Short-term changes of leaf area index, light transmission, and gap in a temperate mixed deciduous forest ecosystem in Bartın, Turkey

İLYAS BOLAT

ÖMER KARA

MELİH ÖZTÜRK

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İlyas BOLAT[1,*], Ömer KARA[2], Melih ÖZTÜRK[3]

[1]Department of Forest Engineering, Division of Soil Science and Ecology, Faculty of Forestry, Bartın University, Bartın, Turkey
[2]Department of Forest Engineering, Division of Watershed Management, Faculty of Forestry,
Karadeniz Technical University, Trabzon, Turkey
[3]Department of Landscape Architecture, Division of Landscape Techniques, Faculty of Forestry, Bartın University, Bartın, Turkey

Abstract: In this study, leaf area index (LAI), light transmission, and gap were estimated by using the hemispherical photograph analysis technique with Hemisfer software version 1.5.3 for a temperate mixed deciduous forest. The height of the overall vegetation in the stand ranged from 15 to 20 m, and the diameters of the trees in the stand at breast height varied between 14 and 28 cm. This study showed that the mean value of LAI increased by 4% in the 5-year period from 2007 to 2012. LAI was significantly ($P < 0.05$) greater in 2012 than in 2007, whereas the mean percentage of light transmission was significantly lower in 2012 than it was in 2007. In addition, there was a significant ($P < 0.01$) correlation between LAI and light transmission, and there was also a statistically significant correlation between the gap and light transmission ($P < 0.05$). According to long-term meteorological data (1982–2012), this study also demonstrated that the mean air temperature rose approximately 1.0 °C between 2007 and 2012. Consequently, this study indicated that LAI varies with respect to time and the increase of LAI leads to a decrease in light transmission. Additionally, the air temperature and precipitation have a significant influence on the LAI.

Key words: Climate change, environmental factors, gap, light transmission, productivity of forest, soil

1. Introduction

Leaf area index (LAI), defined as one-half of the total green leaf area (m²) per unit ground surface area (m²) (Chen and Black, 1992), affects several significant ecosystem processes, such as evapotranspiration, photosynthesis, interception, rainfall, surface albedo, and dry deposition. Therefore, it is a considerable structural characteristic of the forest ecosystem since these processes are greatly affected by the amount of leaf area, quantified as LAI (Maass et al., 1995; Buermann et al., 2001; Schleppi et al., 2007; Bonan, 2008). LAI is also firmly linked with litterfall, microclimate, and productivity (Gower et al., 1999), and it is strongly affected by climate, the fertility of the soil, the availability of water, and tree density and species (Gholz, 1982; Gower et al., 1995; Bond-Lamberty et al., 2002). When the LAI is low, plants absorb less solar radiation, and the overall surface albedo is largely that of the soil. The absorption of radiation increases with greater LAI values, and surface albedo responds more to the optical properties of foliage rather than soil (Buermann et al., 2001; Bonan, 2008).

Light energy directly drives many fundamental plant and biophysical processes (photosynthesis, stomatal conductance, transpiration, and temperature of the leaves) (Baldocchi and Collineau, 1994). The structure of the forest canopy, topographic position, weather, type and distribution of clouds, and seasonal and diurnal variations in the sun's position largely determine the light regimes in a forest's understory (Canham, 1988; Rich et al., 1993). It is difficult to quantify the light environment in a plant canopy since the environment displays significant spatial and temporal variability. This variability is associated with structural and environmental heterogeneity on a variety of space and time scales. Therefore, the pattern of light transmission is affected by various factors, such as the spatial organization of the overstory's stems, branches, and foliage, and the height and depth of structure of canopy (Baldocchi and Collineau, 1994; Beaudet and Messier, 2002).

Gap fraction refers to the percentage of sky seen from beneath the canopy, whereas gap size is defined as the dimensions of a gap. For the same gap fraction, there can

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* Correspondence: ilyasbolat@bartin.edu.tr

be different distributions of gap sizes (Chen et al., 1997). Small spaces in forest canopies (i.e. canopy gaps) form as a result of canopy level disturbances caused by the death of an individual tree or a small cluster of trees (Clinton, 2003). It has been reported in the literature that canopy gaps modify the resources required for plant growth, such as light, water, and soil nutrients (Canham and Marks, 1985; De Freitas and Enright, 1995; Promis et al., 2009). For example, the availability of light for the understory's plants in a forest ecosystem can be increased suddenly by these openings. Such events must be taken into account, because they are necessary for the further growth of tree seedlings and thus for the generation of forests. These events also promote the rapid growth of plants, giving them competitive advantages over neighboring plants (Kursar and Coley, 1999; Oguchi et al., 2006).

Therefore, knowledge about LAI, light transmission, and canopy gaps and their influence on the stand are of great importance for understanding the growth and generation processes in forest ecosystems. This study had four objectives: 1) to determine the short-term change of LAI; 2) to exhibit the effect of the air temperature and precipitation on the LAI; 3) to establish the short-term change of light transmission and gap; and 4) to determine the relationships among LAI, light transmission, and gap in the mixed forest ecosystem in Bartın, Turkey, between the years 2007 and 2012.

2. Materials and methods

2.1. Study area
The study area is within the Bartın watershed in northwestern Turkey (41°38′N, 32°20′E), and it covers an area of approximately 3.7 ha. The elevation of the forest land is approximately 100 m and the average slope is 55%, with a north-northeast aspect (Figure 1) (TGDF, 2011). According to the Thornthwaite method (Thornthwaite, 1948), the study area has a humid, mesothermal climate with little or no deficiency of water, and it was characterized as being similar to oceanic climate conditions (B2B1′rb4'). Based on climatological data from the past 31 years (TSMS, 2012), the mean annual temperature in the study area was 12.6 °C and the mean annual precipitation was 1045.6 mm, with about 35% of the rainfall occurring in the growing season between May and September. The mean temperature of the coldest month (January) was 4.1 °C, and the mean temperature of the hottest month (July) was 22.3 °C. Both young and mature European hornbeams (*Carpinus betulus* L.), oaks (*Quercus petraea* (Matt.) Liebl.), and oriental beeches (*Fagus orientalis* Lipsky) exist at the study site constituting a mixed forest (i.e. GnMKn). The overall height of the vegetation varies between 15 and 20 m, whereas the diameters of the trees at breast height range between 14 and 28 cm. The tree ages vary between

50 and 60 years with an average of about 55 years. The percentage of closure of the canopy ranges between 70% and 100% (TGDF, 2011).

2.2. Canopy leaf area
The hemispherical photographing technique is a common methodology that is used by many researchers to determine the light transmission of forests (Dignan and Bren, 2003; Promis et al., 2009). The principle of the methodology depends upon the calculation of the percentage of light transmission through the canopy gaps. Consequently, it is based on distinguishing the sky from vegetation in photographs taken in the upwards direction from the floor of the forest (Schleppi et al., 2007). The study was performed in July of 2007 and July of 2012. In total, 60 hemispherical photographs were taken systematically from the ten sites using a Sigma 8-mm fisheye lens mounted on a Canon EOS 5D digital SLR camera in 2007 and 2012 years (Figure 1). For the calculation of LAI, light transmission, and canopy gaps the digital photographs that were taken were analyzed using the hemispherical photograph analysis technique with Hemisfer software version 1.5.3 (Swiss Federal Institute for Forest, Snow, and Landscape Research (Schleppi et al., 2007)). During the analyses of the digital photographs, automatic thresholding, based on the study of Nobis and Hunziker (2005), was used. Lang's method (1987) was applied for the analysis of the LAI. Parts of the trees other than the leaves, such as stems and branches, influence the values of LAI, so corrections recommended by Schleppi et al. (2007) for nonlinearity and slope and by Chen and Cihlar (1995) for the clumping effect were integrated into the calculations. The exact dates and times of the photographs were determined taking weather conditions into account, e.g., photographs were not taken when it was raining or snowing or when there was direct sunlight. Therefore, during the analysis of the photographs, errors arose from the colors that were avoided.

2.3. Sampling and analyses of soils
Soil samples were collected from the same sites where the hemispherical photographs were taken with a metal cylinder that had a diameter and a length of 8.1 and 6.5 cm, respectively. Samples were then transferred into labeled plastic bags. In total, 20 soil samples were taken to the laboratory for analysis. After all of the samples were air-dried, plant and root residues and stones were removed. The remaining soil samples were then ground, passed through a 2-mm sieve, and prepared for analysis. The hydrometer method was used to calculate the particle-size distribution of the soil (Bouyoucos, 1962). The pH of the soil in a 1:2.5 soil:water suspension was measured using a pH meter, while the electrical conductivity of the soil was determined with an electrical conductivity meter using a 1:5 soil:water extract. The organic carbon content
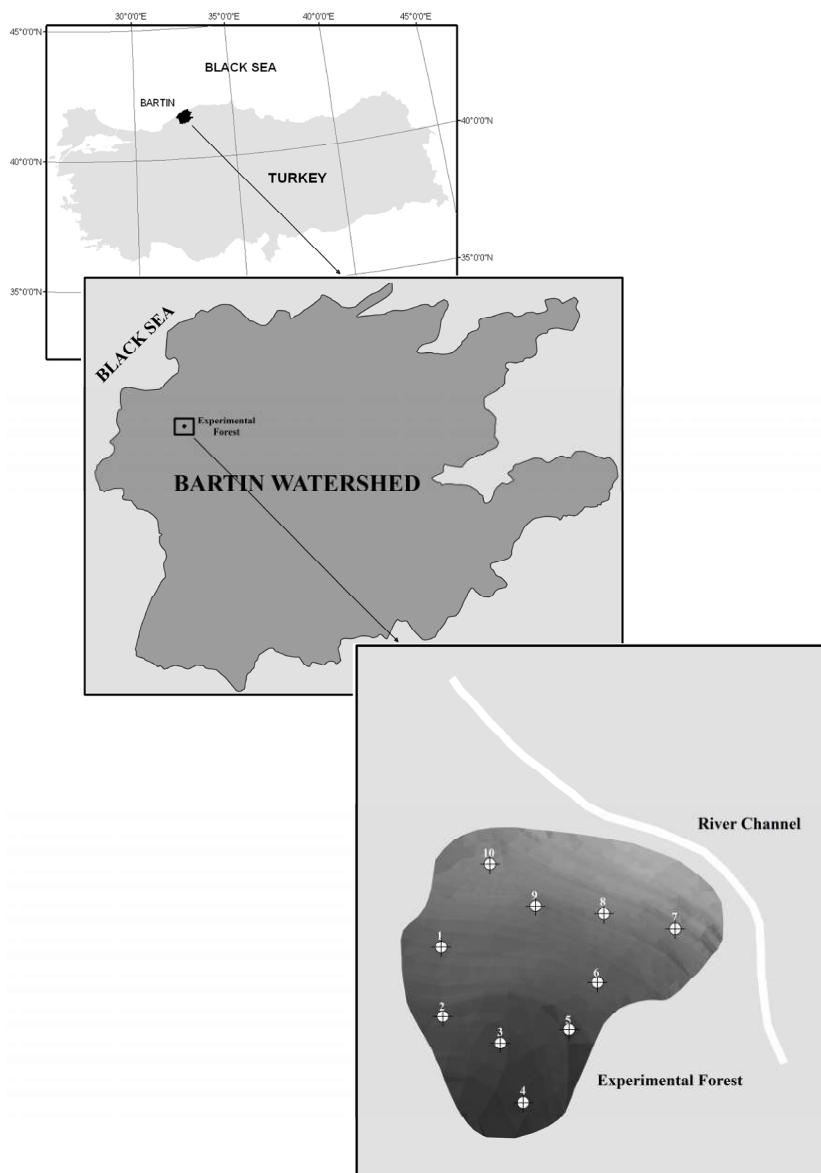
Figure 1. Study area within Bartın watershed, Turkey.

of the soil was estimated using potassium dichromate oxidation, and the total nitrogen content was determined using Kjeldahl digestion (Rowell, 1994). The bulk density of the soil (g cm^{-3}) was calculated using mass and volume (Blake and Hartge, 1986). The particle density of the soils (g cm^{-3}) was measured using the pycnometer method, and the pore space was calculated using the bulk and particle densities (Brady, 1990).

2.4. Statistical analysis

The data presented are the means of two replicates, and they are expressed on an oven-dried weight basis. SPSS 16.00 was used for evaluation of the data that were obtained in the study. The LAI data, physical characteristics data, and chemical characteristics data were subjected to paired-

samples t-tests to determine the significant differences between the forest's conditions in 2007 and 2012. A 95% confidence limit (P < 0.05) was chosen to indicate significant differences between samples. A correlation analysis was used to examine the relationships among LAI, air temperature, precipitation, gap, and light transmission.

3. Results and discussion

3.1. Soil characteristics

Except for the percentage of clay content and the C_{org}/N_{total} ratio of the soils, there were no significant differences (n = 20, P > 0.05) in the physical and chemical properties of the soils between 2007 and 2012 (Table). The properties of the soil samples were almost the same for 2007 and 2012. On

Table. Physical and chemical properties of soils (0–6.5 cm depth).

Soil properties	2007	2012
Bulk density (g cm^{-3})	0.96 (±0.11) [a]	1.02 (±0.09) [a]
Pore space (%)	59.70 (±4.08) [a]	59.50 (±3.46) [a]
Particle density (g cm^{-3})	2.51 (±0.02) [a]	2.51 (±0.08) [a]
Sand (%)	22.25 (±3.83) [a]	21.81 (±4.67) [a]
Clay (%)	39.20 (±13.93) [a]	59.60 (±8.54) [b]
Organic C (%)	4.14 (±0.21) [a]	3.47 (±0.92) [a]
Total N (%)	0.31 (±0.02) [a]	0.35 (±0.06) [a]
Soil pH (H$_2$O)	5.19 (±0.39) [a]	5.60 (±0.75) [a]
Electrical conductivity (dS m^{-1})	0.08 (±0.02) [a]	0.10 (±0.05) [a]
C$_{org}$/N$_{total}$ ratio	13.41 (±1.06) [a]	9.62 (±1.21) [b]

Values in the same row followed by different letters indicate a significant difference (P < 0.05) between 2007 and 2012 (paired samples t-test).
Values represent the means of 20 samples (±SD).

the other hand, the percentage of clay content was higher in 2012 (59.60 ± 8.54%) than it was in 2007 (39.20 ± 13.93%). The soil C$_{org}$/N$_{total}$ ratio of the soil was greater in 2007 (13.41 ± 1.06) than it was in 2012 (9.62 ± 1.21). High C$_{org}$/N$_{total}$ ratios (>20) in forest ecosystems result from the poor mineralization of N and C, while low C$_{org}$/N$_{total}$ ratios (<20) occur as the result of intensive carbon mineralization and the rapid breakdown of nitrogen-containing compounds (Zeller et al., 2000).

3.2. Short-term changes of LAI, light transmission, and gap

The LAI values of the stand ranged from 2.04 to 2.90 m^2 m^{-2} in 2007 and from 2.06 to 2.95 m^2 m^{-2} in 2012. The mean value of LAI increased from 2007 (2.40 ± 0.25 m^2 m^{-2}) to 2012 (2.50 ± 0.33 m^2 m^{-2}), and this increase was significant (P < 0.05), as shown in Figures 2a and 2b. In this study, both temperature and precipitation increased evidently (Figures 3a and b), which prolonged the growing seasons and thus may have increased the mean LAI. This increase in LAI could also point out increases in primary productivity, biomass, and other biophysical properties in the forest ecosystem. It was stated in some studies (e.g., Bonan, 2008; Meier and Leuschner, 2008; Öztürk et al., 2015) that air temperature is effective on leaf area and LAI development. It was also reported in the literature that there was a positive relationship between precipitation or soil water availability and LAI in mature stands (Bequet et al., 2012). Similarly, Buermann et al. (2001) concluded that reductions in precipitation and temperatures during the summer affected the LAI's interannual variation. In this study, it was found that the mean air temperature between 1982 and 2007 was 12.5 °C, whereas the mean air temperature between 2008 and 2012 was 13.6 °C

(Figure 3a). There were statistically significant (P < 0.05) differences between 1982–2007 and 2008–2012 in terms of the mean air temperature. Furthermore, the mean LAI showed strong positive (r = 0.96, P < 0.01) correlations both with the mean air temperature and precipitation. Although no statistically significant differences were found in the mean precipitation between 1982–2007 (1031.5 mm) and 2008–2012 (1053.5 mm), a slight increase in the mean precipitation between 2008 and 2012 was observed
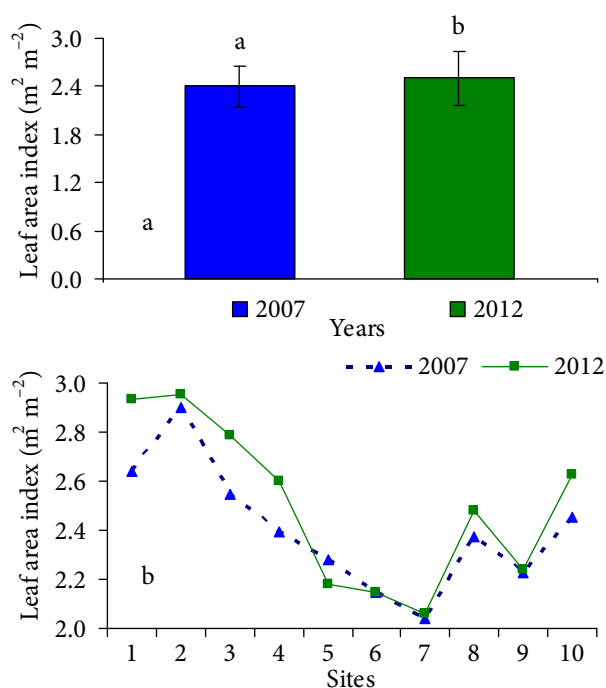

Figure 2. Variation in the leaf area index of different years (a and b).
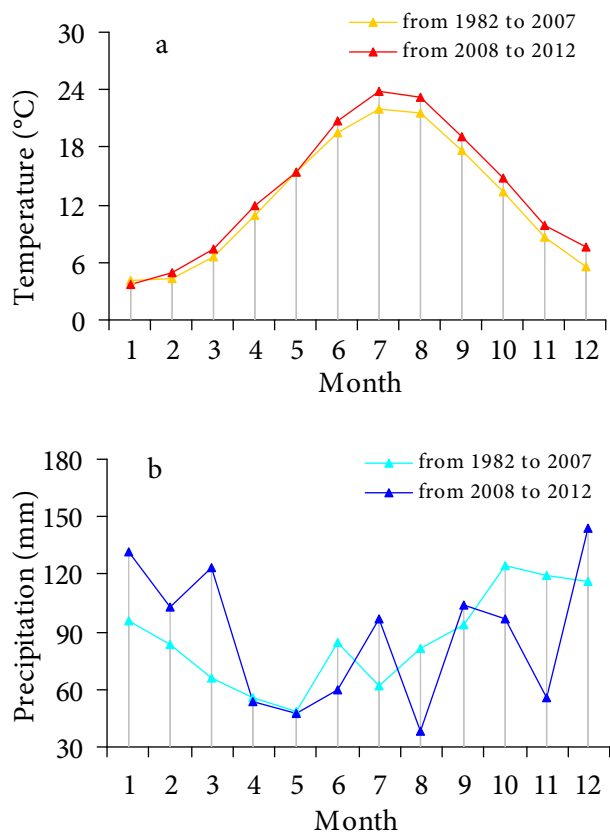
Figure 3. Changes of temperature (°C) (a) and precipitation (mm) (b) between 1982–2007 and 2008–2012.

(Figure 3b). The initial sequence of stand development can be extended to another generation of trees. The literature indicates that LAI and other properties, such as decomposition rates and water use in the stand, may remain stable from one generation to another if the replacement process occurs slowly (Waring and Running, 2007).

Breda and Granier (1996) reported that a high LAI is an indication of the high fertility of the site and the optimal health and productivity of the stand. The literature also indicates that LAI is a particularly important characteristic of an ecosystem, because it is a direct measure of the photosynthetically active surface area that can convert light energy into plant biomass. Therefore, it should not be surprising that there are strong relationships between LAI, climate, soil, biomass, and productivity in many terrestrial ecosystems (Grier and Running, 1977; Barnes et al., 1998; Jensen, 2002). Depending on site conditions, and especially water supply, soil fertility, and nutrients, the LAI changes and increases within ecosystems. Hence, LAI varies significantly among ecosystems, ranging from less than 1 m^2 m^{-2} in arid ecosystems to 20 and as high as 23 m^2 m^{-2} in western juniper ecosystems (Maass et al., 1995; Perry

et al., 2008). A typical LAI for a productive forest is 4–6 m^2 m^{-2} (Bonan, 2008). Barnes et al. (1998) reported that LAI values have been determined for a wide range of temperate forest ecosystems; they are typically greater than 5 m^2 m^{-2} during most of the growing season in deciduous forests or during all of the growing season in coniferous forests. Those values are greater than the LAI values obtained in our study. Some authors indicated that the LAI varies from 0.5 to 8 m^2 m^{-2} in temperate deciduous forests (Le Dantec et al., 2000) and from 5.6 to 9.5 m^2 m^{-2} in European beech stands (Leuschner et al., 2006). These differences could be due to the type and age of the stand and the availability of water in the soil, which is determined by climate and the properties of the soil. Previous studies have confirmed this assertion (Breda and Granier, 1996; Leuschner et al., 2006).

Maximum and minimum percentages of light transmission in the stand varied from 12.40% to 21.40% in 2007 and from 10.78% to 20.13% in 2012. The mean percentage of light transmission (16.38 ± 3.73%) in 2012 was significantly lower than the percentage of light transmission (18.26 ± 2.77%) in 2007 (P < 0.05) (Figure 4a). Canham et al. (1990) reported that light transmission values range from 0.3% to 3.8% for a northern hardwood site dominated by a uniform canopy of sugar maple and beech. Baldocchi and Collineau (1994) stated that, in some cases, 9% to 25% of incoming sunlight penetrates to the floor of a fully leafed deciduous forest at midday in temperate
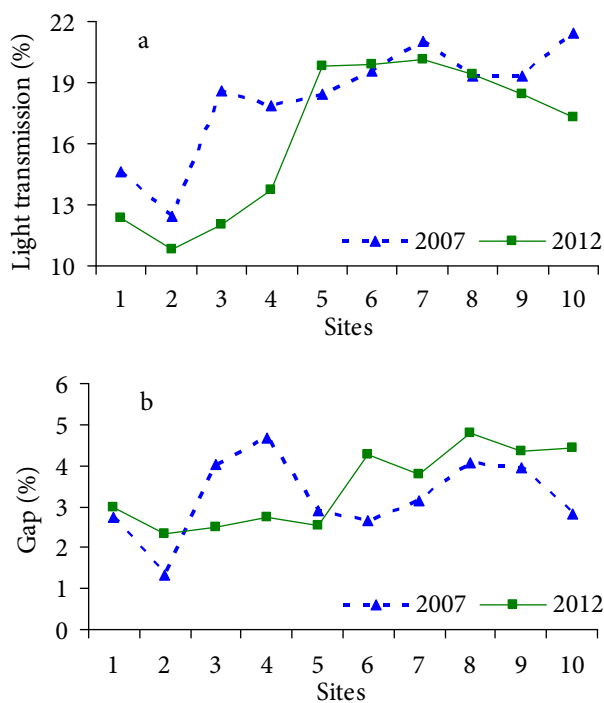

Figure 4. Variation in the light transmission (a) and gap (b) of different years.

broadleaf forests. Beaudet and Messier (2002) reported that plot-level mean light transmission varied from about 11% to 17% among the cuts and from 6.5% to 9.2% among the controls, while microsite-level light transmission ranged from 3.1% to 37.2% in the cuts and from 3.0% to 16.5% in the controls. Differences in the results could be due to structural and environmental heterogeneity on a variety of space and time scales, because several factors, such as tree species, branches, foliage, and canopy structure, influence light transmission. Several authors have implied that the structure of the forest canopy facilitates the transmission of light to leaves that are lower in the canopy (Baldocchi and Collineau, 1994; Hardy et al., 2004; Perry et al., 2008). In addition, hemispherical photography, similarly to methods based on the measurement of light transmission and gap fraction, is affected by ambient light conditions and is especially affected by the presence of the sun and clouds. This considerably limits the use of these methods across sites in large-scale studies (Schleppi et al., 2011).

Gap percentages in 2007 and 2012 in the stand were 1.34%–4.67% and 2.32%–4.78%, respectively. There was no obvious difference (P > 0.05) in the mean gap percentage between 2007 (3.23 ± 0.96%) and 2012 (3.46 ± 0.94%) (Figure 4b). The gap is, quite literally, a physical opening in the canopy that allows light to reach seedlings in the forest understory, but it is also an opening in the social fabric. In addition, most tree species require gaps in order to reach maturity (Perry et al., 2008). Trichon et al. (1998) reported that microsite-level canopy openness values range from 1.4% to 5.1% for building forests and mature phase forests and from 7.6% to 28.8% in gap-phase forests in a tropical rainforest in Sumatra. Frazer et al. (2000) observed stand-level mean canopy openness (gaps) ranging from 2.2% to 14.1% for immature, mature, and old-growth Douglas-fir - western hemlock - western red cedar forests on Vancouver Island. Beaudet and Messier (2002) indicated that the mean canopy openness varied from 7.9% to 12.1% among the cuts and from 4.5% to 6.2% among the controls. Those values are greater than the gap values obtained in our study. The differences could be due to the fact that gaps in a stand are influenced by several factors, such as tree species, canopy structure, applied silvicultural interventions, and the presence of the sun and clouds. Since gaps in the forest canopy are natural spacing irregularities formed by fires, wind, insect damage, and tree mortality, the gaps generated by the fall of one or more canopy trees are major factors that influence the structure of tropical, temperature, and boreal forests (Mariscal et al., 2004; Perry et al., 2008). A valuable alternative for the accurate quantification of canopy structure can be accomplished by analysis based on digital hemispherical photography, because the parameters of the canopy's structure (such as gap fraction and canopy cover) can be extracted from the photographs (Jonckheere

et al., 2005). The structure of the forest's canopy (trees and gaps) strongly affects the interception and transmittance of solar radiation, and it changes with space and time, and depending on the species of trees, the sizes and locations of gaps in the canopy, and the angle of solar incidence (Hardy et al., 2004; Perry et al., 2008). The literature indicates that while the presence of gaps may increase the penetration of diffuse light into the lower canopy (Mariscal et al., 2004), more solar radiation is absorbed or reflected and less is transmitted deeper into the canopy as the canopy becomes denser with leaves (Bonan, 2008).

3.3. The relationships among LAI, light transmission, and gap

In the current study, there was a significant correlation (r = –0.883, P < 0.01) between LAI and light transmission (Figure 5a), but there was no correlation (r = –0.406, P = 0.07 > 0.05) between LAI and gap (Figure 5b). Schleppi et
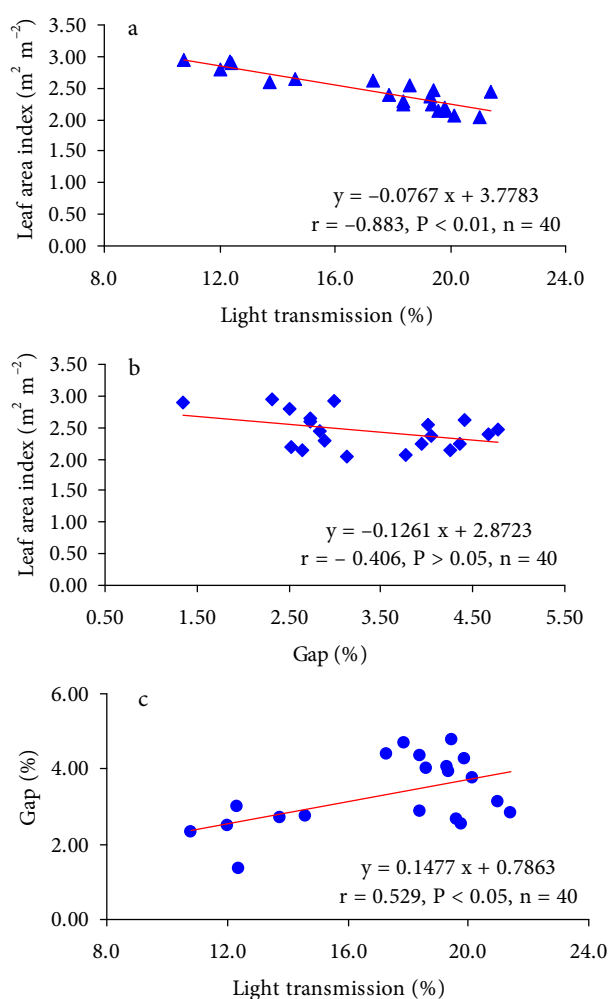

Figure 5. The relations between leaf area index and light transmission (a), leaf area index and gap (b), and gap and light transmission (c) determined for 2007 and 2012.

al. (2011) found that the LAI has a negative correlation with the light index of the ground vegetation. They explained this situation as a shading effect, because the availability of light for the ground vegetation is restricted by a denser tree canopy. It is well known that understory light availability decreases as overstory density increases (Newsome et al., 2010). Other studies also have indicated that there is a converse relationship between the amount of light that reaches the understory and canopy closure, and light index is often well correlated with other biotic and abiotic factors (Grant, 1997; Drever and Lertzman, 2003). The correlation between light transmission and the gap (Figure 5c) was statistically significant and positive (r = 0.529, P < 0.05) in this study. Some authors have demonstrated that variability in the light levels in the understory increases with the partial removal of the overstory (Coates et al., 2003; Beaudet et al., 2011). Our findings are consistent with those of various authors (e.g., Mariscal et al., 2004; Perry et al., 2008) who have reported that the structure of the forest canopy facilitates the transmission of light to leaves that are lower in the canopy.

The causes of the spatial and temporal dynamics of the LAI are canopy closure and stand development (crown expansion). Canopy closure and stand development proceed depending upon the conditions of the habitat. An increment in the canopy closure leads to a decrease in the penetration of light beneath that canopy. Thus, the decrease in light transmission is an indicator for the increment of the canopy closure. Although the increase in the LAI can be influenced by many factors, it mostly changes according to habitat quality (availability of soil nutrients, precipitation, and appropriate temperatures) and shade tolerance. As indicated in this study, the overall LAI increased 4% from 2007 to 2012. In addition, there was a statistical difference between 2007 and 2012. Since there were almost no definite changes in the soil characteristics except for the percentage of clay content and the C_{org}/N_{total} ratio (decomposition rate), the growth rate of the trees due to genetic and environmental factors (especially temperature and precipitation) can be declared as the cause for the change in the LAI. These LAI results are significant indicators of the closure, health, and productivity of the forest's vegetation. Therefore, LAI values can be evaluated as a parameter in monitoring the biomass productivity in future studies. In addition, LAI values may be used in the calculation of the carbon budget. On the other hand, the increasing of air temperature by about 1 °C can be an indicator of predicting climate change.

Acknowledgments

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