論　文（Original article）

Effects of thinning on canopy interception loss, evapotranspiration, and runoff in a small headwater *Chamaecyparis obtusa* catchment in Hitachi Ohta Experimental Watershed in Japan

Tayoko KUBOTA[1)*], Yoshio TSUBOYAMA[2)] and Tatsuhiko NOBUHIRO[3)]

Abstract

The effects of thinning on canopy interception loss, evapotranspiration, and runoff were investigated by a paired catchment experiment in a small headwater catchment in Japan. A 0.88-ha catchment covered with a *Chamaecyparis obtusa* plantation that was planted in 1986 was intensively thinned in March 2009 following a 3-year calibration period (2006-2008). To avoid disturbing the soil surface, thinning was conducted by forest workers using chainsaws, and the thinned trees were left on the forest floor where they fell. Thinning removed 50 % of the trees, 30 % of the timber volume, and 22.5 % of the basal area. Canopy interception loss decreased by 4 % in the first year after thinning, and it returned gradually to the pre-thinning level for 3 years. The maximum increase in the annual runoff, 147 mm, occurred in the second year after thinning. The mean annual increase in the runoff during the post-thinning period (2010-2012) was 54 mm, although this was not statistically significant. The mean annual evapotranspiration significantly reduced by 140 mm, and the reduction was especially large during the growing season. In conclusion, it seemed that the intensive thinning in a small headwater plantation was effective to increase net precipitation and stream water for a short period.

Key words: thinning, canopy interception loss, evapotranspiration, runoff, paired catchment experiment

1. Introduction

Devastation of abandoned forests has been a concern since the late 1990s in Japan (Japanese Forestry Agency 1998). High stand densities in unmanaged forests may reduce tree growth and understory vegetation by blocking sunlight, which may cause surface erosion (Onda et al. 2010). The Japanese Forestry Agency promotes thinning activities to improve forests and to meet Japan's commitment to reduce greenhouse gas emissions under the Kyoto Protocol (Japanese Forestry Agency 2013). Intensive thinning, which removes more than 40 % of trees, is also promoted to reduce operating cost. Following the promotion of forest thinning, the effects of thinning on water yield have recently become a concern in Japan.

The effects of timber harvesting, including thinning, on water yields in catchments have been examined by a lot of paired catchment experiments throughout the world (Bosch and Hewlett 1982, Brown et al. 2005). Although experiments to determine the effects of clear cutting or partial cutting on water yield have been conducted in several experimental watersheds in Japan (Nakano 1971), most studies on the effects of thinning on hydrological change in Japan focused on plot-scale investigations of evapotranspiration (Hattori and Chikaarashi 1988, Murai 1970, Nanko et al. 2015) and on transpiration (Komatsu et al. 2013, Morikawa et al. 1986). Kubota et al. (2013) investigated the change of evapotranspiration by thinning in a basin scale, however they did not describe the change of canopy water balance or water yield by thinning. Therefore, to develop a reliable management plan for untended forests to prevent flooding and increase available water, more case studies in Japan should focus on the interactions between various thinning intensities and hydrological changes on catchment scales.

The objective of this study was to determine the effects of intensive thinning on canopy interception loss, evapotranspiration, and runoff in the *Chamaecyparis obtusa* small headwater catchment in Japan using a paired catchment experiment.

2. Methods

2.1 Study area

The Hitachi Ohta Experimental Watershed is located about 140 km northeast of Tokyo (36°34′N and 140°35′E) (Fig. 1a). Its altitude ranges from 283 to 341 m. The two catchments, which are designated HA (control) and HV (thinning), are 0.84

Received 6 March 2017, Accepted 14 December 2017
1) Tohoku Research Center, Forestry and Forest Products Research Institute (FFPRI)
2) Principal Research Director, FFPRI
3) Hokkaido Research Center, FFPRI
* Tohoku Research Center, FFPRI, 92-25 Nabeyashiki, Shimokuriyagawa, Morioka, Iwate, 020-0123 JAPAN; e-mail: ktayoko@affrc.go.jp

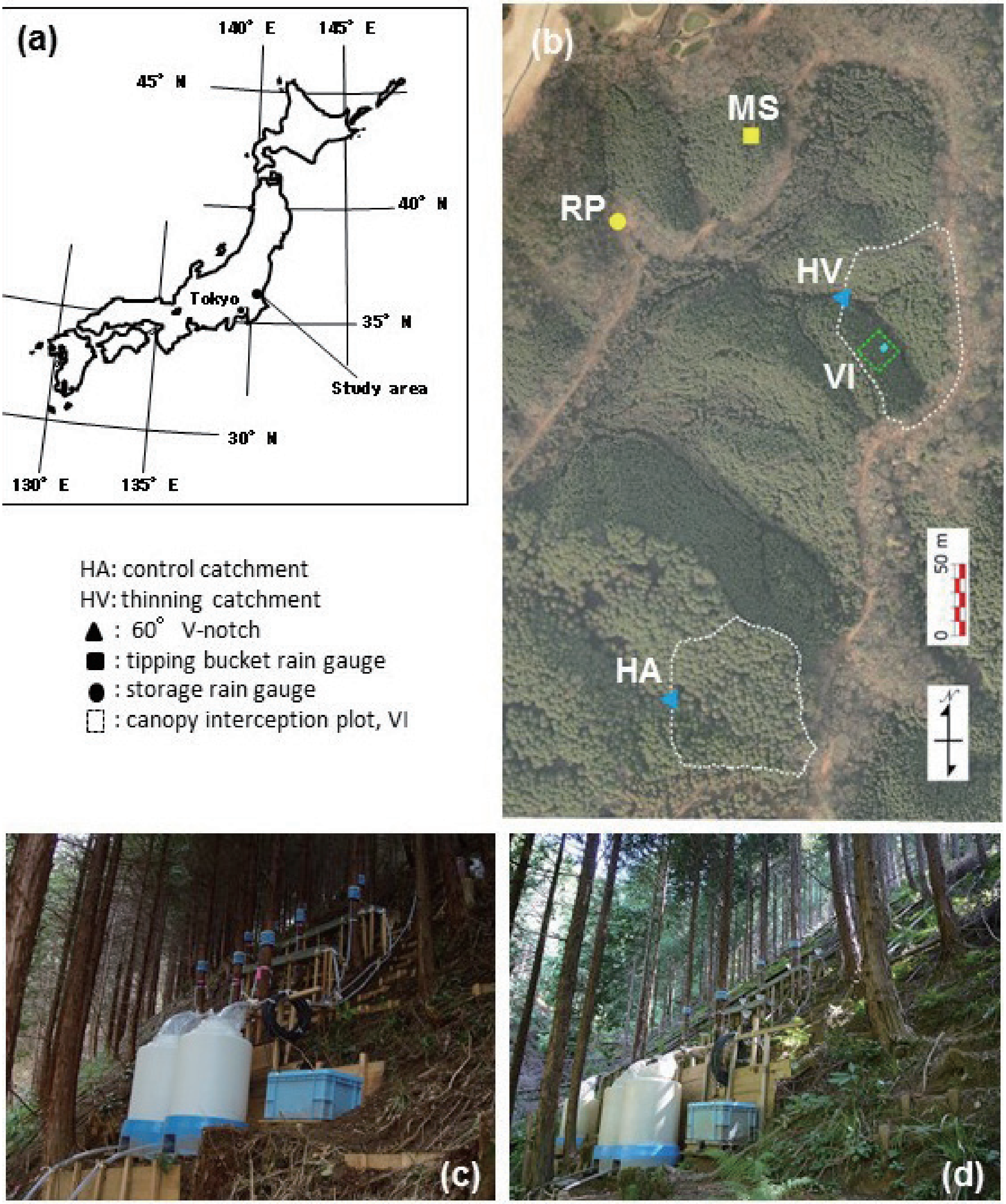

Fig. 1. Hitachi Ohta Experimental Watershed. (a) Location of study site; (b) control and thinning catchments; (c) canopy interception plot before thinning; (d) canopy interception plot after thinning.

ha and 0.88 ha, respectively (Fig. 1b).

The surficial geology in the study area is metamorphic, primarily consisting of schist and amphibolite (Sidle et al. 1995, Tsuboyama 2006). Soils are clay loam derived from volcanic ash. Soil pits were excavated to bedrock at total nine sites within HA and HV, and the mean soil depth was 0.68 ± 0.34 m (Tsuboyama 2006). Mean hillslope gradient in HA and HV was 26.8° ± 9.9° and 31.1° ± 11.1°, respectively.

Chamaecyparis obtusa and *Cryptomeria japonica* were artificially planted in catchments HA and HV in 1924 and 1986, respectively. *C. obtusa* covered most of the catchment and *C. japonica* existed only along streambanks. Hardwood species (e.g., *Quercus serrata*) exist at the upstream edge in HV (Fig. 1b). The main understory vegetation in HA contains *Hydrangea hirta*, *Hydrangea involucrata*, and *Microlepia marginata* (Kato et al. 1995, Murakami et al. 2000). While there was little understory vegetation except in HV, although *Eurya japonica* and *Callicarpa mollis* (1-3 m height) were mainly found in gaps.

There are two major periods of rainfall: a rainy season in early summer and an autumn typhoon season. Although sporadic snowfall occurs, there is no persistent snowpack. The snow is only a minor component of the hydrological budget (Tsuboyama 2006). The monthly mean air temperature from 2006 to 2012 ranged from 2.0°C in January to 23.6°C in August, with an annual average of 12.4°C.

Observation period was from 2006 to 2012. We defined that the pre-thinning period was from 2006 to 2008 and the post-thinning period was from 2010 to 2012. The year 2009 was eliminated from the analysis due to the thinning year.

2.2 Thinning operation

About half of the trees in HV were thinned mostly on 9 March 2009. To adjust the tree reduction ratio to 50 % of trees and 30 % of timber volume, a small number of trees were thinned again on 26 May 2009. Although the trees to be thinned were randomly selected, relatively smaller trees were removed (Table 1). All thinning was performed by forest workers using chainsaws to minimize the disturbance of the soil surface. A skid trail was not constructed. The thinning timbers were left randomly where they fell; they were neither arranged to the contour line nor removed.

2.3 Precipitation and other meteorological observations

Precipitation was measured using a tipping bucket rain gauge (TE525MM; Campbell Scientific, USA; capacity 0.5 mm of water), with a gauge (RT-5E; Ikeda, Japan; capacity 0.1 mm) as backups, at the meteorological station (MS; Fig. 1b). Precipitation was logged every 10 min. The MS is an open site on a ridgetop with a size of approximately 15 m × 7 m. Because grown trees surround the MS intercept precipitation, a storage rain gauge was placed in a more open site, RP, to correct precipitation data (Fig. 1b). This gauge consists of a 0.2-m diameter polyethylene funnel connected to a 10-L polyethylene bottle.

Table 1. Canopy structure in the HA control catchment and the HV thinning catchment.

	HA[1]	HV Pre-thinning[2] 2006-2008	HV Post-thinning[3] 2010-2012
Planted year	1924	1986	1986
Stand density (stem ha^{-1})	783	2229	1132
Basal area (m^2 ha^{-1})	63	32.4	25.1
Tree height (m)	18	10.8	12.1
DBH (cm)	32	13.6	16.8
Total volume (m^3 ha^{-1})	553	308	218

[1] Values surveyed in 1993 (Murakami et al. 2000).
[2] Values surveyed in 2008.
[3] Values calculated for residual trees.

2.4 Throughfall, stemflow, and runoff

Throughfall and stemflow were measured approximately every 10 days at the interception plot VI (20 m × 20 m) (Figs. 1b-1d). Throughfall was collected by two troughs (4 m (L) × 0.26 m (W) × 0.12 m (H)). Stemflow was collected by a urethane collar surrounding the tree. Stemflow was measured on 10 trees before thinning and on five residual trees after thinning. The collected throughfall and stemflow were directed into 100-L tanks (one for throughfall and two for stemflow) by hoses. The water level in the tank was measured every 10 min by pressure-type water gauges (CS450; Campbell Scientific, USA) recorded by a data logger (CR10X; Campbell Scientific, USA), and converted to water head. Streamflow was monitored using gauging weirs (60°, V-notch) at the outlets of the HV and HA (Fig. 1b).

2.5 Canopy water balance

To compare the canopy water balance before and after thinning, the following equation was used:

$$P = I + T + S \quad (1)$$

where P is precipitation (mm), I is canopy interception loss (mm), T is throughfall (mm), and S is stemflow (mm).

2.6 Evapotranspiration

To estimate the variation in evapotranspiration, a short-term water budget method (Suzuki 1985) was used:

$$E = P - Q = \int_{t_1}^{t_2} \mathrm{p(t)dt} - \int_{t_1}^{t_2} \mathrm{q(t)dt}, \quad (2)$$

where E is evapotranspiration (mm), $p(t)$ is the precipitation intensity (mm day^{-1}) and $q(t)$ is the runoff rate (mm day^{-1}). t is the time in days. t_1 and t_2 are the first and final days, respectively, of the hydrologic period used to calculate the water budget. The procedure described by Suzuki (1985) was used to determine the hydrologic period to calculate the water budget. If multiple estimated values were obtained on the same day, they were averaged.

2.7 Estimation of annual water yield by paired catchment experiment

Simple linear regression was used to relate annual runoff measured in HA and HV during the pre-thinning period 2006-2008, as follows.

$$Q_{HV} = aQ_{HA} + b, \quad (3)$$

where Q is runoff (mm), a and b are empirical coefficients, and subscripts HA and HV indicate the two catchments. Equation (3) was used to predict runoff in HV during the post-thinning period 2010-2012, as if there had been no thinning. The difference between the predicted value and measured values was quantified to indicate the magnitude of any response to the treatment.

3. Results

3.1 Precipitation and runoff during the observation period

The mean annual precipitation was almost the same between the pre- and post-thinning periods (Table 2), however the monthly precipitation pattern differed (Fig. 2a). In 2006, precipitation was high throughout the year and especially monthly precipitation in June was high. Precipitation in May 2012, when is the onset of the rainy season, was very high, although the annual precipitation in 2012 was normal compared to the average. Variation of runoff corresponded precipitation well both in HA and HV (Fig. 2b). The effect of thinning on runoff increase might not appear on monthly runoff pattern.

3.2 Change in canopy interception

Precipitation, throughfall, stemflow, interception loss, and their ratios to precipitation (*T/P*, *S/P*, and *I/P*, respectively) during the pre- and post-thinning periods are listed in Table 2. The mean *T/P* ratio was 72 % during the pre-thinning period and increased to 78 % during the post-thinning period. They were not significantly different (p=0.07 by Student's t-test). The *T/P* ratio did not return to the pre-thinning level in the third years from the thinning. The mean *S/P* ratio was 8 % during the pre-thinning period and decreased to 4 % during the post-thinning period. They were significantly different between pre- and post-thinning periods (p=0.005 by Student's t-test). The *I/P* ratio decreased in the first and second year after the thinning and returned to the pre-thinning level in the third year after the thinning. The mean *I/P* ratio was 20 % during the pre-thinning period and decreased to 18 % during the post-thinning period. They were not significantly different (p=0.3 by Student's t-test). The mean interception loss had seemingly nearly unchanged following the thinning, because the increase in throughfall and

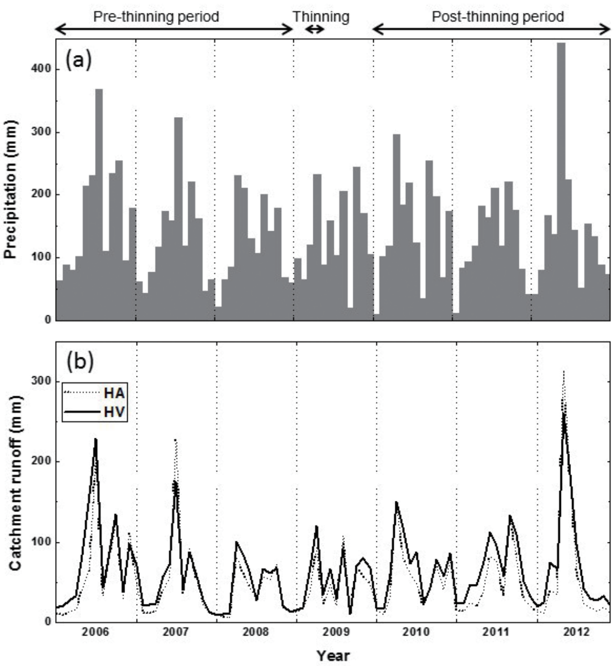

Fig. 2. (a) Monthly precipitation and (b) monthly runoff in the HA control and the HV thinning catchments during the pre- and post-thinning periods.

Table 2. Change in throughfall, stemflow and canopy interception loss due to thinning in the HV thinning catchment.

	P[1]	*T*[1]	*S*[1]	*I*[1]	*T/P*	*S/P*	*I/P*
	mm	mm	mm	mm	%	%	%
Pre-thinning							
2006	2020	1452	179	389	72	9	19
2007	1571	1095	134	342	70	9	22
2008	1499	1104	113	282	74	8	19
Mean	1697	1217	142	338	72	8	20
Post-thinning							
2010	1783	1417	89	277	79	5	16
2011	1500	1181	59	260	79	4	17
2012	1735	1329	54	351	77	3	20
Mean	1672	1309	67	296	78	4	18

[1] *P*, *T*, *S*, and *I* represent precipitation rainfall, throughfall, stemflow, and canopy interception loss, respectively. Missing data of throughfall and stemflow, were completed using the following regression lines; T=0.82P-0.85 (r^2=0.99, n=316) and S=0.10P-0.28 (r^2=0.92, n=280) for the pre-thinning period (2006-2008); T=0.83P-0.52 (r^2=0.96, n=403) and S=0.06P-0.18 (r^2=0.81, n=381) for the post-thinning period (2010-2012).

the decrease in stemflow canceled each other in the equation (1).

3.3 Change in evapotranspiration

The monthly mean of daily evapotranspiration in HV was significantly different between the pre- and the post-thinning period (p=0.01 by Student's t-test; Fig. 3). The annual reduction in evapotranspiration in HV was 140 mm, and especially large during the growing season (April to October). The total evapotranspiration during the growing season was 598 mm during the pre-thinning period and 495 mm during the post-thinning period. While the monthly evapotranspiration in HA was not significantly different between the pre- and the post-thinning period (p=0.1 by Student's t-test).

3.4 Change in runoff

The mean annual runoff increased following the thinning. The result of the paired catchment experiment was summarized in Table 3 and shown in Fig. 4. The measured annual runoff in HV was larger than the runoff predicted by the equation (3) in the first and especially second year after the thinning, and returned to the pre-thinning level in the third year after the thinning. The mean increases in the annual runoff (measured-predicted runoff) were 93 mm and 54 mm for first 2 years and during the post-thinning period, respectively. These were not significant compared with those during the pre-thinning period ($p > 0.05$ by Student's t-test).

4. Discussion

4.1 Effects of thinning on canopy water balance and evapotranspiration

The annual T/P did not return to the pre-thinning level in the third year after the thinning (Table 2). Nobuhiro et al. (2013)

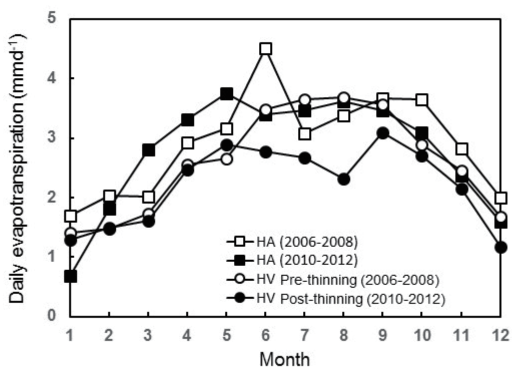

Fig. 3. Mean daily evapotranspiration in the HA control and the HV thinning catchments during the pre- and post-thinning periods.

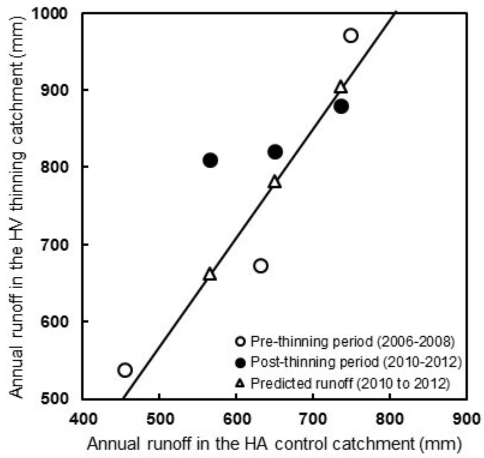

Fig. 4. Relationship between annual runoff for the HA control and the HV thinning catchments. The regression line is for the pre-thinning data; Q_{HV}=1.4Q_{HA}-138.8 (r^2=0.9).

Table 3. Annual precipitations, runoffs, and runoff rates in the HA control catchment and the HV thinning catchment, and the effect of thinning on runoff in HV estimated by the paired catchment experiment.

		HA control catchment		HV thinning catchment			
	Precipitation (mm)	Runoff (mm)	Runoff rate (%)	Measured runoff (mm)	Runoff rate (%)	Predicted runoff[1] (mm)	Water yield[2] (mm)
Pre-thinning							
2006	2020	749	37	971	48	923	48
2007	1571	630	40	674	43	754	-80
2008	1499	455	30	538	36	506	32
Mean	1697	611	36	728	42	728	0
Thinning year							
2009	1613	545	34	669	41	727	36
Post-thinning							
2010	1783	650	36	821	46	783	38
2011	1500	565	38	809	54	662	147
2012	1735	736	42	880	51	905	-25
Mean	1672	650	39	837	50	783	54

[1] Predicted runoff is based on a regression equation for the pre-thinning period (2006–2008): Q_{HV}=1.4Q_{HV}−139 (r^2=0.90).
[2] Water yield was caluculated by subtracting predicted runoff from measured runoff

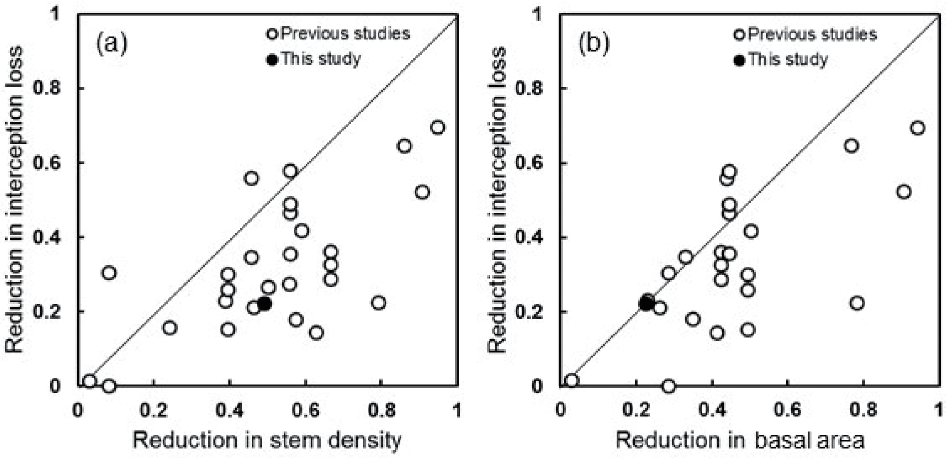

Fig. 5. The relationship between interception loss and (a) the reduction in stem density following thinning, and (b) the reduction in basal area.

measured the leaf area index (LAI) with a plant canopy analyzer (LAI 2000, LI-COR, USA), as well as the horizontal canopy area, several times every month at nine points within the canopy interception plot VI (Figs. 1b-1d) from 2007 through 2011. The mean annual LAI was 4.7 during the pre-thinning period. It decreased to 2.7 in March 2009 after thinning, and recovered to 3.4 by 2011, but it did not return to the pre-thinning level. In contrast, the total horizontal area of the canopy in VI was 593 m^2 during the pre-thinning period, and it decreased to 364 m^2 in March 2009 after thinning. It constantly recovered to 582 m^2 by February 2010, and continued to increase to 706 m^2 until August 2011. Thus, the horizontal canopy area quickly returned to the pre-thinning level, but the total amount of foliage probably recovered slowly because LAI did not recover to the pre-thinning level. Therefore, not only the horizontal canopy closure but also the total amount of foliage has an impact on throughfall volume.

The relation between the reduction of canopy interception loss and the reduction of stem density or basal area in the first year after the thinning in this study was compared to those of the previous studies in a similar manner to Nanko et al. (2015) (Fig. 5). The basal area reduction was 22.5 % in this study. This was relatively small because of poor tree growth in this study area. The reduction of interception loss related to the reduction of stem density was average compared with the previous studies and that related to the reduction of basal area was high in this study. These were attributed to small reduction of the basal area in spite of 50 % removal of trees.

Evapotranspiration during the growing season reduced from 598 mm to 495 mm (a 17 % decrease) due to the thinning in this study. Morikawa et al. (1986) measured transpiration before and after thinning in a *C. obutusa* stand in Japan by the heat pulse method. They showed that transpiration per a tree increased following the thinning whereas transpiration of the stand decreased after thinning during the growing season (April to September). The reduction of evapotranspiration in HV following the thinning was likely owed to the reduction of total transpiration due to the reduction of trees, because the mean interception loss did not change following to the thinning in this study.

4.2 Effect of thinning on runoff increase

The famous review of 94 paired catchment experiments by Bosch and Hewlett (1982) concluded that yield increased with decreasing forest cover and yield decreased with increasing forest cover. They suggested that the approximate magnitude of water yield change could be estimated by the percentage of the reduction of forest cover. There was, however, no relationship between the mean annual runoff increases following uniform thinning and the reductions of basal area (Fig. 6, Table 4), although the increase was more or less in proportion to the

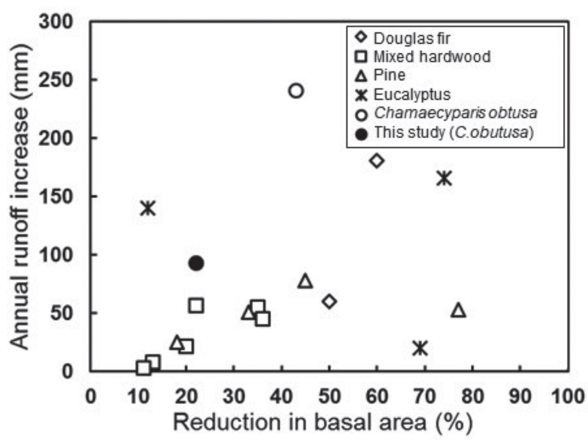

Fig. 6. Relationship between reduction in basal area and mean increases in annual runoff following uniform thinning in previous paired catchment experiment studies and this study.

Table 4. A summary of worldwide paired catchment experiments on uniform thinning effects.

Catchment	Area (ha)	Vegetation and soils	Description of cut	Mean annual precipitation (mm)	Reduction of basal area (%)	Runoff increases by years following thinning (mm)						References
						1st	2nd	3rd	4th	5th	mean	
H.J. Andrews, Oregon, USA												
HJA-7	15	Douglas fir; unaltered volcanic lastics	1974, shelterwood cut	2190	60	191	243	172	211	91	181	(1)
Coweeta, North Carolina, USA												
19	28	Mixed hardwoods; granitic origin, deeply weathered sandy clay loam up to 6 m	1949, understory cut	2001	22	101	61	66	20	37	57	(2)
41	29		1955, selective cutting	2009	35	Averaged 55 mm per year						(3)
Fernow, West Virginia, USA												
2	15	Mixed hardwoods; sandstone and shale, stoney silt loam, 1-1.5 m deep	1957-1958, trees over 43 cm DBH cut	1500	36	25	64				45	(4)
5	36		1957-1958, trees over 28 cm DBH cut	1473	20	25	18				22	(4)
3	34		1957-1958, trees over 13 cm DBH cut	1500	13	-3	8				8	(4)
Alum Creek, Ark., USA												
WS2	1	Pine with hardwood under story; stoney loam soils 0.75-1 m deep	1970, thinned, under-growth killed by herbicide application	1333	45	107	58	89	58		78	(3)
Coyote Creek, Oregon, USA												
CC-1	69	Douglas fir; mixed conifers; well-drained gravelly loam derived from breccia parent material, 150 cm deep	1971, shelterwood cut	1229	50	60 (average over 5 yr.)						(5)
Beaver Creek, Utah, USA												
17	121	ponderosa pine; volcanic basalt, cinder parent materials, stony clay loam and stony silt loam, less than 1 m	1969-1970, overstory cut	722	77	63	58	53	48	43	53	(6)
8	730		1974-1975, overstory cut	744	33	70	61	52	42	32	51	(6)

(1) Harr et al. (1982), (2) Johnson and Kovner (1956), (3) Bosch and Hewlett (1982), (4) Reinhart et al. (1963), (5) Harr et al. (1979), (6) Baker (1986), (7) Ruprecht et al. (1991), (8) Stoneman (1993), (9) Lane and Mackay (2001), (10) Lesch and Scott (1997), (11) Özyuvaci et al. (2004), (12) Dung et al. (2012)

Table 4. A summary of worldwide paired catchment experiments on uniform thinning effects (continued).

Catchment	Area (ha)	Vegetation and soils	Description of cut	Mean annual precipitation (mm)	Reduction of basal area (%)	Runoff increases by years following thinning (mm)						References
						1st	2nd	3rd	4th	5th	mean	
Western Australia												
Hansen	80	Eucalyptus with small-leaved sclerophyllous shrubs understory; duricrust and fine pisolitic gravels,	1985, thinning	1300	74	65	129	304			166	(7)
Yarragil 4L	126	Eucalyptus; lateritic dricrust and lateritic gravels	1983, thinning	1120	69	4	31	9	6	48	20	(8)
Tantawangalo Creek catchment, Southern Australia												
Willbob	85.6	Eucalyptus mixed forest; shallow loam-clay-loam A horizons overlie deep sandy clay loam to clay B2 horizons, 0.9-2.0 m	1989, selective thinning	1100	12	140 (converted to yearly runoff from monthly deviation of total streamflow over 52 months)						(9)
South Africa												
Biesievlei	27.2	Pinus radiata plantation; deeply weathered Cape Granite, wish shale lens, overlying sand stone	1964, 2nd thinning after 1st thinning in 1954	1427	18	5	29	42			25	(10)
Belgrad Forest, Turkey												
W II	77.5	Oak and beech, mixed hardwood; carboniferous clay schists and Neogene loamy gravelly deposits	1986, standard individual selective cutting	1091	11 (in volume)	3 (average over 10 yr.)						(11)
Japan												
M5	0.35	Chamaecyparis obutusa; Cambisol soils ranging from 0.6 to 1.8 m, underlying by schist	2006, thinning	1732	43	320	162				241	(12)
HV	0.88	Chamaecyparis obutusa; metamorphic consisting of schist and amphibolite, clay loam derived from volcanic ash	2009, thinning	1685	22	38	147	-25			93	This study

(1) Harr et al. (1982), (2) Johnson and Kovner (1956), (3) Bosch and Hewlett (1982), (4) Reinhart et al. (1963), (5) Harr et al. (1979), (6) Baker (1986), (7) Ruprecht et al. (1991), (8) Stoneman (1993), (9) Lane and Mackay (2001), (10) Lesch and Scott (1997), (11) Özyuvaci et al. (2004), (12) Dung et al. (2012)

severity of the cutting in the mixed hardwood and the pine forests. Lane and Mackay (2001) concluded that the percentage of basal area removed was not an indicator of the magnitude of flow increases, because mean annual runoff increase was 70 mm in the patch cutting conducted at the 22 % reduction of basal area, while it was 140 mm in the selective thinning conducted at the 12 % reduction of basal area in eucalyptus forests in Southern Australia. These were because the rate of increase in catchment runoff after thinning were attributed to the regeneration rate and the annual precipitation in addition to the rates of the reduction of basal area.

In eucalypt plantations, observable runoff increases following thinning were small due to the high growth rate and rapidly increasing water consumption predominate (Lane and Mackay 2001, Lesch and Scott 1997). In oak and beech mixed hardwood in Turkey, there was not any significant increase during the later month after cutting because the replenishment of the understory buffered the effects of reduced crown closure and in turn the interception and transpiration losses (Özyuvaci et al. 2004). In this study the understory species seemingly had not regenerated vigorously and regeneration had not effect of the annual runoff increase.

Reinhart et al. (1963) summarized that usually the results of treatment were more pronounced in well-watered area, such as the Fernow, Coweeta Hydrologic Laboratory in North Carolina, and Kamabuchi in Japan, while areas of low precipitation were likely to show less effect, such as Wagon Wheel Gap in Colorado and Sierra Ancha Experimental Forest in Arizona. Stoneman (1993) indicated that the smaller increase from Yarragil 4L catchment compared to Hansen catchment was attributed to less rainfall (Table 4). Baker (1986) reported that the potential for increasing water yield in ponderosa pine was small because pine forest inherently occurs on drier sites. On the other hand, the removal of 43 % of the basal area of 0.35-ha *C. obtusa* plantation forest produced extreme water yield (241 mm) in Mie prefecture, Japan, where the mean precipitation is approximately 2000 mm (Dung et al. 2012). The Authors explained that precipitation occurred during the growing season might directly contribute to runoff increase. The removal of 22.5 % of the basal area yielded the maximum annual runoff increase 147 mm in this study. The thinning in *C. obtusa* plantations in areas of high precipitation likely yield relatively large amount of runoff increase.

Bosch and Hewlett (1982) also concluded that the largest increase was generally found in the first couple of years following treatment, and the water yield later diminished as the forest regrew and leaf area increased. The water yield was large in the second year (2011) after thinning in this study (Table 3). Most of the previous experiments reported that forest crown closure recovered relatively quickly. The crown closure in this study recovered the pre-thinning level for one year in this study (Table 3). The canopy interception loss recovered the pre-thinning level in the third year after thinning. The reduction of total transpiration in the stand likely has a longer effect on runoff increase than the reduction of canopy interception loss. However, the annual runoff returned to the pre-thinning level simultaneously with the recovery of the canopy interception loss in this study. In conclusion, it seemed that the intensive thinning in small *C. obtusa* headwater plantation was effective to increase net precipitation and stream water for a short period.

Acknowledgments

This study was supported by the project “Practical Technology Development” of the Agriculture, Forestry, and Fishery Research Council in Japan. We thank the staff of the Ibaraki Prefectural Forestry Office for their excellent assistance during the thinning. We thank Drs. Koji Tamai, Takanori Shimizu, Shin’ichi Ida, and Naoki Kabeya for their tremendous help in conducting the field measurement, and two anonymous reviewers and an Associate Editor for providing critical comments.

References

Baker, Jr. M. B. (1986) Effects of ponderosa pine treatments on water yield in Arizona. Water Resour. Res., 22, 67-73.

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

Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W. and Vertessy, R. A. (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. J. Hydrol., 310, 28-61.

Dung, B. X., Gomi, T., Miyata, S., Sidle, R. C., Kosugi, K. and 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.

Harr, R. D., Fredriksen, R. L. and Rothacher, J. (1979) Changes in streamflow following timber harvest in southwestern Oregon. U.S. Dep. Agric. For. Serv. Res. Pap., PNW-249, 1-22.

Harr, R. D., Levno, A. and Mersereau, R. (1982) Streamflow changes after logging 130-year-old Douglas fir in two small watersheds. Water Resour. Res., 18, 637-644.

Hattori, S. and Chikaarashi, H. (1988) Effect of thinning on canopy interception in a hinoki stand. J. Jpn. For. Soc., 70, 529-533 (in Japanese).

Japanese Forest Agency (1998) Annual Report on Forest and Forestry in Japan. Fiscal year 1997.

Japanese Forest Agency (2013) Annual Report on Forest and

Forestry in Japan. Fiscal year 2012.

Jonson, E. A. and Kovner, J. L. (1956) Effect on streamflow of cutting a forest understory, For. Sci., 2, 82-91.

Kato, M., Onodera, S. and Kobayashi, M. (1995) Dynamics of nitrate nitrogen concentrations in soil solutions and spring water on a forested watershed. J. Jpn. For. Soc., 77, 516-526 (in Japanese with English abstract).

Komatsu, H., Shinohara, Y., Nogata, M., Tsuruta, K. and Otuki, K. (2013) Changes in canopy transpiration due to thinning of a *Cryptomeria japonica* plantation. Hydrol. Res. Letters., 7, 60-65.

Kubota, T., Tsuboyama Y. and Nobuhiro T. (2013) Change of evapotranspiration due to stand thinning in the Hitachi Ohta Experimental watershed. J. Jpn. For. Soc., 95: 37-41 (in Japanese with English abstract).

Lane, P. N. J. and Mackay, S.M. (2001) Streamflow response of mixed-species eucalypt forests to patch cutting and thinning treatments. For. Ecol. Manag., 143, 131-142.

Lesch, W. and Scott, D. F. (1997) The response in water yield to the thinning of *Pinus radiate, Pinus patula* and *Eucalyptus grandis* plantations. For. Ecol. Manag., 99, 295-307.

Morikawa, Y., Hattori, S. and Kiyono, Y. (1986) Transpiration of a 31-year-old *Chamaecyparis obutusa* Endl. Stand before and after thinning. Tree Physiol., 2, 105-114.

Murai, H. (1970) Studies on precipitation interception by forest vegetation. Bull. Gov. For. Exp. Stn., 232, 25-64 (in Japanese with English summary).

Murakami, S., Tsuboyama, T., Shimizu, T., Fujieda, M. and Noguchi, S. (2000) Variation of evapotranspiration with stand age and climate in a small Japanese forested catchment. J. Hydrol., 227, 114-127.

Nakano, H. (1971) Effect on streamflow of forest cutting and change in regrowth on cut-over area. Bull. Gov. For. Exp. Sta. 240, 1-251 (in Japanese with English summary).

Nanko, K., Onda, Y., Kato, H. and Gomi, T. (2015) Immediate change in throughfall spatial distribution and canopy water balance after heavy thinning in a dense mature Japanese cypress plantation. Ecohydrol Published online in Wiley Online Library, DOI: 10.1002/eco.1636.

Nobuhiro, T., Tsuboyama, Y., Kubota, T. and Tamai, K. (2013) Change in canopy structure and throughfall accompanying thinning in a Japanese cypress forest, in northern Ibaraki. Kanto J. For. Res., 64, 41-44 (in Japanese with English abstract).

Onda, Y., Gomi, T., Mizugaki, S., Nonoda, T. and Sidle, R. C. (2010) An overview of the field and modelling studies on the effects of forest devastation on flooding and environmental issues. Hydrol. Process., 24, 527-534.

Özyuvaci. N., Özhan. F., Gökbulak. F., Serengil, Y. and Balci A. N. (2004) Effect of selective cutting on streamflow in an oak-beech forest ecosystem. Water Res. Manag. 18, 249-262.

Reinhart, K. G., Eschner, A. R., Trimble, Jr. G. R. (1963) Effect on streamflow of four forest practices in the mountains of West Virginia. U.S. Agric. For. Serv. Res. Pap., NE, 1-59.

Ruprecht, J. K., Schofield, N. J., Crombie, D. S., Vertessy, R. A., and Stoneman, G. L. (1991) Early hydrological response to intense forest thinning in southwestern Australia. J. Hydrol., 127, 261-277.

Sidle, R. C., Tsuboyama, Y., Noguchi, S., Hosoda, I., Fujieda, M. and Shimizu, T. (1995) Seasonal hydrologic response at various spatial scales in a small forested catchment, Hitachi Ohta, Japan. J. Hydrol., 168, 227-250.

Stoneman, G. L. (1993) Hydrological response to thinning a small jarrah (*Eucalyptus marginata*) forest catchment. J. Hydrol., 150, 393-407.

Suzuki, M. (1985) Evapotranspiration estimates of forested watersheds in Japan using the short-term period water-budget method. J. Jpn. For. Soc., 67, 115-125 (in Japanese with English abstract).

Tsuboyama, Y. (2006) An experimental study on temporal and spatial variability of flow pathways in a small forested catchment, Bull. For. For. Prod. Res. Inst., 5, 135-174.

常陸太田試験地内の源頭部小流域における間伐が樹冠遮断量、蒸発散量および流出量に与える影響

久保田 多余子 [1)*]、坪山 良夫 [2)]、延廣 竜彦 [3)]

要旨

源頭部小流域における間伐が樹冠遮断量、蒸発散量および流出量に及ぼす影響を対照流域法によって調べた。1986 年に植栽したヒノキ林を 3 年間のキャリブレーション期間（2006-2008 年）の後、2009 年 3 月に強度に間伐した。土壌表面の攪乱を防ぐため、間伐はチェーンソーを用いて人力で行い、間伐木はその場に切り捨てた。間伐強度は本数で 50 %、材積で 30 %、また胸高断面積合計で 22.5 % であった。樹冠遮断量は間伐後最初の年に 4 % 減少し、徐々に回復して間伐 3 年後には間伐前の水準に戻った。年流出量の増加量は間伐 2 年目に最大値となり、147 mm であった。間伐後（2010-2012 年）の年流出量の増加量の平均値は 54 mm であった。この増加量は有意ではなかった。間伐後の平均年蒸発散量は有意に 140 mm 減少し、特に蒸散期の減少量が大きかった。このように、源頭部小流域における強度間伐は、短期間でみれば、林内降雨量を増やし、流出量を増すのに効果的であると考えられた。

キーワード：間伐、樹幹遮断量、蒸発散量、流出量、対照流域法

原稿受付：平成 29 年 3 月 6 日　原稿受理：平成 29 年 12 月 14 日
1) 森林総合研究所 東北支所
2) 森林総合研究所 研究コーディネータ
3) 森林総合研究所 北海道支所
* 森林総合研究所 東北支所　〒 020-0123 岩手県盛岡市下厨川字鍋屋敷 92-25