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The effect of slight thinning of managed coniferous forest on landscape appreciation and psychological restoration

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Abstract

We investigated the influence of slight thinning (percentage of woods: 16.6%, basal area: 9.3%) on landscape appreciation and the psychological restorative effect of an on-site setting by exposing respondents to an ordinarily managed coniferous woodland. The experiments were conducted in an experimental plot in the same coniferous woodland in May (unthinned) and October 2013 (thinned). The respondents were the same 15 individuals for both experiments. Respondents were individually exposed to the enclosed plot and the forest-view plot within the same tent for 15 min. In both sessions, respondents were required to answer three questionnaires measuring their mood (Profile of Mood States), emotion (Positive and Negative Affect Schedule), and feeling of restoration (Restorative Outcome Scale) to investigate the psychological restorative effect before and after the experiment. They completed two other questionnaires measuring appreciation for the environment (Semantic Differential) and the restorative properties of the environment (Perceived Restorativeness Scale) following the experiments. We first analyzed the difference in landscape appreciation between the unthinned and thinned conditions. We did not find any statistical difference in appreciation for the environment (Semantic Differential) or the restorative properties of the environment (Perceived Restorativeness Scale); rather, we found that weather conditions had a primary influence on landscape appreciation. With respect to the psychological restorative effect, a two-way repeated analysis of valiance (ANOVA) revealed significant main effects for a selection of indices, depending on the presence or absence of thinning. However, multiple comparison analyses revealed that these effects seemed to be due to the difference in the experimental experience rather than the presence or absence of thinning. In conclusion, the effect of the slight thinning of the managed coniferous forest was too weak to be reflected in the respondents' landscape appreciation or to exert a psychological restorative effect. Therefore, planners should consider stronger thinning as it is unlikely to result in serious damage to users' appreciation and may increase their landscape appreciation of coniferous woodland and enhance its psychological restorative effect.

Keywords: Forest bathing, Forest management, Profile of Mood States (POMS), Restorative Outcome Scale (ROS), Positive and Negative Affect Schedule (PANAS), Semantic Differential (SD) method, Perceived Restorativeness Scale (PRS)

Introduction

In Japan, the shortage of timber after the end of World War II prompted the creation of a national policy to plant Japanese cedar (*Cryptomeria japonica*) and Hinoki cypress (*Chamaecyparis obtusa*). Currently, forests cover 67% of the land area and approximately 40% of these forests are artificial (Food and Agriculture Organization 2007). However, when domestic timber prices slowed due to the total liberalization of wood imports in 1964, the motivation of private forest owners to manage their forests rapidly diminished.

Forests not only function to provide woodlands but also serve as multifaceted places where biodiversity is preserved, soil outflow is prevented, water sources are recharged, and forest bathing areas are provided. To manage forests that have not been profitable for forestry enterprises, subsidies are used to encourage forest management practices such as tree thinning and weeding to

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enhance their multifunctional functions for the benefit of society. However, scientific evidence is required to prove the effectiveness and validity of such practices due to the use of tax exemptions from inputting subsidies to financial sources (Forestry Agency of Japan 2016).

Japan is a mostly warm and humid country with a suitable climate for growing trees. Thus, to enhance the many functions of artificial forests while responding to future timber demands, it is necessary to artificially thin and prune dense forests. Thinning allows light to filter into the forest, which enhances the growth of the remaining trees and increases the forest's value and biodiversity. This leads to the maximization of the value of the forest, including expectations for additional functions, such as soil support and water source recharging.

Furthermore, thinning maximizes the use of appropriately managed forests as places of recreation and forest bathing, even in artificial forests. Therefore, to maximize the value of forests domestically, national and local governments should require the appropriate thinning of artificial forests by providing subsidies to forestry associations and/or forest owners. However, we should point out that such policies have not been progressing well and have not achieved sufficient outcomes to date (Forestry Agency of Japan 2016).

More than 30 years have passed since Ulrich's (1984) scientific study of the restorative effect of green and nature, during which time the primary focus has been on psychology in relation to city life (Herzog and Chernik 2000; Hartig et al. 2003; Laumann et al. 2003; Morita et al. 2009; Velarde et al. 2007). According to Haluza et al. (2014), since the beginning of this century, the physical and psychological restorative effects or other immune-related effects of forest enclosures have been investigated primarily in developed countries, in which aging populations and declining birth rates have become serious issues. In Japan in particular, since the concept of forest bathing was defined in 1982 (Morita et al. 2009), studies on the physical and psychological restorative effects of the forest have rapidly advanced, specifically in the second half of the 1990s. For example, in the areas of medicine and physiology, Ohira et al. (1999) reported that forest bathing was effective for immune restoration, and Li et al. (2007; 2008a) found that immune cells were more active after a 3-day stay in the forest. Li et al. (2008b) also indicated that the benefits of forest bathing were influenced not only by the components of air, such as phytoncide, but also by the environment itself, compared with staying in urban areas for the same duration. Ochiai et al. (2015a; 2015b) showed that 2 h of forest bathing reduced physiological parameters such as stress hormones, blood pressure, and adrenaline in middle-aged and elderly people. The Profile of Mood States (POMS; McNair et al. 1964) and the State-Trait Anxiety Inventory (STAI; Spielberger et al. 1970; Spielberger et al. 1983) are commonly applied to analyze mood (Oishi et al. 2003; Park et al. 2009; Tsunetsugu et al. 2010; Park et al. 2010) and anxiety state (Takanashi 2011). Moreover, research using newly developed indices such as the Perceived Restorativeness Scale (PRS; Korpela and Hartig 1996; Hartig et al. 1997a; Hartig et al. 1997b), the Restorative Outcome Scale (ROS; Korpela et al. 2008; Korpela et al. 2010), and the Subjective Vitality Scale (SVS; Ryan and Frederick 1997) has shown that forest bathing results in psychological restoration and improved vigor (Takayama and Kagawa 2013; Takayama, Korpela, Lee et al. 2014b; Tyrväinen et al. 2014). Furthermore, Kobayashi et al. (2015) performed a large-scale field experiment throughout Japan in 60 forests known as "therapy bases" maintained for forest bathing. Finally, a few notable studies have confirmed the considerable physiological and psychological effects not only of remote forests but also of urban forests (Tsunetsugu et al. 2013; Tyrväinen et al. 2014b). Thus, studies have shown that forest environments result in physical and mental restorative effects and have detailed the mechanisms behind these effects.

However, forest management planning is required to activate the health-restorative function of a forest. Information on the arrangement of physical forest environments and their management is needed to make forests a comfortable place to be. In the context of the effects of the physical forest environment and forest bathing, Horiuchi et al. (2014) reported that when individuals observed a real forest scene, the level of cerebral oxygenated hemoglobin in the prefrontal area of the brain declined and mood improvements were greater than in respondents who were cut off from forest environments. Park et al. (2011) demonstrated a relationship between physical conditions, such as temperature and illumination, and impression evaluation and mood restoration. Fujisawa et al. (2012) and Takayama et al. (2012) studied the light environment in forests and reported that in a bright environment with sunlight passing through the trees, the blood volume in the brain decreased and mood improvement effects were higher than in a dark environment within the same forest. These research findings suggest that it is important to properly manage the forest's internal environment to make forest bathing more comfortable. However, forest management requires an understanding of the unique situation within each forest depending on its intended use (Brunson and Reiter 1996; Gobster 1999; Ribe 2006). For example, compared with remote artificial forests, forests near tourist spots or suburban forests require management to maintain biological diversity while at the same time satisfying the needs of tourists and residents of nearby neighborhoods (Brunson and Reiter 1996; Gobster 1999; Ribe 2006). Therefore, to manage urban forests with highly diverse uses such as forest bathing and other recreational activities, an administrator must be well informed about the level of management required in relation to intended uses.

Other studies have assessed the relationship between forest management methods and public evaluation. For instance, Buhyoff and Leuschner (1978) reported that favorability ratings for forests decreased sharply after the pinewood nematode caused damage to more than 10%; Takahashi et al. (2006) suggested that preferences vary depending on the mix of tree types and the proportion of hardwood and softwood; and Oishi et al. (1994), Takayama et al. (2009), and Takayama et al. (2014) investigated the relationship between tree density and the comfortability of the forest environment. Several investigators have studied the effects of the types and numbers of trees, tree density, the presence or absence of fallen trees, and planting patterns on the evaluation of landscape beauty, among other parameters.

The relationship between the evaluation of forest beauty and thinning, which is a typical method of sustaining forests, has also been investigated (Ribe 2005; Guan et al. 2010; Deng et al. 2012). Daniel (2006) highlighted that forest users tend to prefer somewhat managed forests to entirely natural forests. However, Edwards et al. (2012) showed that thinning was not the only task necessary to preserve forests in good condition. Even if thinning improves the internal forest environment, the evaluation of the forest has been shown to decrease after thinning. Nevertheless, further studies are necessary to collect data on the extent of users' impact and the reduction in esthetic evaluation by controlling the forest type, stand age, forest compartment placement, and the degree of thinning.

Other studies have investigated the relationship between forest landscape management and recreation. Brunson and Sheldy (1992) found that the landscape quality of a forest and recreational activities were closely linked. Kunisaki and Imada (1996) reported that managing the density of trees along roads such as promenades, forest trails, and forest roads increased users' satisfaction, even if sufficient thinning could not be conducted for the entire forest. The Gifu Prefectural Research Institute for Forests (2004) reported that good visitor ratings could be maintained by establishing a range of approximately 20 m from both sides of the sidewalk. Lastly, Oku (2007) investigated the ease of carrying out various activities in the forest, which included an analysis of the level of management required for each type of use.

Another important aspect is how users' evaluations of forests change depending on the degree of thinning and its relationship to mental and physical recovery. Unfortunately, only a few previous studies have considered this topic, such as Oishi et al. (2003), and current research remains insufficient for specialists to form actionable conclusions. Urban forests located close to cities, or in resort or vacation areas that have already been in service for tourism or other recreational uses, offer facilities that are reasonably maintained and managed, unlike distant forests (e.g., *okuyama*; forests and mountains far from urban areas) that are in a state of abandonment. However, health consciousness has recently emerged as a public issue, and forest managers must further enhance their general evaluation of forests to continually provide forest bathing experiences that bring a restorative effect to visitors. Therefore, management criteria are required that provide guidelines on the optimal amount and frequency of thinning, weeding, and pruning to establish appropriate goals and guide forest management. With insufficient evidence, forest administrators must decide arbitrarily on the need for and degree of thinning using their own judgment, experience, demand, and other plans (for example, timber production planning), without measurable objectives. If we cannot promote the benefits of thinning due to a lack of information on forest management and the mental and physical restorative effects of forest environments, both forest administrators and users may miss a great opportunity.

In this study, we performed an experiment in which adjusted thinning was carried out in a partially managed urban forest located in a suburban summer resort. The purpose of the study was to investigate how thinning influenced impressions and evaluations of the forest environment and its restorative effects on people who enjoy forest bathing.

Methods/experimental

Study design

The experiment was divided into two parts and conducted in May and October, when the average temperature and humidity were expected to be similar (see the "Results and discussion" section). The study area chosen was within the Fuji Iyashinomori Woodland Study Center, which is an experimental forest associated with the University of Tokyo located in Yamanakako Village. This institute is located near Lake Yamanaka, one of the five lakes around Mt. Fuji (Fig. 1), and the experimental plot measured 2500 m^2 (50 m × 50 m; Fig. 2, Table 1).

The forest chosen as the research site (approximately 40 ha) is managed by two technical staff members of the Fuji Iyashinomori Woodland Study Center. The university budget covers the management expenses of the forest. The area around the Center, the buildings, gardens, forest road, and sidewalks are highly managed. However, the management status of the Larch plantation area chosen as the research site was similar to other surrounding private forests and was not highly managed, at least at the time of the experiment. The forest physiognomy (forest type) of the experimental plot was a man-made (artificial) forest primarily comprising approximately 80-year-old larch trees *(Larix kaempferi)*; however, the amount of hardwood trees was increasing, and the forest was turning into a mixed-type forest. In 2012, 1 year before the experiment, the shrubs and young trees were cut and removed from the forest. Therefore, the canopy was almost closed, but the horizontal prospect was in quite good condition (Figs. 3 and 4 and Table 2).

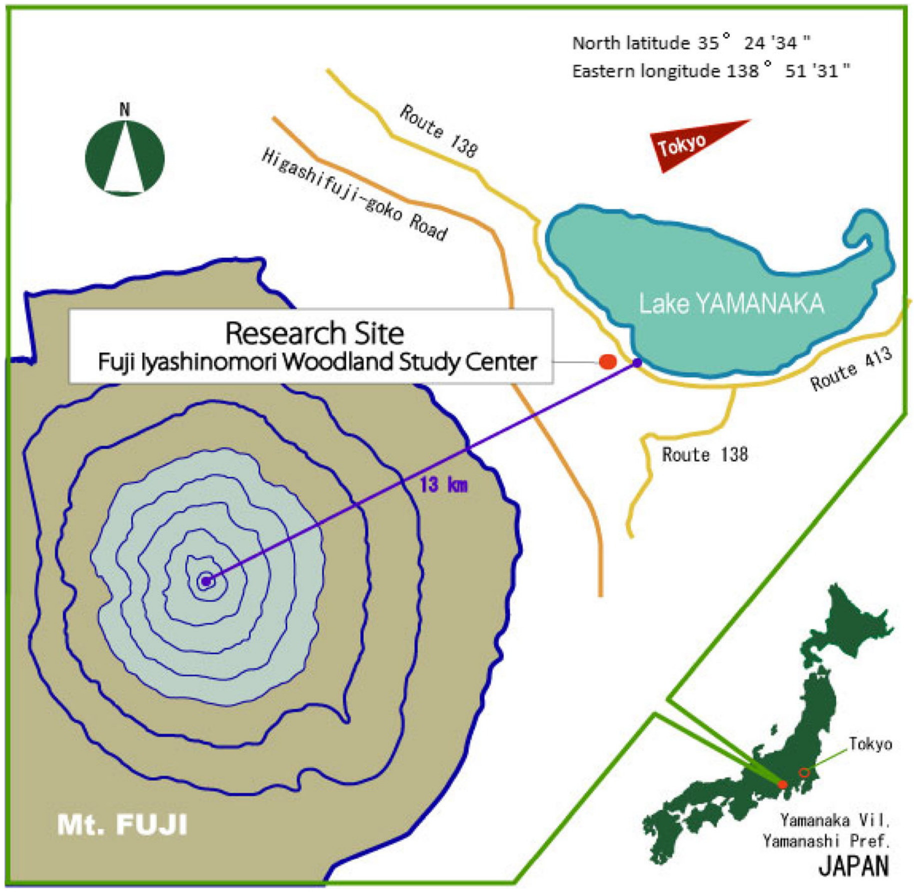

Fig. 1 Location of the research site

Following the completion of the first experiment in May 2013, corrective thinning of the study area was carried out in August of the same year. Crews used two chain saws and one portable winch during the thinning operation, with a target of approximately 15–20% thinning. Four workers from Fuji Iyashinomori Woodland Study Center worked for a total of 9 h for 2 days in late August. The second experiment was conducted in October of the same year. The period between the two experiments was important because the smell of the trees, typified by phytoncide, would be stronger immediately after the thinning. In the experimental period, we provided warm coats for the participants so they could control the experimental conditions in comfort. Table 2 shows the distribution of vegetation used for the experimental stimuli, based on the basal area at breast height in May (in October).

Respondents

Graduate students and teaching staff members from the Forest Science Department of the University of Tokyo were chosen as the respondents in this experiment. Therefore, we could assume that all respondents were favorable toward and had fundamental knowledge and experience of forests. We broadened the sample to include middle-aged teaching staff to avoid the bias that may have occurred by choosing only students. Fifteen respondents (11 men and 4 women) with a mean age of 35.9 ± 8.19 years (Table 3) participated in this study. The respondents had no history of cardiovascular disease or mental illness and were not taking any medications that could affect their psychological responses related to feelings, affect, and subjective restorativeness. Following a detailed description and explanation of the study procedures and the possible risks and benefits of participation, each respondent signed an informed consent form. Respondents were randomly divided into group A or group B and asked to abstain from consuming caffeinated beverages for 12 h and not to engage in strenuous exercise or consume alcohol for a minimum of 24 h before the experiment. The ethical committee of the Mt. Fuji Research Institute approved all procedures applied in the present study, which were performed in accordance with the guidelines of the Declaration of Helsinki.

We performed a statistical power analysis using the free software G*power v. 3.1.9.2. The actual power (1-β error probability) was 0.575 for a repeated measures, within-between interaction test, calculated by a post hoc achieved

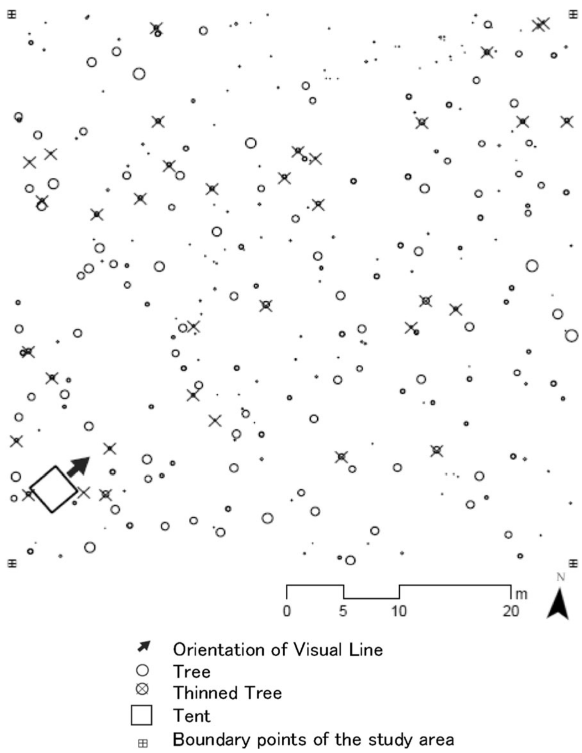

Fig. 2 Situation of the experimental area

power analysis with an effect size of 0.25 and α error of probability of 0.05. Nevertheless, previous studies have indicated that a sample size of 12–15 respondents is enough to draw significance conclusions (Li et al. 2008a; Li et al. 2008b; Park et al. 2009; Horiuchi et al. 2014).

Questionnaires

The study used five psychological questionnaires. Figure 5 shows the administration procedure for each questionnaire. The purpose was to evaluate the characteristics of the forest environment and to investigate its psychological restorative effect. Because the psychological evaluations were in the form of language information, generally it would be easy to interpret them in comparison with physiological data to facilitate future forest management. Therefore, we decided to use five psychological questionnaires in the experiment. Specifically, the POMS, ROS, and PANAS measured the psychological restorative effect, and the SD method and PRS measured the characteristics of the forest environment.

Table 1 Research site characteristics and weather conditions

	May	October
Location	Fuji Iyashinomori Woodland Study Center, Yamanaka Lake Town, Yamanashi Prefecture	
Experimental area	2500 m^2 (50 m × 50 m)	
Forest status	Well-managed mixed forest (80-year-old Larch and Dogwood)	
Weather		
Day1	Fair	Cloudy
Day2	Fair	Cloudy and/or partly sunny
Day3	Fair	Cloudy and/or partly sunny
Day4	Fair	Cloudy and/or partly rainy
Monthly mean temp. (°C)	12.8	10.9
Monthly mean humidity (%)	84.6	90.9

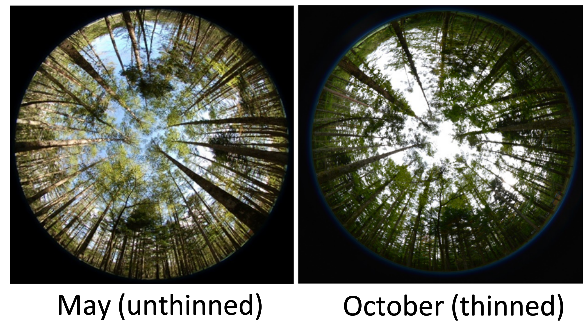

Fig. 3 Hemispherical photographs of the study area

1) Profile of Mood States (POMS)
   The POMS (McNair et al. 1964) is a well-established, factor-based, analytically derived measure of psychological distress. Its reliability and validity have been well documented (McNair et al. 1964). The POMS measures six mood states: tension and anxiety (T-A), depression-dejection (D), anger and hostility (A-H), vigor (V), fatigue (F), and confusion (C). We used the Brief Form Japanese Version of the POMS (Yokoyama et al. 1990). Each subscale has five items measured on a 5-point Likert scale; thus, the statistical analyses included the raw scores for all 30 items.
2) Positive and Negative Affect Schedule (PANAS)
   The PANAS (Watson et al. 1988a; Watson et al. 1988b) measures positive affect (PA) and negative affect (NA) using 20 items (10 items each for PA and NA). The scales have high internal consistency, are largely uncorrelated, and remain stable at appropriate levels over a 2-month period (Watson et al. 1988b). Normative data, factorial elements, and external evidence of the scales' convergent and discriminant validity are also available (Watson et al. 1988b). We used the Japanese version of the PANAS (16 items; 8 items each for PA and NA; measured on a 7-point Likert scale; Sato and Yasuda 2001) and used each respondent's total PA and NA scores in the statistical analyses.
3) Restorative Outcome Scale (ROS)
   The ROS (Korpela et al. 2008) was based on previous measures and findings regarding restorative

Fig. 4 View of the study area

outcomes (Kaplan et al. 1993; Hartig et al. 1998; Staats et al. 2003). The ROS consists of six items for measuring restorative emotional and cognitive outcomes in a given environment. Each item is measured on a 7-point Likert scale (1: "not at all" to 7: "completely"), the reliability of which was confirmed in previous studies (Korpela et al. 2008; Korpela et al. 2010). In this study, we used the Japanese version, the ROS-J, and checked the reliability and validity according to Fujisawa and Takayama (2014). The total score of the six items was used for statistical analyses.

4) Semantic Differential (SD) method
A questionnaire using the SD method was applied to examine the impression of the different environments. Osgood (cited in Iwashita 1983) initially developed the SD method for qualitatively evaluating people's impressions of the environment and space, using adjective pairs or adjective–verb pairs of words with opposite meanings. Park et al. (2011) and Takayama et al. (2014) proved the effectiveness of this scale in previous studies; therefore, in this study, we selected 25 adjective and adjective–verb pairs that were considered appropriate for evaluating impressions of the forest environment. A 7-point Likert scale was used for the measurement.

5) Perceived Restorativeness Scale (PRS)
The restorative properties of the environment were investigated using the PRS. The questionnaire was developed by Harting (2005) based on the attention restoration theory proposed by Kaplan and Kaplan (1989) and Shibata et al. (2008), then translated into Japanese and subsequently revised. The Japanese version of the PRS comprises 26 items that measure the extent to which a particular environment restores mental alertness; for example, "being away," "fascination," "coherence," "scope," and "compatibility" on an 11-point Likert scale. "Familiarity" and "preference" were also measured (Kaplan and Kaplan 1989; Shibata et al. 2008).

Table 2 Species data for May and October

		May (unthinned)	October (thinned)
Stand density (number/ha)		1200/ha (n = 301)	1056/ha (n = 251)
Stand basal area (m^2/ha)		48.8	44.3
Species composition (basal area; %)	Larch (*Larix kaempferi*)	66.2%	66.1%
	Dogwood (*Cornus kousa*)	10.1%	10.1%
	Red pine (*Pinus densiflora*)	7.0%	7.3%
	Fir (*Abies firma*)	6.4%	6.4%
	Japanese-alder (*Alnus japonica*)	1.9%	1.8%
	Veitch's silver fir (*Abies veitchii*)	1.8%	1.8%
	Fuji cherry (*Prunus incisa*)	0.8%	0.8%
	Maple (*Acer*)	0.7%	0.7%
	Japanese wing nut (*Pterocarya rhoifolia*)	0.7%	0.7%
	Others	4%	4%

Procedure

All respondents were divided into either group A or group B in May and remained in the same groups for the October experiment. There were two study conditions, and each respondent participated in both in a certain order in May and October (Fig. 5). One condition included viewing a real forest, whereas the other was in the same place but respondents did not view the real forest. Cloth sheets were

Table 3 Respondents' characteristics

	Number of respondent	Mean age	S.D.
All	15	35.9	±8.19
Male	11	37.4	±7.58
Female	4	31.8	±9.53

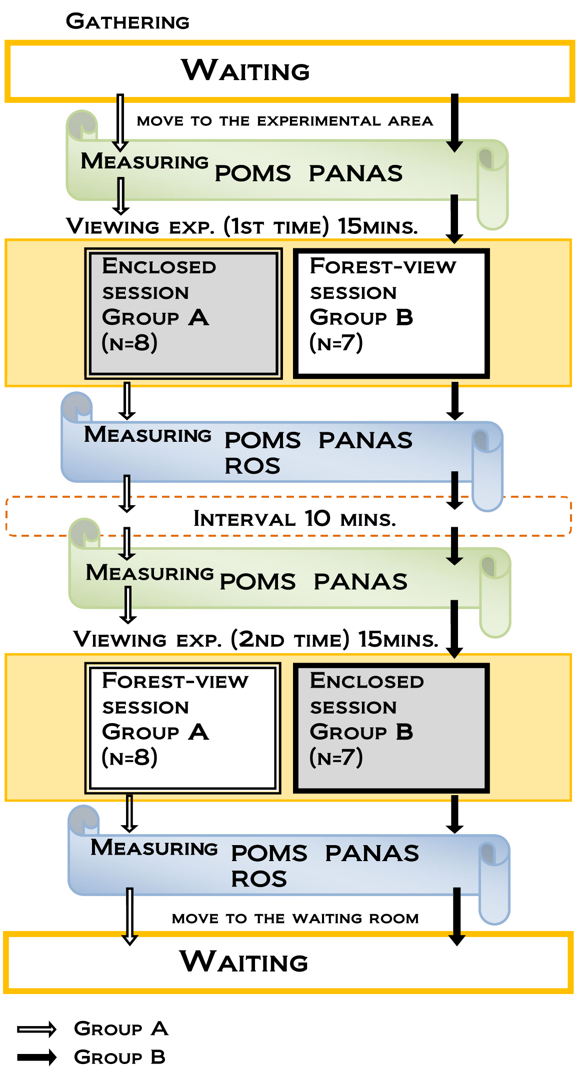

Fig. 5 Experimental procedure. The same experimental procedure was used in the May (unthinned) and October (thinned) experiments. Only the results of the forest view session were used in the analysis (for both May and October); the data from the enclosed sessions were not analyzed

hung on both sides and in front of the respondent for the entire duration of the study. The cloth in front of the respondent was opened and closed for the forest-view and enclosed conditions (with and without forest viewing, respectively) in both May and October.

Respondents' psychological responses were measured in both the forest-view and enclosed conditions. Each respondent sat on a comfortable chair during both conditions. The POMS, PANAS, and ROS were administered before and after, and the SD and PRS were administered after each 15-min experimental session. Respondents sat in a comfortable chair in an upright position to complete the POMS, ROS, and PANAS questionnaires. Respondents were then instructed to view the landscape in front of them, either the forest or the enclosed setting, for 15 min. The post-measurements were then completed (i.e., POMS, ROS, PANAS, SD, and PRS). After completing either the forest-view or enclosed condition, the other experimental stimulus was introduced.

Carrying out the experiment according to the schedule shown in Fig. 5 required approximately 2 h per respondent, and only three or four people could be tested each day because of the individual experimental design. Therefore, the 15 respondents were tested over four consecutive days in each of May and October.

Environmental measurements

Environmental conditions (i.e., temperature and relative humidity, wind velocity, and radiant heat) were measured using a portable amenity meter (AM-101, Kyoto Electronic Manufacturing, Co. Ltd, Kyoto, Japan). Illumination intensity was measured using an illuminometer (T-10, Konica Minorta, Japan). These parameters were measured every 5 min throughout the 15 min of each experimental session.

Data analysis

We aggregated the study index data and calculated the mean and standard deviation (SD). Only the results of the forest-view sessions were used for the analysis in both May and October. We conducted a two-way repeated measure analysis of valiance (ANOVA) on the POMS, PANAS, and ROS data to investigate the psychological restorative effect of forest thinning. The interaction and simple main effects were calculated to investigate the relationship between the response changes of the exposure to the stimulus (before and after exposure) and the thinning (May–October). The SD method and PRS, which were used as indicators of landscape appreciation, were only administered after exposure to the stimulus. Therefore, we compared the results of the May and October experiments using paired *t*-tests to investigate whether the evaluations changed after the forest thinning. We calculated the average values of the environmental condition indicators over the 15 min of each experimental session, and compared the values of each indicator between May and October using paired *t*-tests. Data are expressed as mean ± SD.

Results and discussion

Physical environment

Table 4 shows the results of the physical environment measurements for the unthinned and thinned conditions. First, in the thinned experimental environment in October, the temperature and humidity were significantly higher ($p < 0.01$) than in the unthinned environment in May, the wind was calmer ($p < 0.05$) and the radiant heat was lower ($p < 0.05$). Illuminance was significantly lower in the thinned condition ($p < 0.01$) than in the unthinned condition. The sound

Table 4 Results of *t*-test comparison between the unthinned and thinned settings (physical environment)

Item		Unthinned		Thinned		*t*	*p*		*r*
		Mean	S.D.	Mean	S.D.				
Temperature (°C)	*n* = 50	17.1	±2.52	18.6	±0.92	2.90	0.006	**	0.383
Relative humidity (%)		37.7	±20.42	92.4	±4.64	13.70	0.000	**	0.891
Wind velocity (m/s)		0.30	±0.19	0.16	±0.13	4.92	0.000	*	0.576
Radiant heat (°C)		21.8	±2.84	18.8	±1.05	2.19	0.034	**	0.299
Illuminance (Lux)	*n* = 119	668.4	±236.86	335.6	±171.84	8.23	0.000	**	0.604
Sound pressure (dB)		L.O. up to 45.5		L.O. up to 46.1		–	–	–	–

L.O. shows the measurement limit (less than 40 dB) of the sound-level meter. The dB was listed from the minimum (measurement limit) to the maximum (actual number) as information of the sound pressure
**$p < 0.01$, *$p < 0.05$, paired *t*-test

pressure level for the thinned and unthinned conditions was similar, considering 45–46 dB as the measurement limit.

To carry out the on-site comparative experiments, the state of the forest environment should be equal in the unthinned and thinned conditions. Therefore, we chose to carry out the experiments in May and October, which generally have similar weather conditions. However, as shown in Table 4, we observed significant differences in the thermal environment and illumination. More specifically, the results show that in the thinned forest environment in October, the luminance was slightly lower and the temperature was higher than in the unthinned environment in May.

Landscape appreciation

Table 5 compares the evaluations of the unthinned and thinned forest environments. We observed a significant difference in the two measures (scales) of "bright-dark" ($p < 0.05$) and "dry-wet" ($p < 0.01$). In other words, the thinned forest environment was evaluated to be relatively dark and wet. We also observed different trends ($p < 0.1$) in three scales: "gentle lighting-too bright," "dull-refreshing," and "thin-thick." Respondents used the labels "gentle light," but not "refreshing" or "thin" to describe the thinned forest environment.

Table 6 compares the restorative properties of the two forest environments based on the appreciation of the respondents. The results show no significant difference between the indicators used to measure the restorative properties (being away, fascination, coherence, scope, and compatibility) and familiarity and preference.

These results indicate that although the thinning operation physically changed the stand density and basal area of the forest environment (Fig. 2, Table 2), the impression evaluation and restorative properties indicators showed almost no difference between the forest environments (Tables 5 and 6). The SDs suggested that the thinned forest environment was evaluated as darker and wetter. However, this result was not because of the influence of the thinning, but rather reflected the difference in the climate and weather conditions during the experiment; for example, the luminance was lower and the humidity was higher (Table 4).

Table 4 also indicates that respondents felt the thinned condition was relatively "dull" (dull–refreshing) and the light in the forest "gentle" (gentle lighting–too bright), which implies that the climate and weather conditions in the thinned condition, when the humidity was higher and the luminance was lower, had an influence.

Psychological restorative effect

Because both the thinning and the exposure to the forest environment could influence the psychological restorative effect, we conducted a two-way repeated measures ANOVA, with the presence or absence of thinning and the observations before and after exposure to the forest environment as factors, to analyze the interaction between the factors and the main effect (Tables 7 and 8). The results showed no interaction effect between the presence and absence of thinning and before and after the experiment for the six indicators of the POMS (T-A, D, A-H, V, F, C).

We also examined each main effect of the presence or absence of thinning and the observations before and after the experiment. For the former, we observed a significant effect in C ($p < 0.01$) and a trend in T-A ($p < 0.1$). For the latter, we observed a significant effect in T-A, D, and C ($p < 0.01$, respectively), and a trend in F ($p < 0.05$) (Table 7).

Based on the results of the multiple comparison tests, the numeric values of T-A, D, F, and C showed a significant reduction and the respondents' mood was improved ($p < 0.01$) in the unthinned condition. In the thinned condition, the numeric values of T-A, D, C, and A-H decreased significantly ($p < 0.05$), and F also showed a declining trend ($p < 0.1$) (Table 8).

The psychological restorative effect was assessed by performing a two-way repeated measures ANOVA on the PANAS data, considering the presence or absence of thinning (unthinned–thinned) and the observations before

Table 5 Results of *t*-test comparison between unthinned and thinned settings (Semantic Differential Method)

	Unthinned		Thinned		*t*	*p*		*r*
	mean	*S.D.*	mean	*S.D.*				
Bright (1) - Dark (7)	2.3	±0.8	3.1	±1.19	-2.48	0.027	*	0.552
Open (1) - Closed (7)	2.3	±1.11	2.7	±1.35	-1.03	0.320		0.266
Artificial (1) - Natural (7)	5.7	±0.82	5.4	±1.3	0.59	0.565		0.156
Smelly (1) - Odorless (7)	3.6	±1.35	3.3	±1.23	0.48	0.639		0.128
Still (1) - Animated (7)	5.0	±1	4.5	±1.13	1.37	0.192		0.345
Comfortable (1) - Uncomfortable (7)	2.5	±1.06	2.7	±1.22	-0.49	0.629		0.131
Quiet (1) - Noisy (7)	3.2	±1.35	3.3	±1.5	-0.24	0.815		0.064
Ugly (1) - Beautiful (7)	5.6	±0.74	5.3	±0.9	1.07	0.301		0.277
Pleasing sound (1) - Irritating noise (7)	2.5	±1.41	3.1	±1.25	-1.21	0.245		0.309
Friendly (1) - Unfriendly (7)	2.4	±0.74	2.3	±0.72	0.32	0.751		0.087
Dull (1) - Refreshing (7)	5.9	±0.64	5.1	±1.44	1.87	0.082	#	0.448
Orderly (1) - Chaotic (7)	3.7	±1.39	3.7	±1.18	0.12	0.906		0.033
Warm (1) - Cool (7)	4.9	±1.03	4.7	±1.23	0.72	0.484		0.189
Insecure (1) - Secure (7)	4.9	±1.1	4.6	±1.18	0.66	0.519		0.174
Gentle lighting (1) - Too bright (7)	2.8	±0.94	2.3	±0.7	1.88	0.081	#	0.449
Thin (1) - Thick (7)	4.0	±0.66	3.3	±0.98	1.78	0.096	#	0.431
Flat (1) - Three dimensional (7)	5.3	±1.5	5.3	±1.35	0.00	1.000		0.000
Awaking (1) - Soothing (7)	4.7	±1.16	4.9	±1.44	-0.39	0.700		0.105
Enchanted (1) - Disenchanted (7)	3.5	±0.74	3.2	±1.08	0.79	0.442		0.207
Fragrant (1) - Malodorous (7)	3.5	±0.74	3.3	±0.7	0.94	0.364		0.244
Non enjoyable (1) - Enjoyable (7)	5.7	±0.59	5.8	±0.78	-0.27	0.792		0.072
Restless (1) - Calm (7)	5.4	±1.18	5.3	±1.44	0.26	0.796		0.071
Dry (1) - Wet (7)	3.8	±0.86	5.3	±0.96	-3.90	0.002	**	0.722
Nondescript (1) - Unique (7)	3.4	±0.74	3.7	±1.03	-1.05	0.313		0.27
Healthy (1) - Unhealthy (7)	2.5	±0.52	2.4	±0.83	0.62	0.546		0.164

Likert scale of seven stages was used for this questionnaire
**$p < 0.01$, *$p < 0.05$, #$p < 0.1$ paired *t*-test

and after the experiment (pre–post) as factors, similar to the POMS (Tables 9 and 10).

We did not observe any interaction between the presence and absence of thinning and pre–post observations on the two PANAS indices (negative and positive). Additionally, no significant effect was found for the main effects (Table 9). The results of the multiple comparison tests showed no significant difference between the respondents' negative and positive emotions before and after the experiment in both the unthinned and thinned conditions (Table 10). To assess the psychological restorative effect, we carried out a two-way repeated measures ANOVA on the ROS data with the presence and absence of thinning and pre–post measures as factors, similar to the POMS and PANAS analyses (Tables 11 and 12).

We did not find an interaction between the presence of thinning and the pre–post measures. For the main effects, we observed a significant effect before and after the experiment ($p < 0.05$), but not between the presence and absence of thinning (Table 11). In the unthinned condition, there was a significant difference between pre and post ROS scores ($p < 0.01$). However, although the post scores also increased in the thinned condition, the difference was not significant (Table 12).

Table 6 Results of *t*-test comparison between unthinned and thinned settings (Perceived Restorativeness Scale)

	Unthinned		Thinned		*t*	*p*	*r*
	Mean	S.D.	Mean	S.D.			
Being away	34.2	±5.98	33.9	±8.54	0.11	0.912	0.031
Fascination	35.1	±6.3	33.1	±8.32	0.72	0.481	0.191
Coherence	20.3	±4.27	21.3	±5.62	−0.45	0.657	0.121
Scope	22.7	±5.85	26.5	±5.88	−1.62	0.128	0.397
Compatibility	27.5	±4.19	28.9	±2.67	−0.84	0.413	0.221
Familiality	5.2	±2.83	6.0	±2.83	−0.86	0.403	0.225
Preference	11.7	±2.23	11.7	±3.37	−0.06	0.954	0.016

paired *t*-test

Table 7 Results of two-way repeated measures ANOVA for Profile of Mood States (mood)

POMS	Main effect								Interaction		
	Condition Unthinned vs. thinned				Time Pre vs. post				Condition × time		
	F	p		η^2	F	p		η^2	F	p	η^2
Tension-Anxiety	3.51	0.072	#	0.032	5.02	0.033	*	0.110	0.06	0.805	0.001
Depression-Dejection	0.20	0.662		0.002	4.41	0.045	*	0.115	1.06	0.312	0.006
Anger-Hostility	2.03	0.165		0.018	1.76	0.195		0.044	1.04	0.318	0.009
Vigor	1.88	0.182		0.021	1.35	0.256		0.031	0.01	0.923	0.001
Fatigue	2.15	0.153		0.013	4.12	0.052	#	0.105	1.16	0.291	0.007
Confusion	35.35	0.000	**	0.189	4.57	0.041	*	0.093	0.20	0.661	0.002

**$p < 0.01$, *$p < 0.05$, #$p < 0.1$ two-way repeated measures ANOVA

We did not observe an interaction between the POMS (mood), PANAS (emotion), and ROS (restorative feeling) indices. This implies that there was no complex effect between the thinning of the forest environment and spending time in it. As for the psychological effects on mood, emotion, and the feeling of restoration, we did not observe any particular effect, either in terms of thinning or of forest stay.

A main effect of thinning was observed on mood C ($p < 0.01$) and T-A ($p < 0.1$) (Table 4). Based on these results, it appears that thinning effectively influenced the C and T-A indicators of mood. However, comparing the results for each indicator in the presence or absence of thinning in Table 8, the average POMS C score in the unthinned condition was 5.80, whereas that in the thinned condition was 3.40. After the experiment, the average POMS C score in the unthinned condition was 4.07 and that in the thinned condition was 2.00. Each of these values showed a significant difference. This indicates that the thinning did not decrease respondents' confusion, but their experimental experience in May helped to reduce their confusion because we carried out the second session in October within the same experimental area. Comparison of the mean T-A scores showed that they were significantly higher in the unthinned than the thinned condition ($p < 0.05$), but we did not observe any significant difference in the same comparison after the experiment. Therefore, we conclude that the experimental experience itself primarily influenced the respondents, rather than the influence of the thinned forest environment (Table 8).

Table 8 Results of multiple comparison tests between before and after thinning (setting) and pre–post (exposure to the forest) for Profile of Mood States (mood)

	Unthinned						Thinned					
	Pre		Post		p		Pre		Post		p	
	Mean	S.D.	Mean	S.D.			Mean	S.D.	Mean	S.D.		
Tension-Anxiety	4.20	±3.34	2.20	±2.91	0.006	**	3.07	±2.59	1.33	±1.45	0.017	*
Depression-Dejection	1.47	±1.85	0.20	±0.56	0.002	**	1.33	±2.09	0.53	±0.62	0.043	*
Anger-Hostility	0.40	±0.74	0.20	±0.77	0.383		0.80	±1.22	0.27	±0.57	0.023	*
Vigor	5.07	±3.31	3.87	±3.54	0.160		4.07	±3.30	3.00	±2.63	0.211	
Fatigue	2.73	±2.22	0.93	±1.16	0.002	**	2.87	±2.87	1.80	±1.76	0.061	#
Confusion	5.80	±2.24	4.07	±1.22	0.005	**	3.40	±5.65	2.00	±1.83	0.021	*
	Pre						Post					
	Unthinned		Thinned		p		Unthinned		Thinned		p	
	Mean	S.D.	Mean	S.D.			Mean	S.D.	Mean	S.D.		
Tension-Anxiety	4.20	±3.34	3.07	±2.59	0.043	*	2.20	±2.91	1.33	±1.45	0.116	
Depression-Dejection	1.47	±1.85	1.33	±2.09	0.561		0.20	±0.56	0.53	±0.62	0.152	
Anger-Hostility	0.40	±0.74	0.80	±1.22	0.021	*	0.20	±0.77	0.27	±0.57	0.687	
Vigor	5.07	±3.31	4.07	±3.30	0.153		3.87	±3.54	3.00	±2.63	0.214	
Fatigue	2.73	±2.22	2.87	±2.87	0.698		0.93	±1.16	1.80	±1.76	0.017	*
Confusion	5.80	±2.24	3.40	±5.65	0.000	**	4.07	±1.22	2.00	±1.83	0.000	**

**$p < 0.01$, *$p < 0.05$, #$p < 0.1$ ANOVA-Bonferroni

Table 9 Results of two-way repeated measures ANOVA for Positive and Negative Affect Schedule (emotion)

PANAS	Main effect						Interaction		
	Condition Unthinned vs. thinned			Time Pre vs. post			Condition × time		
	F	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
Negative	0.63	0.434	0.001	0.77	0.387	0.001	0.12	0.731	0.001
Positive	0.23	0.636	0.001	1.13	0.296	0.001	0.05	0.820	0.001

two-way repeated measures ANOVA

We also confirmed the effect of the stay in the forest on mood (POMS; T-A, D, C) and restorative feeling (ROS). Further, there was a tendency for the forest to restore the respondents' exhausted mood (Table 7). The results were supported by the multiple comparison test results shown in Table 8; in the unthinned condition, the mean scores for T-A, D, F, C (POMS), and ROS showed a significant decrease after compared with before the experiment ($p < 0.01$). In the thinned condition, a similar decrease in T-A, D, A-H, and C mean scores was observed ($p < 0.05$) and a decreasing trend was observed in F ($p < 0.1$). These results suggest that the respondents' mood improved and they felt restored by being in the forest environment during the experiment, irrespective of thinning. Importantly, this finding has not been reported in other research to date.

Regarding negative and positive emotion (PANAS), we did not observe any significant relationship in the interaction, the main effect, or in the multiple comparison tests, indicating that neither the thinning (unthinned–thinned) nor the forest stay (pre–post) had a direct effect on respondents' emotions. This is consistent with the results of previous studies, including that of Takayama et al. (2014b).

In this study, we conducted slight thinning to decrease the forest density by 16.6% and the total basal area by approximately 9.3% (Fig. 2 and Table 2). Appreciation of the forest environment did not differ significantly depending on whether the forest was thinned or unthinned. However, we observed a significant difference (or a trend) in some of the indicators (bright–dark, dry–wet, gentle lighting–too bright, dull–refreshing, thin–thick), and as already discussed, it seems that this was because of the influence of the weather conditions during the experiments (Table 1).

In contrast, in the analysis of appreciation for the environment, the thin–thick indicator showed a trend: thinned (3.33) was evaluated as more deserted than unthinned (4.00). Moreover, because the physical changes due to the thinning and the appreciation corresponded, as a decrease in tree density and the total basal area of the thinned condition was recognized, we suggest the possibility that the thinned forest strengthened the impression of the forest environment being deserted.

For the restorative properties of the forest environment, there was no significant difference between the thinned and the unthinned environment for any of the indicators related to the restorative properties (being away, fascination, coherence, scope, and compatibility).

In general, the above results suggest that slight thinning, as executed in this study, does not affect appreciation of the environment and its restorative properties, except for a few indices. A few studies (e.g., Gifu Prefectural Research Institute for Forests 2004 and Oku 2007) have reported an increase in the psychological restorative effect and a general improvement in respondents' impressions with increased thinning. However, our result shows that this does not always apply to all factors. In other words, even with thinning of the somewhat managed forest, the relaxation effect (including the psychological restorative effect) will not

Table 10 Results of multiple comparison tests between before and after thinning (setting) and pre–post (exposure to the forest) for Positive and Negative Affect Scale (emotion)

	Unthinned					Thinned				
	Pre		Post		*p*	Pre		Post		*p*
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Negative	12.4	±4.82	11.0	±4.61	0.252	13.0	±5.21	12.5	±4.02	0.701
Positive	23.5	±8.58	20.5	±9.49	0.174	23.9	±7.26	21.9	±7.43	0.336
	Pre					Post				
	Unthinned		Thinned		*p*	Unthinned		Thinned		*p*
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Negative	12.4	±4.82	13.0	±5.21	0.658	11.0	±4.61	12.5	±4.02	0.263
Positive	23.5	±8.58	23.9	±7.26	0.806	20.5	±9.49	21.9	±7.43	0.484

ANOVA-Bonferroni

Table 11 Results of two-way repeated measures ANOVA for Restorative Outcome Scale (subjective restorativeness)

ROS	Main effect							Interaction		
	Condition Unthinned vs. thinned			Time Pre vs. post				Condition × time		
	F	*p*	η^2	*F*	*p*		η^2	*F*	*p*	η^2
	0.05	0.829	0.001	5.94	0.021	*	0.111	1.35	0.255	0.002

*two-way repeated measures ANOVA

necessarily increase. This is an important finding that has not been reported in other papers on this topic (e.g., Ribe (1989); Ryan (2005); Ribe (2009); Schroeder and Green (1985); Gundersen and Frivoid (2011); Tyrväinen et al. (2014a)). Explanations for this observation include (1) the experimental plot, i.e., the experimental area of this study was a forest in which the density and undergrowth were already moderately managed before the experiment, and (2) the slight thinning enforced in this experiment did not reach the threshold value to make a difference in the appreciation of the forest environment and its restorative properties. To manage forests that have been only partially managed previously and have already gained a certain level of positive evaluation, it might be possible to carry out a continuous evaluation by repeated slight thinning with minimal effort.

Landscape appreciation and psychological restorative effect

Considering the relationship between landscape appreciation (appreciation for and restorative properties of the environment) and its psychological restorative effect, there was a main effect (or trend) for the thinned compared with the unthinned forest (Table 8).

We do not discuss confusion further here, as it was considered to be influenced by the presence or absence of the experimental experience rather than the influence of thinning, as discussed previously. In contrast, improving the forest environment by thinning seemed to reduce the tension and anxiety of the respondents. However, its effect on appreciation for the forest environment was confirmed as a trend that was probably due to a difference in the thickness ($p < 0.1$) attribute and was actually rated higher in the thinned than the unthinned condition (Table 5).

In an attempt to aggregate the above discussion, at first sight it seems that thinning can improve respondents' appreciation of the forest environment, resulting in the reduction of tension and anxiety (main effect; $p < 0.1$; Table 7). However, looking at the results of the multiple comparison tests (Table 8), although a significant difference was observed in the comparison of average scores regarding the presence or absence of thinning before the experiment, no such difference was observed after the experiment. Thus, the forest seems to reduce tension and anxiety more than confusion, regardless of thinning.

Thinning and psychological restorative effect

Following thinning, the physical indicators of management in the experimental area, such as tree density and total basal area, were reliably reduced. However, with respect to the psychological restorative effect, it was directly confirmed that there was almost no indicator influenced by thinning. In other words, there seemed to be no effect on any of the mood indices (T-A, D, A-H, V, F, C), emotion (negative and positive affect), or restorative feeling, although a restorative effect seemed to be confirmed in some indicators after spending a certain period of time in the forest environment. Therefore, the difference in the psychological restorative effect may be a result of the precondition in which the original research plot was to some extent managed already as an artificial forest, or by the control condition in which weaker thinning was carried out in this study.

Based on the above discussion, and assuming the response system (stimulus → appreciation → response) according to Lazarus's stress model (Kosugi et al. 2002), we could suggest that the change in the external environment influenced the environmental appreciation of "deserted-dense" (Table 5). Finally, the result of this appraisal (greater appreciation for deserted) did not have a restorative psychological effect. In other words,

Table 12 Results of multiple comparison tests between before and after thinning (setting) and pre–post (exposure to the forest) for Restorative Outcome Scale (subjective restorativeness)

Unthinned						Thinned				
Pre		Post		*p*		Pre		Post		*p*
Mean	S.D.	Mean	S.D.			Mean	S.D.	Mean	S.D.	
25.73	±3.22	29.53	±4.37	0.001	**	26.60	±3.64	28.27	±4.50	0.110
Pre						Post				
Unthinned		Thinned		*p*		Unthinned		Thinned		*p*
Mean	S.D.	Mean	S.D.			Mean	S.D.	Mean	S.D.	
25.73	±3.22	26.60	±3.64	0.353		29.53	±4.37	28.27	±4.50	0.178

**$p < 0.01$, ANOVA-Bonferroni

conducting weaker thinning of a moderately managed forest for recreational use, as in this study, could enhance the appreciation of the forest by decreasing the tree density; nevertheless, the results also imply that there may be no psychological restorative effect of staying in a forest.

Conclusions

The results of this study indicate that when performing thinning in a forest located in a summer resort spot near the city used primarily for forest recreation and forest bathing, approximately half the amount (15 to 20%) of standard thinning (30 to 40%) in forestry regions was sufficient to accomplish the management of the forest without changing the user's appreciation and the restorative effect.

In general, managing the density of trees, the design of paths, installation of facilities such as billboards and arbors, and management plans that secure all of these aspects are potential challenges to enhancing the physical and mental restorative effect of the forest. However, because the forest environment itself is composed of a variety of flora and fauna, and facilities age quickly, it is essential to consider the cost of constructing these facilities (which must be new) and maintaining the diversity of animals and plants, which is the infrastructure of the forest. For example, if we need to implement a forest management method that involves reducing the tree density by at least 16–17% and the total basal area by 9–10%, the removal of primarily small-diameter and suppressed trees will achieve this while maintaining the forest's mental and physical restorative effects and, at the same time, reducing management costs. Thus, we can propose to develop a rational and sustainable management method that protects large-diameter trees to ensure future management funds.

Summary

The following three points summarize the main findings of the study:

- The evaluation of the restorative effects of the forest environment did not change after the slight thinning of the urban forest that had been maintained to some extent, except for some impression evaluations.
- The weak thinning of the suburban forest had less of an effect on impression evaluations than did the effect of the weather conditions during the experimental period.
- The psychological restorative effects of the lightly maintained suburban forest were not always improved by weak thinning.

Limitations

Because the present study involved conducting two experiments in different forest conditions (thinned and unthinned) with the same respondents, we selected 15 people who could participate in both conditions. Similar to other psychological experiments conducted on-site (e.g., Oishi et al. 2003; Park et al. 2009; Tsunetsugu et al. 2010; Park et al. 2010; Horiuchi et al. 2014), this study could be considered as an empirical case study conducted with a no-function condition because the respondents were the same in both experiments. However, the number of respondents used to obtain the results was relatively small, and the properties of the forest environment varied depending on the climatic zones, biota, and management conditions of each region. Therefore, we must be sufficiently cautious in generalizing the knowledge gained through this experiment. We strived to carry out the two experiments in May and October under similar conditions except for the thinning; nevertheless, strict control of some conditions, such as the weather and season-specific flora and fauna, was not possible. Moreover, the experiments were carried out while the respondents were relaxing on a chair in the forest, but we must acknowledge that other activities, such as taking a leisurely stroll, are also common in a forest. Thus, we need to perform further experiments to understand the effects of thinning while performing other activities such as strolling. In addition, the respondents who participated in this research were graduate students or faculty members in forest science, which means there is a possibility that the results of this experiment might not apply to general forest users. Lastly, the difficulty of controlling weather conditions is a critical problem for on-site experiments. For strict control, it would be necessary to use a climate-controlled room with pre-determined weather conditions.

Future research

To generalize the results of this study, additional research is necessary, including experiments and laboratory tests using videos and photos as well as a greater range of respondents. Furthermore, we found that thinning improved the impression of the forest environment, as measured by an improvement in some indicators of mood. This aspect can be understood through theories such as Appleton's (1996) prospect-refuge theory, which posits that one's fear of the natural environment can be mitigated. Thus, to make forests comfortable spaces for recreation and mental restorative purposes, it is important for forest managers to gather additional information concerning the relationship between the prospect of a forest and a sense of fear, insecurity, or nervousness of the forest environment; however, this type of empirical research is not yet common.

In this study, the psychological restorative effect of forests was not increased by thinning. However, as Appleton (1996) states in his "prospect-refuge theory," a good prospect environment in which one can observe while remaining unseen by others is a necessary condition for peace of mind; hence, higher psychological and physical restorative effects may be expected when dense forests are thinned more than they were in this study. It is important to conduct additional experiments to assess users of the forest and its restorative effects. For example, an additional experiment could compare two forest environments of the same type, one unmanaged and natural and the other a maintained forest used for recreation or forest bathing.

Abbreviations
PANAS: Positive and Negative Affect Schedule; POMS: Profile of Mood States; PRS: Perceived Restorativeness Scale; ROS: Restorative Outcome Scale; SD: Semantic Differential

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Authors' contributions
NT, MH, HS, and AF contributed to the conception and design of the study, performed the experiments, analyzed the data, and prepared the figures and tables. NT, HS, and AF interpreted the results of the experiment; MH and HS obtained the grants for the study. NT wrote the first draft and all authors revised the manuscript. All authors approved the final version of the manuscript.

Competing interests
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