^{-1} $month^{-1}$. Simple linear regression equations developed between two watersheds for mean monthly flux of each nutrient in the calibration period were used to estimate nutrient fluxes from the treatment watershed during the treatment period as if thinning had not been applied. Then, the changes in the monthly nutrient fluxes were estimated as the differences between measured and values calculated with the linear regression equations and results were evaluated at α level of 0.05 (Zar 1996).

Results and discussion

Simple linear regression equation developed between the control and treatment watersheds in the calibration period for streamflow showed that there was a significant relationship between watershed pairs with a high correlation coefficient (Fig. 2). The equation was:

$$Y = -0.45 + 1.29 \times X\,(r = 0.92; P < 0.0001),$$

where Y is the estimated water yield ($lsec.^{-1}$) for the W-IV and X is the measured water yield ($lsec.^{-1}$) on the W-I. Results of 18% forest thinning on water yield were published in another paper, and more information can be found

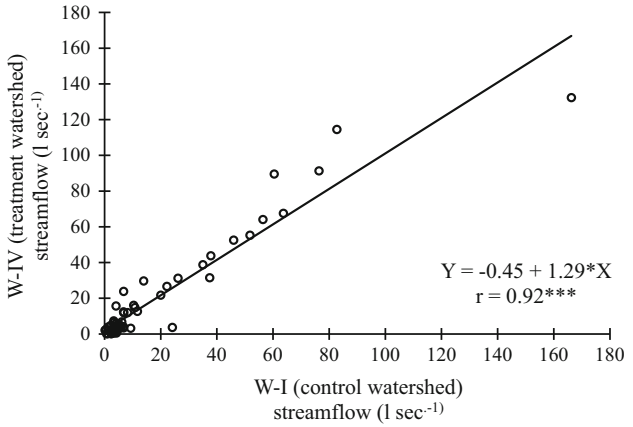


Fig. 2 Relationship between control and treatment watersheds for streamflow during the calibration period

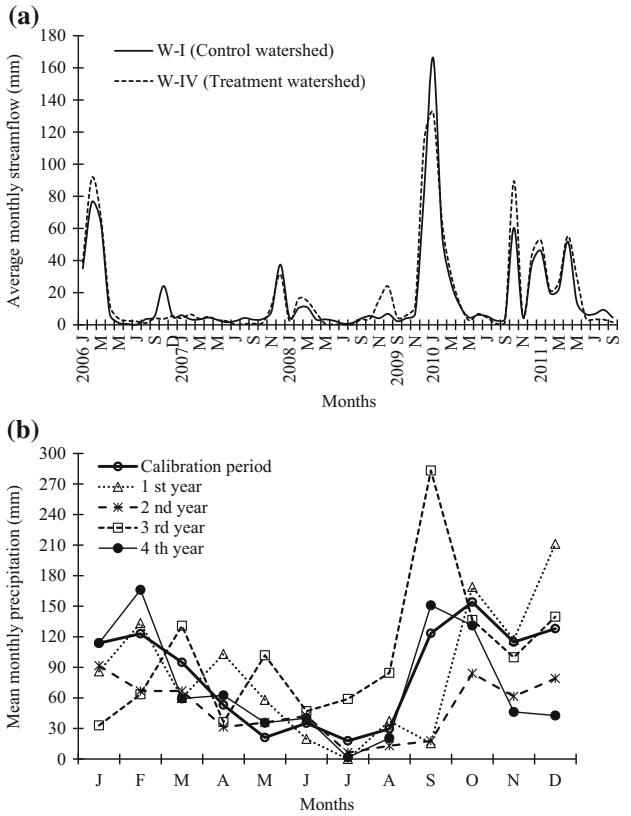


Fig. 3 Trends of monthly streamflows for the control and treatment watersheds during the calibration period (**a**) and monthly precipitation during the calibration period, first, second, third, and fourth post-harvest years (**b**)

there (Gökbulak et al. 2016). The watershed pairs had also similar relationship about two decades ago in another study carried out by Özyuvacı et al. (2004).

Water discharges from the W-I and W-IV followed similar trend during the calibration period depending on precipitation regime and showed increases in rainy months from October to March when most of the annual precipitation fell (Fig. 3).

Nutrient loads in the streamwater draining treatment watershed showed similar pattern, and they were generally greater in wet winter months than dry summer months (Fig. 4). This meant that nutrient losses from the W-IV were influenced by precipitation regime. In fact, Swank et al. (2001) tested the effect of commercial clearcut on streamwater chemistry in a southern Appalachian catchment and found minimum and maximum Ca^{2+} concentrations in winter and in mid-summer months, respectively.

As observed for the water yield, there were significant relationships between watersheds for the mean monthly nutrient outflows with high correlation coefficients. The regression equations between nutrient exports of the watersheds had correlation coefficients generally greater than $r = 0.90$ except for the equation for Na^+ with a r value of 0.72 (Table 1). These significant relationships between watersheds for both water yield and nutrient outflux during the calibration period indicated that the paired watershed methodology was a right approach in this study for quantifying the impact of forest harvest on the streamwater quality (Arthur et al. 1998). Also, statistically significant relationships between these watershed pairs were determined for streamwater quality parameters and water yield in earlier studies at the same site (Özyuvacı et al. 2004; Serengil et al. 2007a, b; Gökbulak et al. 2008, 2016). The orders of ion outflows were similar for both watersheds during the calibration period with descending orders of $SO_4^{2-} > Ca^{2+} > Mg^{2+} > KN > K^+ > Na^+ > Fe^{3+} > NH_4^+$-N $> Al^{3+}$ for W-I and $SO_4^{2-} > Ca^{2+} > Mg^{2+} > K^+ > Fe^{3+} > Na^+ > KN > NH_4^+$-N $> Al^{3+}$ for W-IV (Table 1). Balcı et al. (1986) investigated nutrient losses in the same watersheds from October 1, 1979, to September 30, 1980, and they reported greater Ca^{2+}, Mg^{2+}, KN, K^+, and Na^+ outflows from both watersheds than those in present study. These differences can be attributed to differences between annual precipitations during the studies and duration of the study periods. Their study covered only one year with an annual precipitation of 1518.4 mm, whereas this study covered 6 years with a mean annual precipitation of 1008.7 mm. Compared to pre-harvest period, total annual rainfalls were lower in the post-harvest period except for the third post-treatment year. Total annual precipitations were 1009.8 mm for the first, 596.5 mm for the second, 1215.2 mm for the third, and 870.5 mm for the fourth post-treatment years. During the calibration period, SO_4^{2-} and Ca^{2+} had the greatest loads, whereas Al^{3+} and NH_4^+-N had the lowest loads in both watersheds (Table 1). Mean monthly losses for SO_4^{2-} and Ca^{2+} were 4.94 and 4.45 kg ha^{-1} for the W-I and 3.75 and 3.21 kg ha^{-1} for the W-IV. Mean monthly Al^{3+} and NH_4^+-N exports were 0.02 and 0.05 g ha^{-1}, respectively, and both W-I and W-IV had similar Al^{3+} and NH_4^+-N losses (Table 1). Besides Al^{3+} and NH_4^+-N outflows, streams

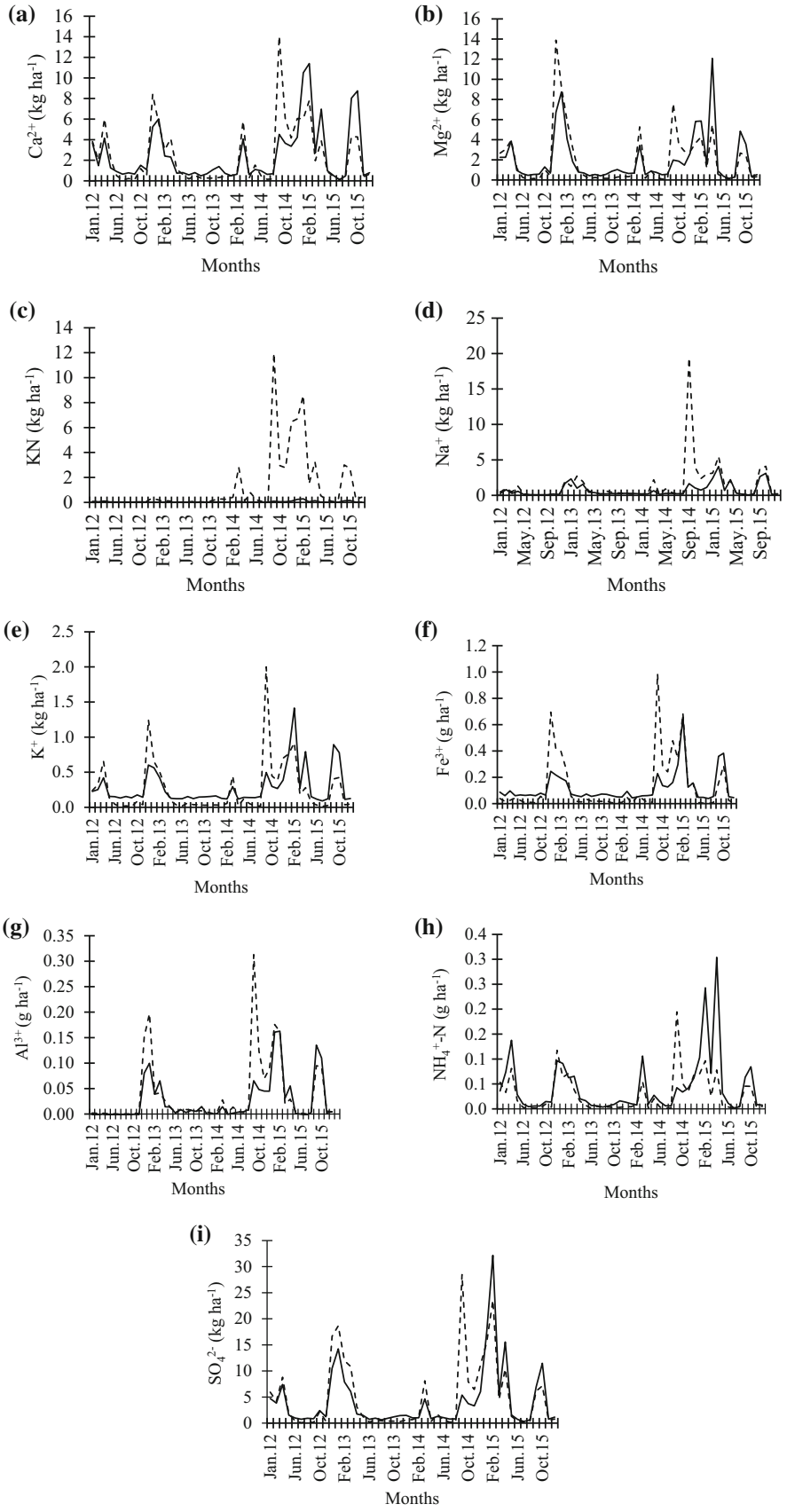


Fig. 4 Trends of measured and estimated **a** Ca^{2+}, **b** Mg^{2+} **c** KN, **d** Na^{+}, **e** K^{+}, **f** Fe^{3+}, **g** Al^{3+}, **h** NH_4^{+}-N, **i** SO_4^{2-} exports during the treatment period in the W-IV. *Dashed* and *solid lines* represent measured and estimated values, respectively

Table 1 Calibration equations between control (W-I) and treatment (W-IV) watersheds for mean monthly losses of stream water chemical parameters during the calibration period

Parameters	Regression equations	Correlation coefficient (r)	Mean monthly values (mean ± SER)		Significance level
			W-I	W-IV	
Ca^{2+} (kg ha^{-1} m^{-1})	$Y = 0.11 + 0.69 * X$	$r = 0.94$ ($n = 69$)	4.45 ± 0.05	3.21 ± 0.04	$P < 0.001$
Mg^{2+} (kg ha^{-1} m^{-1})	$Y = 0.16 + 0.77 * X$	$r = 0.94$ ($n = 69$)	2.75 ± 0.04	2.28 ± 0.03	$P < 0.001$
KN (kg ha^{-1} m^{-1})	$Y = 0.01 + 0.03 * X$	$r = 0.96$ ($n = 51$)	2.12 ± 0.04	0.07 ± 0.001	$P < 0.001$
Na^{+} (kg ha^{-1} m^{-1})	$Y = 0.05 + 0.31 * X$	$r = 0.72$ ($n = 26$)	0.31 ± 0.01	0.14 ± 0.003	$P < 0.001$
K^{+} (kg ha^{-1} m^{-1})	$Y = 0.09 + 0.71 * X$	$r = 0.92$ ($n = 42$)	0.38 ± 0.01	0.36 ± 0.01	$P < 0.001$
Fe^{3+} (g ha^{-1} m^{-1})	$Y = 0.04 + 0.65 * X$	$r = 0.90$ ($n = 57$)	0.18 ± 0.003	0.16 ± 0.002	$P < 0.001$
Al^{3+} (g ha^{-1} m^{-1})	$Y = -0.002 + 1.10 * X$	$r = 0.96$ ($n = 60$)	0.02 ± 0.001	0.02 ± 0.001	$P < 0.001$
NH_4^{+} - N (g ha^{-1} m^{-1})	$Y = 0.002 + 1.02 * X$	$r = 0.94$ ($n = 50$)	0.05 ± 0.01	0.05 ± 0.01	$P < 0.001$
SO_4^{2-} (kg ha^{-1} m^{-1})	$Y = 0.32 + 0.70 * X$	$r = 0.95$ ($n = 51$)	4.94 ± 0.09	3.75 ± 0.06	$P < 0.001$

draining both W-I and W-IV had low Fe^{3+}, Na^{+}, and K^{+} exports. Contrary to other ions, the watersheds had different KN loads in their streams and it was 2.12 kg ha^{-1} for W-I and 0.07 kg ha^{-1} for W-IV (Table 1).

Despite very little increases in Ca^{2+} export from 1.94 to 2.28 kg ha^{-1}, Mg^{2+} from 1.06 to 2.43 kg ha^{-1}, KN from 0.04 to 0.05 kg ha^{-1}, K^{+} from 0.23 to 0.26 kg ha^{-1}, Fe^{3+} from 0.07 to 0.09 g ha^{-1}, and SO_4^{2-} from 3.19 to 3.71 kg ha^{-1}, significant changes were not observed in the nutrient exports for the first post-treatment year regardless of the chemical parameters (Table 2). Timber removal did not have a significant effect on Ca^{2+} loads in the streamflow except for fourth post-treatment year. In the fourth post-treatment year, Ca^{2+} outflow significantly decreased from 4.31 to 2.59 kg ha^{-1} (Table 2) and measured Ca^{2+} export varied between 3.33 and 1.40 kg ha^{-1} during the 4-year post-treatment period. Overall mean measured and estimated monthly Ca^{2+} outflows averaging over post-treatment years were 2.40 and 2.47 kg ha^{-1}, respectively. Result of our study for Ca^{2+} export was not consistent with those of Arthur et al. (1998), Swank et al. (2001), and Clinton (2011) that an increase in the Ca^{2+} outflux was detected after the harvest. However, the result of our study was consistent with the study carried out by Siemion et al. (2011) that slight timber harvest did not affect Ca^{2+} outflow in the treatment watershed. On the other hand, although Balcı et al. (1986) found a decrease in the Ca^{2+} concentration with the increase in streamflow, Ca^{2+} load did not show an increase even during the wet year in the third post-treatment year in present study. Previous studies showed that Ca^{2+} concentration generally increased if timber harvest was greater than that applied in this study (Swank et al. 2001; Wang et al. 2006; Paré and Thiffault 2016). For instance, Siemion et al. (2011) determined that Ca^{2+} concentration increased with the intensity of timber harvest from 22 to 28 and 68%. Also, Martin et al. (2000) examined effects of both clearcut and stripcut on the Ca^{2+} loads in the streamwater, and they found that both treatments caused increases in the Ca^{2+} losses in the watersheds. The differences between results of present study and others can be attributed to the intensity of timber harvest because harvest intensity in this study was lower than the harvest intensities in other studies.

Contrary to Ca^{2+} loads in the streamflow, except for the first post-treatment year, significant increases were found for KN exports from 0.02 to 0.10 kg ha^{-1}, from 0.04 to 2.40 kg ha^{-1}, and from 0.09 to 2.29 kg ha^{-1} for the second, third, and fourth post-treatment years, respectively ($P < 0.05$) (Table 2). During the post-treatment period, mean monthly measured KN export varied between 0.05 and 2.40 kg ha^{-1} while average monthly estimated KN values changed from 0.02 to 0.09 kg ha^{-1}. Also, overall

Table 2 Mean monthly measured and estimated values (mean ± SER) of chemical water quality parameters for treatment watershed during the treatment period

Post-treatment years	Water quality parameters								
	Ca^{2+} (kg ha^{-1})	Mg^{2+} (kg ha^{-1})	KN (kg ha^{-1})	Na^{+} (kg ha^{-1})	K^{+} (kg ha^{-1})	Fe^{3+} (g ha^{-1})	Al^{3+} (g ha^{-1})	NH_4^{+}- N (g ha^{-1})	SO_4^{2-} (kg ha^{-1})
2012									
Measured	2.28 ± 0.12	2.43 ± 0.16	0.05 ± 0.003	–	0.26 ± 0.02	0.09 ± 0.01	0.01 ± 0.002	0.03 ± 0.002	3.71 ± 0.22
Estimated	1.94 ± 0.09	1.06 ± 0.10	0.04 ± 0.002	–	0.23 ± 0.01	0.07 ± 0.003	0.008 ± 0.002	0.04 ± 0.002	3.19 ± 0.18
Significance	$P > 0.05$	$P > 0.05$	$P > 0.05$	–	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$
2013									
Measured	1.40 ± 0.07	1.76 ± 0.11	**0.10 ± 0.004**	0.83 ± 0.03	**0.15 ± 0.01**	0.11 ± 0.01	0.03 ± 0.002	**0.02 ± 0.001**	4.05 ± 0.23
Estimated	1.50 ± 0.08	1.73 ± 0.12	**0.02 ± 0.0001**	0.37 ± 0.03	**0.21 ± 0.01**	0.10 ± 0.003	0.03 ± 0.002	**0.03 ± 0.002**	3.23 ± 0.22
Significance	$P > 0.05$	$P > 0.05$	***P* < 0.05**	$P > 0.05$	***P* < 0.05**	$P > 0.05$	$P > 0.05$	***P* < 0.05**	$P > 0.05$
2014									
Measured	3.33 ± 0.17	**1.52 ± 0.10**	**2.40 ± 0.14**	2.76 ± 0.22	0.36 ± 0.02	0.18 ± 0.01	0.05 ± 0.004	0.04 ± 0.002	5.59 ± 0.33
Estimated	2.08 ± 0.07	**1.33 ± 0.04**	**0.04 ± 0.001**	0.56 ± 0.02	0.22 ± 0.005	0.09 ± 0.002	0.02 ± 0.001	0.03 ± 0.001	2.49 ± 0.08
Significance	$P > 0.05$	***P* < 0.05**	***P* < 0.05**	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$
2015									
Measured	**2.59 ± 0.10**	**1.78 ± 0.08**	**2.29 ± 0.11**	**1.76 ± 0.08**	**0.27 ± 0.01**	0.15 ± 0.01	0.05 ± 0.003	**0.03 ± 0.001**	**5.90 ± 0.29**
Estimated	**4.31 ± 0.18**	**3.02 ± 0.14**	**0.09 ± 0.004**	**1.34 ± 0.06**	**0.47 ± 0.02**	0.19 ± 0.01	0.06 ± 0.003	**0.08 ± 0.004**	**7.83 ± 0.39**
Significance	***P* < 0.05**	***P* < 0.05**	***P* < 0.05**	***P* < 0.05**	***P* < 0.05**	$P > 0.05$	$P > 0.05$	***P* < 0.05**	***P* < 0.05**
Overall average									
Measured	2.40 ± 0.03	2.00 ± 0.03	**1.24 ± 0.03**	**1.81 ± 0.03**	0.26 ± 0.004	0.13 ± 0.002	0.04 ± 0.001	**0.03 ± 0.0004**	4.84 ± 0.07
Estimated	2.47 ± 0.03	1.98 ± 0.03	**0.03 ± 0.001**	**0.77 ± 0.01**	0.28 ± 0.003	0.12 ± 0.001	0.03 ± 0.0005	**0.04 ± 0.001**	4.21 ± 0.06
Significance	$P > 0.05$	$P > 0.05$	***P* < 0.05**	***P* < 0.05**	$P > 0.05$	$P > 0.05$	$P > 0.05$	***P* < 0.05**	$P > 0.05$

– Missing values

Average values in bolds mean that there is a significant difference between measured and estimated values of the parameters in that post-treatment year at α level of 0.05

mean monthly discharge of KN averaging over post-treatment years also showed significant increase from 0.03 to 1.24 kg ha^{-1} (Table 2). KN load in the streamflow did not show any significant change in the first post-treatment year, and it was lower throughout the study period compared to some other parameters (Table 2). Fredriksen (1971-72) suggests that concentration of nitrogen is small in the streams since trees and microorganisms take up nitrogen rapidly after nitrogen is solubilized by decomposition of organic compounds following timber harvest. In contrast to the result of present study, Serengil et al. (2007a) did not find significant change in the total nitrogen output after 11% timber removal. Similar to result of this study, significant increases in the concentrations of KN were found after a partial cut (Gravelle et al. 2009) and clearcut (Ensign and Mallin 2001) treatments. The increases in the KN exports after timber harvest were also reported in earlier studies (Arthur et al. 1998; Dahlgren 1998; Wynn et al. 2000). Except for first treatment year, KN was the only nutrient that its load showed increase in the streamwater throughout the study period in this study. Several factors could be responsible for the increase of KN load such as disturbance of forest floor during the harvest practices and decomposition of organic matter under increased soil moisture and temperature conditions after the harvest (Ensign and Mallin 2001).

During the post-harvest period, 18% timber harvesting also did not cause significant increase in both Mg^{2+} and K^{+} exports (Table 2). Mean monthly measured loads were between 1.52 and 2.43 kg ha^{-1} for Mg^{2+} and between 0.15 and 0.36 kg ha^{-1} for K^{+}, whereas average monthly estimated values varied from 1.06 to 3.02 kg ha^{-1} for Mg^{2+} and from 0.21 to 0.47 kg ha^{-1} for K^{+}. A significant increase from 1.33 to 1.52 kg ha^{-1} and a decrease from 3.02 to 1.78 kg ha^{-1} were found for Mg^{2+} exports in the third and fourth post-treatment years, respectively (Table 2). In contrast to Mg^{2+}, significant decreases were observed for K^{+} loads in the streamwater in the second and fourth post-harvest years. Overall mean monthly measured loads were 2.00 kg ha^{-1} for Mg^{2+} and 0.26 kg ha^{-1} for K^{+}, and they did not significantly differ from estimated values of the same parameters. It seemed that 18% timber harvesting was not intensive enough to increase nutrient outflow in the treatment watershed because increases in the K^{+} losses were found by Martin et al. (2000) after both stripcut and clearcut treatments, by Wang et al. (2006) after clearcut, and by Tremblay et al. (2009) after a 50% timber harvest in the watersheds. Similarly, in contrast to present study, Reuss et al. (1997) measured greater Ca^{2+}, Mg^{2+}, and K^{+} exports after a clearcut treatment in a mixed conifer plot and Clinton (2011) also observed significant concentration increases for the same cations in the watersheds with different buffer zone widths. Additionally, Bäumler and Zech (1998) measured higher Ca^{2+}, Mg^{2+}, and K^{+} concentrations in the streamflow after 40% thinning in the Tegernsee Alps compared to the control watershed and Swank et al. (2001) found the largest Ca^{2+}, Mg^{2+}, and K^{+} loads in the streamwater in the third post-treatment year following clearcut treatment at Coweeta. Moreover, Mg^{2+} and K^{+} concentrations were also increased following the 50% logging in a study carried out in Québec by Tremblay et al. (2009).

Sodium loss did not show increase in the second and third post-treatment years due to treatment, whereas it significantly increased from 1.34 to 1.76 kg ha^{-1} in the fourth post-harvest year (Table 2, $P < 0.05$). When whole study period was considered, the results revealed that timber removal affected Na^{+} export significantly and an increase from 0.77 to 1.81 kg ha^{-1} was determined in the overall mean monthly sodium loss from the treatment watershed. The result of present study was consistent with that of a study carried out by Clinton (2011) and Bäumler and Zech (1998) that a greater Na^{+} concentration was measured after the harvest. On the other hand, Swank et al. (2001) observed greatest Na^{+} export in the third post-treatment year, whereas significant Na^{+} export was found in the fourth post-treatment year in present study.

Forest thinning did not also influence Fe^{3+}, Al^{3+}, NH_4^{+}-N, and SO_4^{2-} exports, and measured and estimated values of these chemicals followed similar trend (Fig. 4). Mean monthly loads in the streamflow varied from 0.09 to 0.18 g ha^{-1} for Fe^{3+}, from 0.01 to 0.05 g ha^{-1} for Al^{3+}, 0.02–0.04 g ha^{-1} for NH_4^{+}-N, and from 3.71 to 5.90 kg ha^{-1} for SO_4^{2-} after the 18% harvest in the treatment watershed (Table 2). Similarly, timber harvest did not have any significant impact on overall mean monthly values of these parameters, and overall mean monthly measured exports averaging over the post-treatment years were 0.13, 0.04, 0.03, and 4.84 kg ha^{-1} for Fe^{3+}, Al^{3+}, NH_4^{+}-N, and SO_4^{2-}, respectively. However, significant decreases were occurred from 0.03 to 0.02 g ha^{-1} in the second post-treatment year and from 0.08 to 0.03 g ha^{-1} in the fourth post-treatment year for NH_4^{+}-N load, from 7.83 to 5.90 kg ha^{-1} in the fourth post-treatment year for SO_4^{2-} load in the streamwater. Also, a significant decrease from 0.04 to 0.03 g ha^{-1} in the overall monthly load of NH_4^{+}-N was found in the treatment watershed (Table 2). In contrast to the result of present study, Boggs et al. (2016) measured greater $NH4^{+}$-N loads in the streamwater after both 27 and 33% timber harvests. Wynn et al. (2000) compared the effect of clearcut with forestry best management practices and found that both practices caused significant increases in the $NH4^{+}$-N exports. Wynn et al. (2000), Ensign and Mallin (2001), and Swank et al. (2001) also examined impact of clearcut on $NH4^{+}$-N loads in the stream and measured a greater

exports in the post-harvest period compared to pre-harvest period. Similar increases in the $NH4^+$-N concentrations were also determined by Clinton (2011) and Bäumler and Zech (1998) after timber removal. These studies indicate that intensity of timber harvest plays an important role on $NH4^+$-N loads in the stream and it increases with logging intensity.

Tree harvesting generally causes decreases in the concentration of SO_4^{2-} in the streamwater as found in the fourth harvest year of this study and other studies (Bäumler and Zech 1998; Feller 2005) since high H^+ release due to high nitrification and mineralization after timber harvest can acidify forest soil and soil water and increase the soil absorption capacity for SO_4^{2-} (Martin et al. 2000; Tremblay et al. 2009). In fact, Martin et al. (2000) found decreases in the monthly SO_4^{2-} concentrations for four years after treatment and then its concentration returned to pre-harvest level. Decrease in the SO_4^{2-} concentration was also reported by Baldigo et al. (2005) after clearcut treatment. In contrast, Reuss et al. (1997) found significant increase in the SO_4^{2-} export after clearcut treatment.

Although timber harvest did not have a significant impact on Al^{3+}, Bäumler and Zech (1998), Siemion et al. (2011), and Baldigo et al. (2005) found significant increases in the aluminum concentrations after 40 and 68% timber removal and clearcutting treatments, respectively. The differences between the results of these studies can be attributed to the intensities of timber removals and very low Al^{3+} concentrations in the soil of study site. Similar to Al^{3+} export, Fe^{3+} load also did not show significant change during the post-harvest period after a 18% thinning. In contrast to the result of present study, Tremblay et al. (2009) measured significant increase in the iron concentration up to 71 after a 50% logging treatment carried out in a snowy winter season. Except for a few chemical parameters, the results of present study showed that 18% thinning was not intensive enough to change the streamwater chemistry and hence threaten aquatic life in the stream of this broadleaf forest covered watershed.

Conclusion

This study examined the impact of 18% thinning on the nutrient export in a broadleaf mixed forest ecosystem. The results showed that 18% timber harvesting was not intensive enough to change water chemical quality in the watershed. Timber removal only increased Kjeldahl nitrogen and Na^+ losses but decreased overall mean $NH4^+$-N export during the post-treatment period. Additionally, the treatment caused significant decreases in the exports of Ca^{2+}, Mg^{2+}, K^+, $NH4^+$-N, and SO_4^{2-} in different post-treatment years. Al^{3+} and Fe^{3+} outflows did not show any significant changes after the treatment. Except for the KN and Na^+ exports, the results of this study were not consistent with those of other studies conducted in different regions that timber harvest increased nutrient outflows from the treatment watersheds. This difference can be attributed to several factors such as intensity of timber harvesting, logging strategies, climate conditions, and topography of the watersheds. The harvest intensity was lower in this study compared to other studies, and intensive logging practices can have much more severe impact on soil surface conditions that can increase the proportion of surface flow instead of subsurface and base flows. Moreover, nutrient losses from a certain watershed depend on water yield. Unless water yield increases, nutrient loads in the streamwater cannot increase. Earlier studies already determined a threshold value for timber harvest to increase water yield in the forested watersheds (Bosch and Hewlett 1982). Based on this view, it can be concluded that timber harvest intensity smaller than 20% cannot change streamwater quality as it doesn't change streamflow. Because of diversities among the study sites in terms of climate, vegetation, logging strategies, and timber harvesting intensity, further site-specific harvesting studies with different intensities are needed to determine a threshold value for nutrient exports from the watersheds as determined for water yield. On the other hand, nutrient concentrations of the streamflow are the result of interactions among the several ecological processes such as decomposition of litter, cation exchange, nutrient uptake by plants, evapotranspiration, and weathering and leaching of minerals. Therefore, chemical content and nutrient concentration of the streamwaters can be used as an indicator to monitor the changes taking places within forested watersheds and these parameters can be taken into account when the recovery periods of disturbed ecosystems are evaluated.

Acknowledgements Authors thank Dr. A. Nihat Balcı, Dr. Necdet Özyuvacı for creating such a great research facilities in Ortadere Experimental Watershed Research Station and Ümit Kılıç for the chemical analyses of the water quality parameters. This study was partly supported by TUBİTAK (The Scientific and Technological Research Council of Turkey) with a grant number of TOVAG-105 0 182 between 2006 and 2008 and by Scientific Research Projects Unit of Istanbul University with a grant number of BAP 28027 between 2012 and 2015.

References

APHA–AWWA–WEF (1998) Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, Washington

Arthur MA, Coltharp GB, Brown DL (1998) Effects of best management practices on forest streamwater quality in Eastern Kentucky. J Am Water Resour Assoc 34:481–495

Balcı AN, Özyuvacı N, Özhan S (1986) Sediment and nutrient discharge through streamflow from two experimental watersheds in mature oak-beech forest ecosystems near Istanbul, Turkey. J Hydrol 85:31–47

Baldigo BP, Murdoch PS, Burns DA (2005) Stream acidification and mortality of brook trout (Salvelinus fontinalis) in response to timber harvest in Catskill Mountain watersheds, New York, USA. Can J Fish Aquat Sci 62:1168–1183

Bäumler R, Zech W (1998) Soil solution chemistry and impact of forest thinning in mountain forests in the Bavarian Alps. For Ecol Manag 108:231–238

Boggs J, Sun G, McNulty S (2016) Effects of timber harvest on water quantity and quality in small watersheds in the Piedmont of North Carolina. J For 114:27–40

Bosch JM, Hewlett JD (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J Hydrol 55:3–23

Burns DA, Murdoch PS (2005) Effects of a clearcut on the net rates of nitrification and N mineralization in a northern hardwood forest, Catskill Mountains, New York, USA. Biogeochemistry 72:123–146

Clinton BD (2011) Stream water responses to timber harvest: riparian buffer width effectiveness. For Ecol Manag 261:979–988

Dahlgren R (1998) Effects of forest harvest on stream-water quality and nitrogen cycling in the Casper creek watershed. In: Proceedings of the conference on coastal watersheds: The Casper creek story. May 6, Ukiah, California, pp 45–53. USDA Forest Service, Pacific Southwest research station. General technical report, PSW-GTR-168

Dung BX, Gomi T, Miyata S, Sidle RC, Kosugi K, Onda Y (2012) Runoff responses to forest thinning at plot and catchment scales in a headwater catchment draining Japanese cypress forest. J Hydrol 444–445:51–62

Ensign SH, Mallin MA (2001) Stream water quality changes following timber harvest in a coastal plain swamp forest. Water Res 35:3381–3390

Feller MC (2005) Forest harvesting and streamwater inorganic chemistry in western North America: a review. JAWRA J Am Water Resour Assoc 41:785–811

Fredriksen RL (1971-1972) Impact of forest management on stream water quality in western Oregon. US Department of Agri/US Forest Service

Gökbulak F, Serengil Y, Özhan S, Özyuvacı N, Balcı N (2008) Effect of timber harvest on physical water quality characteristics. Water Resour Manag 22:635–649

Gökbulak F, Şengönül K, Serengil Y, Özhan S, Yurtseven İ, Uygur B, Özçelik MS (2016) Effect of forest thinning on water yield in a sub-humid mediterranean oak-beech mixed forested watershed. Water Resour Manag 30:5039–5049

Gravelle JA, Ice G, Link TE, Cook DL (2009) Nutrient concentration dynamics in an inland Pacific Northwest watershed before and after timber harvest. For Ecol Manag 259:1663–1675

Hubbart JA, Link TE, Gravelle JA, Elliot WJ (2007) Timber harvest impacts on water yield in the Continental/Maritime hydroclimatic region of the United States. For Sci 53(2):169–180

Keppeler E, Ziemer RR (1990) Logging effects on streamflow: water yield and summer low flows at Caspar Creek in northwestern California. Water Resour Res 26(7):1669–1679

Lane PNJ, Mackay SM (2001) Streamflow response of mixed-species eucalypt forests to patch cutting and thinning treatments. For Ecol Manag 143:131–142

Martin CW, Hornbeck JW, Likens GE, Buso DC (2000) Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests. Can J Fish Aquat Sci 57:19–29

Messina MG, Schoenholtz SH, Lowe MW, Wang Z, Gunter DK, Londo AJ (1997) Initial responses of woody vegetation, water quality, and soils to harvesting intensity in a Texas bottomland hardwood ecosystem. For Ecol Manag 90:201–215

Neary DG, Ice GG, Jackson CR (2009) Linkages between forest soils and water quality and quantity. For Ecol Manag 258:2269–2281

Özhan S (1977) Belgrad Ormanı Ortadere yağış havzasında ölü örtünün hidrolojik bakımdan önemli özelliklerinin bazı yöresel etkenlere göre değişimi (In Turkish). Istanbul University, Faculty of Forestry Publication Number: 235, Istanbul

Özhan S, Hızal A, Şengönül K, Gökbulak F, Serengil Y, Özcan M (2008) Hydrological and hydrochemical modeling of watershed systems in Belgrad Forest (Unpublished research project report (supported by the Scientific and Technological Research Council of Turkey (TUBITAK) with a grant number of TOVAG - 105 0 182)

Özhan S, Gökbulak F, Serengil Y, Özcan M (2010) Evapotranspiration from a mixed deciduous forest ecosystem. Water Resour Manag 24(10):2353–2363

Özyuvacı N, Özhan S, Gökbulak F, Serengil Y, Balci AN (2004) Effect of selective cutting on stream water in an oak-beech forest ecosystem. Water Resour Manag 18:249–262

Paré D, Thiffault E (2016) Nutrient budgets in forests under increased biomass harvesting scenarios. Curr For Rep 2:81–91

Reuss JO, Stottlemyer R, Troendle CA (1997) Effect of clear cutting on nutrient fluxes in a subalpine forest at Fraser, Colorado. Hydrol Earth Syst Sci Discuss 1:333–344

Ryan DF, Glasser S (2000) Goals of this report. In: Dissmeyer GE (ed) Drinking water from forests and grasslands: a synthesis of the scientific literature. Chapter 1. GTR. SRS-39. U.S.D.A. Forest Service. S.R.S. Asheville

Serengil Y, Gökbulak F, Özhan S, Hızal A, Şengönül K (2007a) Alteration of stream nutrient discharge with increased sedimentation due to thinning of a deciduous forest in Istanbul. For Ecol Manag 246:264–272

Serengil Y, Gökbulak F, Özhan S, Hızal A, Şengönül K, Balcı AN, Özyuvacı N (2007b) Hydrological impacts of a slight thinning treatment in a deciduous forest ecosystem in Turkey. J Hydrol 333:569–577

Siemion J, Burns DA, Murdoch PS, Germain RH (2011) The relation of harvesting intensity to changes in soil, soil water, and stream chemistry in a northern hardwood forest, Catskill Mountains, USA. For Ecol Manag 261:1510–1519

Stednick JD (1996) Monitoring the effects of timber harvest on annual water yield. J Hydrol 176:79–95

Sun G, Riedel M, Jackson R, Kolka R, Amatya D, Shepard J (2004) Influences of management of Southern forests on water quantity and quality (Chapter 19). In: Gen. Tech. Rep. SRS 75. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. pp 195–234

Suryatmojo H, Masamitsu F, Kosugi K, Mizuyama T (2013) Effects of selective logging methods on runoff characteristics in paired small headwater catchment. Procedia Environ Sci 17:221–229

Swank WT, DeBano LF, Nelson D (1989) Effects of timber management practices on soil and water. Burns, Russell [Tech. comp.]. The scientific basis for silvicultural and management decisions in the National Forest System. GTR-WO-55. USDA Forest Service, Washington, DC

Swank WT, Vose JM, Elliott KJ (2001) Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. For Ecol Manag 141:163–178

Tremblay Y, Rousseau AN, Plamondon AP, Lévesque D, Prévost M (2009) Changes in stream water quality due to logging of the boreal forest in the Montmorency Forest, Québec. Hydrol Process 23:764–776

U.S.D.A 1996. Keys to Soil Taxonomy. 7th ed. Washington, DC

Wang X, Burns DA, Yanai RD, Briggs RD, Germain RH (2006) Changes in stream chemistry and nutrient export following a

Partial harvest in the Catskill Mountains New York USA. For Ecol Manag 223:103–112

Wynn TM, Mostaghimi S, Frazee JW, McClellan PW, Shaffer RM, Aust WM (2000) Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. Trans ASAE 43:927–936

Yaltırık F (1966) Belgrad Ormanı vejetasyonunun floristik analizi ve ana meşcere tiplerinin kompozisyonu üzerinde araştırmalar (In Turkish). General Directorate of Forestry Publication Number: 6, Printing House of Dizerkonca, Istanbul

Zar JH (1996) Biostatistical analysis, 3rd edn. Prentice-Hall, Upper Saddle River