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Research Article

Comparing Canopy Metric Estimations Using Three Conifer Species in the Netherlands

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ABSTRACT

A growing concern associated with fire in The Netherlands is estimating the spread of wildfire; however, often the data needed to estimate canopy fires are lacking. The primary parameter required is canopy bulk density (CBD), which requires estimations of canopy gap fraction and leaf area index (LAI). The accuracy of three indirect methods of estimating CBD (a densiometer, hemispherical canopy photographs (HCP), and a LI-COR LAI 2200c plant canopy analyzer) was compared for three common tree species in the Netherlands [Scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arnold) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)]. No differences between species were found for CBD, but the denser canopies in the Douglas-fir stands did have significantly lower gap fractions than the two pine species. The HCP method produced higher gap fraction estimates than the other two methods, but fell within reported ranges. LAI derived from HCP was the only variable that correlated significantly to CBD, although this correlation was not strong (R=0.53).

Keywords: Gap fraction; Leaf area index; Canopy bulk density

INTRODUCTION

Wildfires within or adjacent to the Wildland-Urban Interface (WUI) are an important issue in a number of countries. For example, WUI fires have accounted for nine of the 25 largest fire loss incidents in the United States of America's history, ranging from $0.5 - $2.4 billion in direct losses per fire (in 2008 constant dollars, NFPA 2009) and WUI fires continue to cause financial loss to resources and structures. Utilizing knowledge in fire ecology and fire effects research over decades by many authors [1-3] for the creation of fuel loads estimation models [4-7], photo guides for appraising surface fuels [8,9], and fire behavior prediction models including BEHAVE and BEHAVEPLUS [10-12], much about fire behavior and the key variables required to accurately model it has been learned. However, both wildland fire and its potential interaction with WUI communities' remains little studied and present potential for significant loss of human lives and property in many parts of the world today.

In the last decade The Netherlands has begun to examine the behavior of wildland fires across its substantial wildland urban interface (WUI). Wildland fires in 2009 (Schoorl), 2010 (Bergen, Strabrechtse Heide), and 2014 (De Hoge Veluwe National Park) have shown the threat is real, with fires leading in 2014 to evacuations of about 500 people. In many cases the threat comes from canopy (crown) fires, which are inherently more difficult to estimate potential behavior because of the challenges of quantifying canopy fuels [13].

Modelling potential canopy fire behavior requires estimates of canopy fuel loads. Four canopy parameters are required: base height, height, cover, and canopy bulk density (CBD), which is the quantity of canopy fuel/canopy volume and represents how compacted canopy fuels are [13], which are then used in many fire spread models [14]. Various direct and indirect methods have been developed to obtain CBD. Either gap fraction and leaf area index (LAI) can be used to calculate and extrapolate canopy fuel data using a correlation between gap fraction and canopy density. LAI (a unit less measurement of single-sided leaf area per unit ground surface area) is a relatively accurate quantitative measure of canopy foliage [15,16]. Both gap fraction and LAI can be estimated by several methods, including using a spherical densiometer (for gap fraction, but not LAI), LI-COR LAI 2200c plant canopy analyzer (LI-COR Environmental, Lincoln, Nebraska, USA), or a hemispherical canopy photograph (HCP).

When measuring the gap fraction using LI-COR systems, five angles of view are computed by dividing the below-canopy by the

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above-canopy readings. The LI-COR's light sensor includes a filter to limit the spectrum of received radiation to <490 nm, minimizing the effect of light scattered by foliage. Directly illuminated foliage will scatter more light in the canopy than will be calculated, reducing LAI values up to 50% [17,18].

HCP utilizes a fish-eye lens under the canopy that can obtain a measure of canopy structure within a 180-degree projection. Photos are interpreted by classifying pixels into sky or canopy, and then converted into indices using an inversion model based on Beer's Law, using the observed gap fraction distribution throughout the photo [19,20]. Gap fractions are computed from HCP by determining the fraction of exposed sky using software such as HemiView (Delta-T Devices, Cambridge, United Kingdom) canopy analysis software to obtain canopy structure information such as LAI, Gap Fraction and canopy opening distributions.

While these three different non-destructive methods are available to estimate canopy bulk densities (CBD), a comparison of the effectiveness of these methods is lacking. Considering the need to obtain estimates of canopy bulk densities (CBD) of three common tree species in the Netherlands that are subjected to recurring wildfire events, our objective was to compare these indirect, non-destructive methods with the hypothesis that HCP would provide the best correlation with CBD simulated by commonly used software. If successful, our results could provide a recommendation of the most time effective, accurate, non-destructive method of estimating CBD that could easily be converted into data that is enterable into fire prediction software, providing land managers tools to more accurately estimate fire behavior and reduce the potential risk to people and property.

MATERIALS AND METHODS

The species studied were native Scots pine (*Pinus sylvestris* L.) and black pine (*Pinus nigra* Arnold), and the introduced Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Black pine plots were on the island of Texel (Figure 1) and Douglas-fir within the northern portion of the Veluwe area in the province of Gelderland. Scots pine was sampled in two areas: within the southern portion of the Veluwe where it contained a dense understory, and an older stand 111 kilometers to the southwest of the Veluwe in Noord-Brabant where a fire had occurred within the last three years, leaving a sparse understory and midstory.

In four stands, twenty-six randomly 400 m² circular plots were

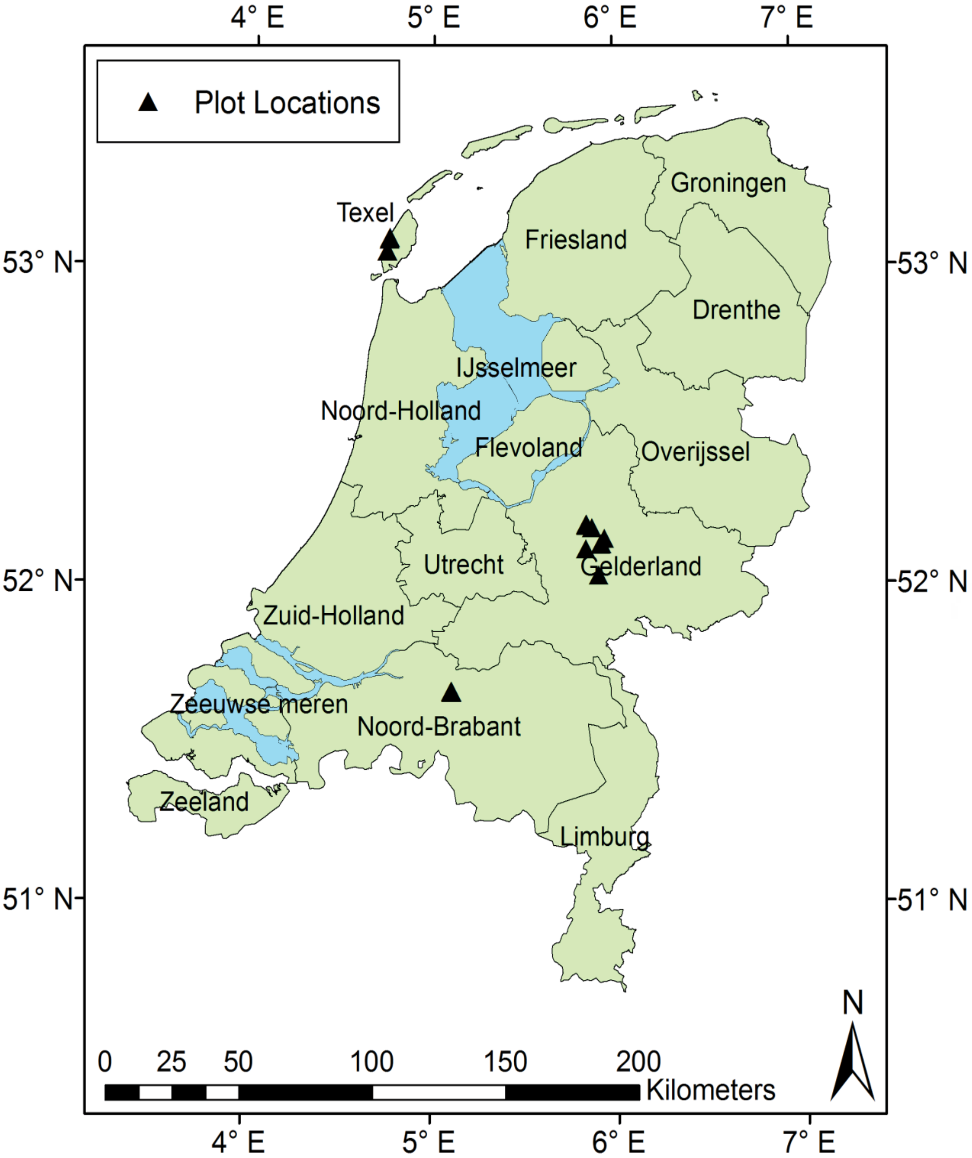

Figure 1: General plot locations utilized for estimating canopy bulk densities of Scots pine, Black pine and Douglas-fir in the Netherlands.

established, and trees taller than 2.0 m were measured for DBH, total height, and height to live crown; the latter two estimated with a clinometer. Along with the data collected utilizing the densiometer, hemispherical canopy photographs (HCP), and a LI-COR LAI 2200c plant canopy analyzer, these data were entered into FEAT/Firemon Integrated (FFI) [21], a commonly used GIS capable software program. FFI integrates FEAT (plot-level ecological and fire ecology assessments (in this case, canopy parameters and gap fractions)) and allows data transfer into the Firemon program to estimate canopy fuels (CBD) within a single software program that effectively provides fuel data for wildland fire managers (https://www.frames.gov/ffi/home).

The species list in FFI did not include black pine or Scots pine as its data files are based on the USDA-NRCS PLANTS database, so species from FFI and FuelCalc were compared and potential surrogate species were selected based primarily on crown structures. Limber pine (*Pinus flexilis* James) was used for black pine and ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) was used for Scots pine. The impact of surrogate species on CBD estimation is unknown. Canopy bulk densities (CBD) were estimated using the stand data input into FFI within FuelCalc. Within Fuelcalc, CBD is calculated using regression equations of available canopy fuels developed for each species. Fuels were summed in 0.33 m height increments from canopy base to the top of the tree, and smoothed with a 4.5 m running mean. Canopy fuels are defined as foliage and half of 0.64 cm branch material [22].

For all plots, HCPs were taken with a SIGMA SD15 digital camera with a 4.5 mm 1:2.8 fisheye lens and 20.7 x 13.8 mm Foveon sensor (SIGMA Corporation, Kanagawa, Japan) set 1.3 m above the ground. Photographs were taken on days with overcast skies to increase contrast between sky and canopy. Photographs were thresholded for pixel classification using SideLook version 1.1 [23] and processed with HemiView canopy analysis software (Delta-T Devices, England) to calculate gap fraction and LAI.

At the center of each plot, a spherical densiometer (Model-A, Forest Densiometer, Rapid City, SD, USA) was used to estimate gap fraction (but not LAI), by averaging observations made in the four cardinal directions. Assuming that four equally spaced dots in each grid square are equal to quarter-square canopy openings, the total number of dots multiplied by 1.04, provided an estimate of percent canopy density. The densiometer was placed level atop the tripod used for the photographs to ensure consistency between methods.

A LI-COR LAI 2200c Plant Canopy Analyzer was used to estimate gap fraction and LAI. It estimates gap fraction at five zenith angles (7°, 23°, 38°, 53°, and 68° from vertical) measured with five concentric lenses on a handheld wand [18], modified with a 45° lens because of the small size of the plots. An initial measurement was taken in an adjacent area with no canopy cover to obtain a base light level reading, thirty measurements were then taken at random locations inside the plot, followed by another open area measurement.

STATISTICAL ANALYSIS

Due to the limited extent of individual forest cover types in the Netherlands, location and species were assumed confounded, and any inferences relating to species thus cannot be distinguished from potential edaphic or climatic variation. Since species were not replicated at each site, we analyzed crown bulk density, gap fraction, and LAI with one-way ANOVAs to determine potential differences in species/location; separate one-way ANOVAs by the three methods were conducted to examine instrument differences. Statistics were performed in SAS 9.2 (SAS Institute, Cary, North Carolina, USA) using PROC GLM or PROC REG with an alpha of 0.05. All data met assumptions of normality and heteroscedasticity, so transformations were unnecessary. Tukey's test was conducted for post-hoc comparisons. Simple linear regressions were created to 1) characterize differences between instruments and, 2) examine the relationship between canopy bulk density and other canopy metrics. Since the purpose of regression analyses was to examine correlations rather than create predictive models, Pearson's correlation coefficient is presented and trendlines are not shown.

RESULTS

The instruments did vary (Table 1) in their estimation of both gap fraction and LAI ($p<0.0001$). For gap fraction, the densiometer and LI-COR both differed from HemiView, which estimated gap fractions 168–189% greater than the other methods, respectively. However, while the gap fraction means were similar between the LI-COR and densiometer, when regressed between the two instruments, no significant correlation was observed. The same was true for gap fraction estimations between the LI-COR and HemiView (Figure 2). Despite their dissimilar means, there was a strong correlation for the HemiView and densiometer estimates of gap fraction. LAI estimated with the LI-COR was more than two-times higher than that estimated by the HemiView (Table 1). There was a moderate-to-weakly significant correlation between LAI values estimated with both instruments (Figure 2).

There were no significant correlations between gap fraction and CBD regardless of instrument used. The only variable to demonstrate a significant but moderate strength correlation with CBD was LAI estimated with HemiView. The stands did vary substantially in LAI estimated by HemiView, with the minimum LAI stand having only 25% of the magnitude of the maximum LAI stand (Figure 3), apparent in the HCPs with the lowest LAI values in stands with large central canopy gaps for all species.

CBD and LAI did not vary by species ($p=0.6341$; $p=0.1664$), although gap fraction ($p=0.0322$) for Scots pine was greater than Douglas-fir (Table 2).

DISCUSSION

That none of the species varied in LAI or CBD was expected given that all were between late stem exclusion and early understory reinitiation stages of stand development. None of these methods appear ideal for estimating CBD in these ecosystems; if accurate

Table 1: Mean Gap Fractions (%), LAI (m^2 m^{-2}), and CBD (kg m^{-3}) recorded by a densiometer, and Hemiview and a LI-COR in the Netherlands.

Factor	N	Gap Fraction (%)	LAI (m^2 m^{-2})	CBD (kg m^{-3})
Densiometer	26	22.5 (2.4) ^{A}	n/a	n/a
HemiView	26	42.7 (2.8) ^{B}	0.83 (0.08) ^{A}	n/a
LI-COR	26	25.4 (2.9) ^{A}	2.02 (0.19) ^{B}	n/a

Different letters within a column by instrument or species represent significant differences.

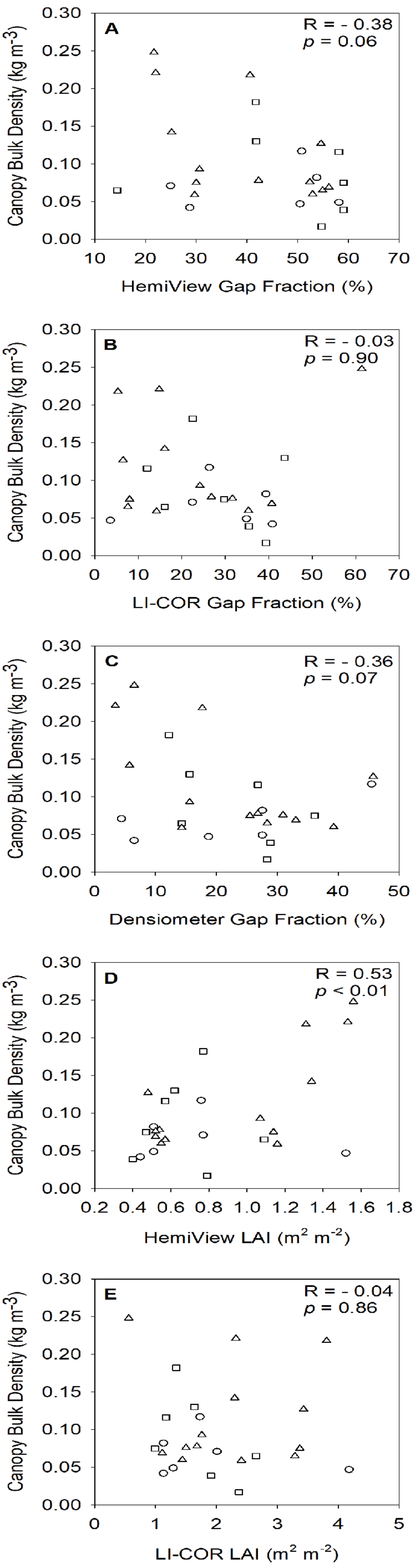

Figure 2: Estimated Canopy Bulk Density with R^{2}s derived from plots using (A) HemiView Gap Fraction, (B) LI-COR Gap Fraction, (C) Densiometer Gap Fraction, (D) HemiView LAI and (E) LI-COR LAI. Douglas-firs are represented by triangles, Scots pines by circles, and black pines by squares.

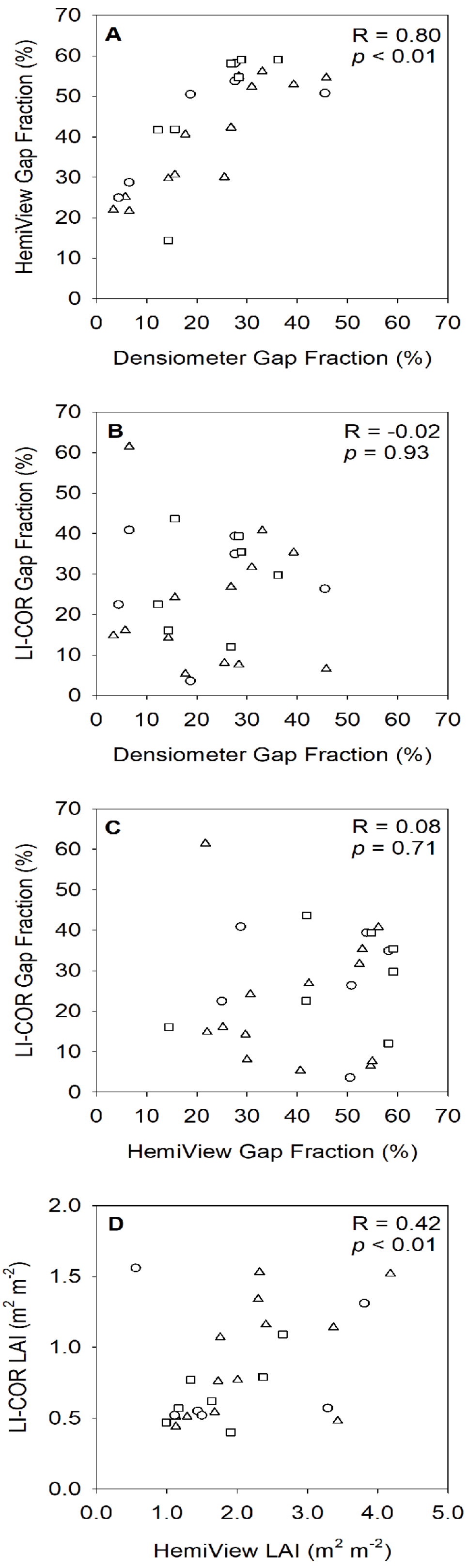

Figure 3: Gap Fraction comparisons with R^{2}s. (A) Densiometer vs. HemiView Gap Fractions; (B) Densiometer vs. LI-COR Gap Fractions; (C) HemiView vs. LI-COR Gap Fractions; (D) HemiView vs. LI-COR LAIs. Douglas-firs are represented by triangles, Scots pines by circles, and black pines by squares.

estimates of CBD are desired, additional measurements need to be made and/or destructive harvesting will be needed.

Our LAI values were within reported ranges for these species. Black

Table 2: Mean Gap Fractions (%), LAI (m^2 m^{-2}), and CBD (kg m^{-3}) recorded for Black Pine, Scots Pine and Douglas-fir.

Factor	N	Gap Fraction	LAI	CBD
		(%)	(m^2 m^{-2})	(kg m^{-3})
Black Pine	7	32.9 (3.5) ^{AB}	1.20 (0.19) ^{A}	0.089 (0.018) ^{A}
Scots Pine	13	32.8 (2.6) ^{A}	1.86 (0.27) ^{A}	0.094 (0.022) ^{A}
Douglas-Fir	6	21.5 (3.2) ^{B}	1.34 (0.20) ^{A}	0.120 (0.024) ^{A}

Different letters within a column by instrument or species represent significant differences.

pine LAI in Spain was most similar to the HemiView estimate, but Scots pine LAI in Belgium was more similar to that from the LI-COR [24,25]. North American LAI for Douglas-fir was most similar to our LI-COR LAI. Both Scots pine and black pine have been observed in Europe with LAI ranging up to 2.7 to 3.0 [26-28].

Differences in gap fraction between the densiometer and HemiView could be from the portion of the canopy observed with each. While both take their data from a circular projection, the area used to calculate canopy density on the spherical densiometer mirror comes from a grid 49% of the total surface area, not the full area. This does result in a smaller overall canopy section being analyzed and potential errors have been noted [29,30]. HemiView software utilizes the entire area of the photograph.

CONCLUSION

Differences in gap fraction and LAI between the LI-COR and HemiView could be caused by the sampling protocol. While the HCP and densiometer estimates were taken from a single point at plot center, the LI-COR data were collected from 30 different sample locations within each stand. However, it should be noted that the LI-COR and densiometer were in close agreement regarding gap fraction estimates. The positive relationship between denser canopies and lower gap fractions found in this study will not only impact canopy fire behavior, but also on understory vegetation growth and densities, and therefore on fuel availability on the forest surface. In the interface between urban development and nature, the reduction in canopy density may therefore result in an increase in fire hazard driven by an increase in surface fuels.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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