Asociación Española de Teledetección

Universidad de Alcalá

III Taller del Grupo de Incendios Forestales

Modelling the vertical distribution of canopy fuel loads in *Pinus sylvestris* stands using low-density Airbone Laser Scanning and the Spanish National Forest Inventory

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INTRODUCTION

Forests of Galicia (North-western of Spain)

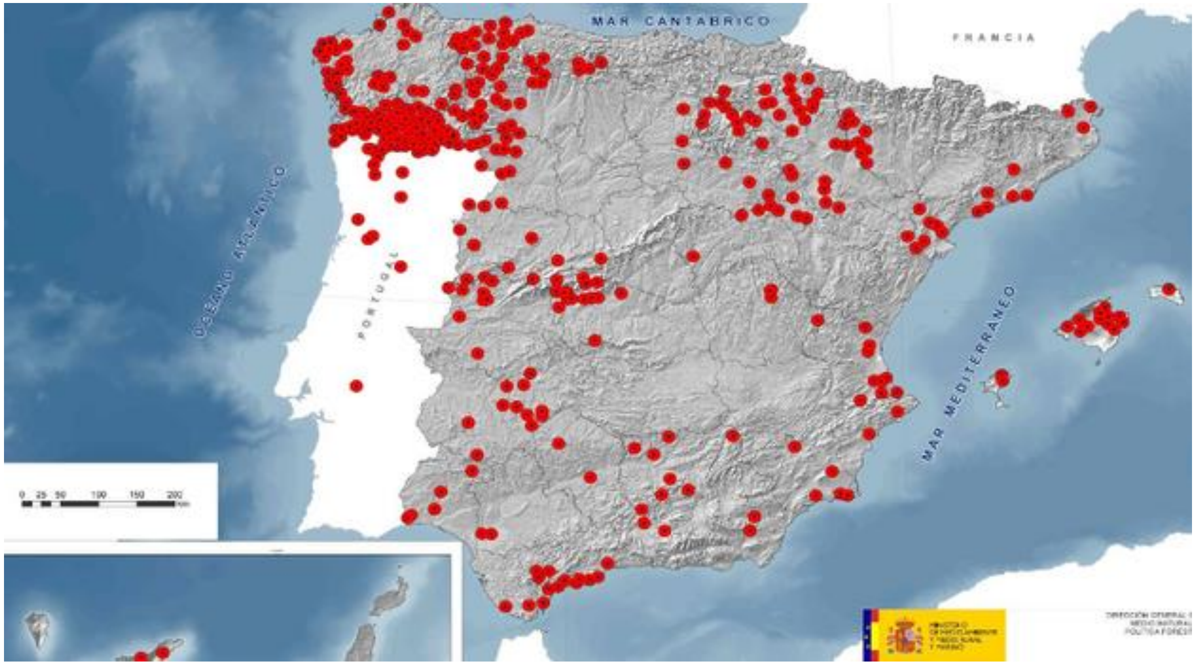
- Total area: 3 million ha.
- Forest land: 2 million ha (66%)
- Approximately 30% of the tree covered area in Galicia comprises pure and even-aged pine stands (*Pinus pinaster*, *P. radiata* and *P. sylvestris*)
- Providing 27% of the total annual harvest volume in Spain.

INTRODUCTION

Wildfires are the main forest disturbance and are among the main environmental concerns in Galicia.

More than 530,000 hectares of forest land (26.5%) were burned in Galicia between 1997 and 2016. The main structural causes are:

- Changes on land use (afforestation and rural abandonment)
- Fire suppression is currently prioritized over fire prevention
- Lack of forest management, silviculture and fuel-hazard reduction in afforestation



INTRODUCTION

Therefore, wildfire analysis and prevention spatial planning with fire behavior simulators are decisive but currently absent or underdeveloped.

Our main objective is to estimate the fire hazard to decide the best options to use the limited resources for fire prevention.

INTRODUCTION

Crown fire hazard

- Crown fire occurrence and subsequent crown fire behavior are strongly dependent on fuel characteristics, especially canopy bulk density (CBD) and canopy base height (CBH).

- CBD indicates the fuel available for combustion per volume in the canopy (kg/m^3).
  - Related to stand volume, stand biomass or stand basal area.
  - Affected by pruning and especially thinning

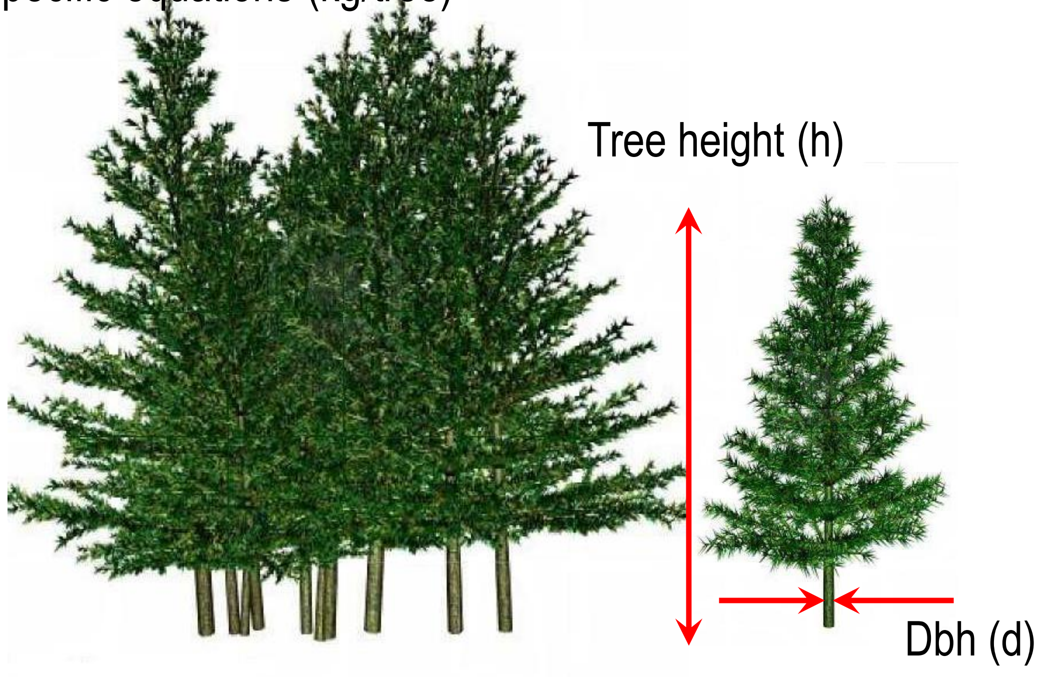
- and CBH is the lowest height at which there is sufficient canopy fuel to propagate fire vertically from surface to the canopy (m).
  - Related to stand mean height or dominant height.
  - Affected by thinning and especially pruning

CBD and CBH estimates

- CBD and CBH can not be directly measured but must be estimated from the vertical distribution of fine fuels in canopy (needles or leaves and twigs less than 0.6 cm).

Vertical fine fuel biomass profiles estimated with species-specific equations (kg/tree)

$$W_{hac} = 0{,}0509 \cdot d^{2{,}1818} \cdot h^{3{,}6929} \cdot \left(1 - \exp\left(-\left(\frac{h_i'}{0{,}6727}\right)^{1{,}7191}\right)\right)$$



INTRODUCTION

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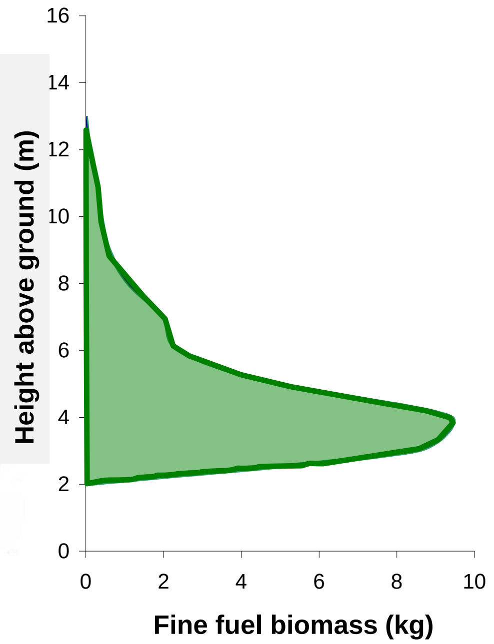

INTRODUCTION

CBD and CBH estimates

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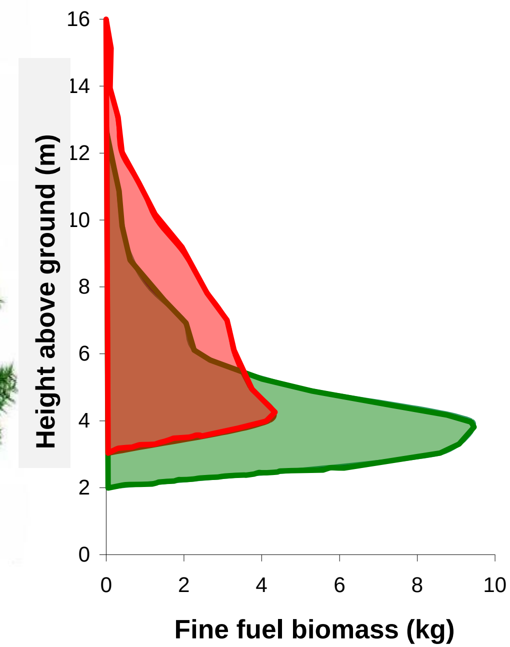


INTRODUCTION

CBD and CBH estimates

- CBD & CBH can not be directly measured but must be estimated from the vertical distribution of fine fuels in canopy (needles or leaves and twigs less than 0.6 cm).

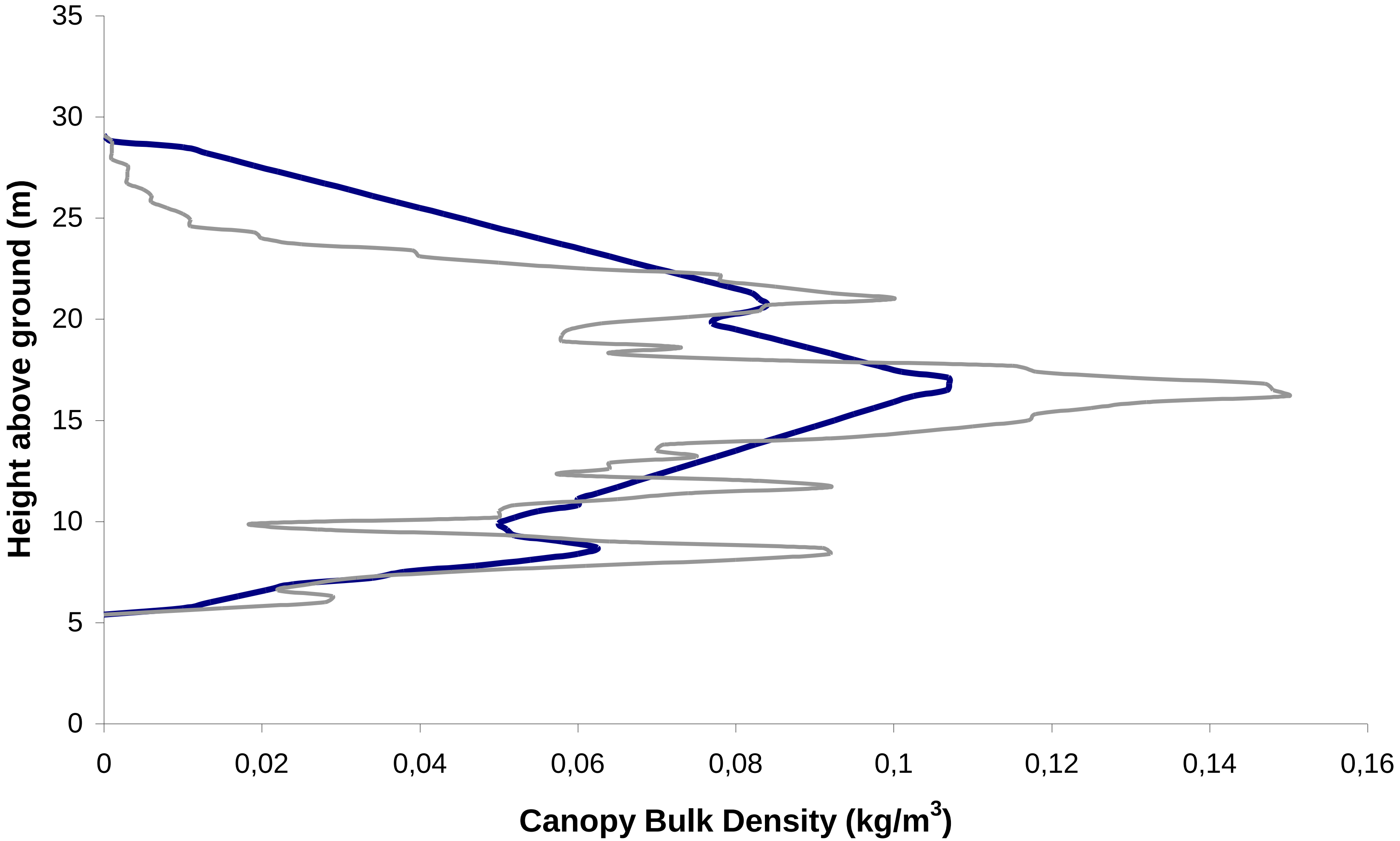
- According to (Sando and Wick, 1972) the next steps must be followed:

1. A canopy fuel profile is created using the aggregated weight of crown fuel within 0.3-m sections of the canopy
2. A 4-m running average of CBD (kg/m^3) around those 0.3-m sections is calculated

1. Sando, R.W., Wick, C.H. 1972. A method of evaluating crown fuels in forest stands. USDA Forest Service. Research paper NC-84.

INTRODUCTION

CBD and CBH estimates

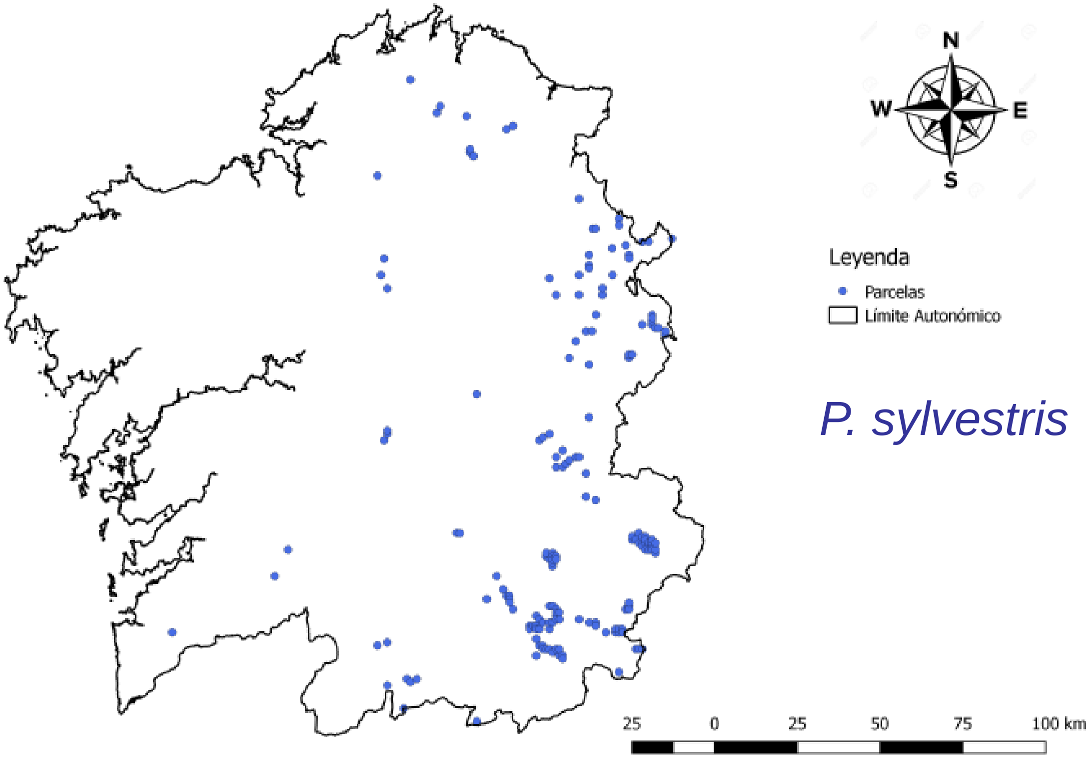


OBJECTIVE

- To model the vertical profile of fine canopy fuel in pine stands and then, to fit a systems of equations to relate the canopy variables defining the vertical distributions to airborne laser scanning metrics.

MATERIAL AND METHODS

Field data



P. sylvestris

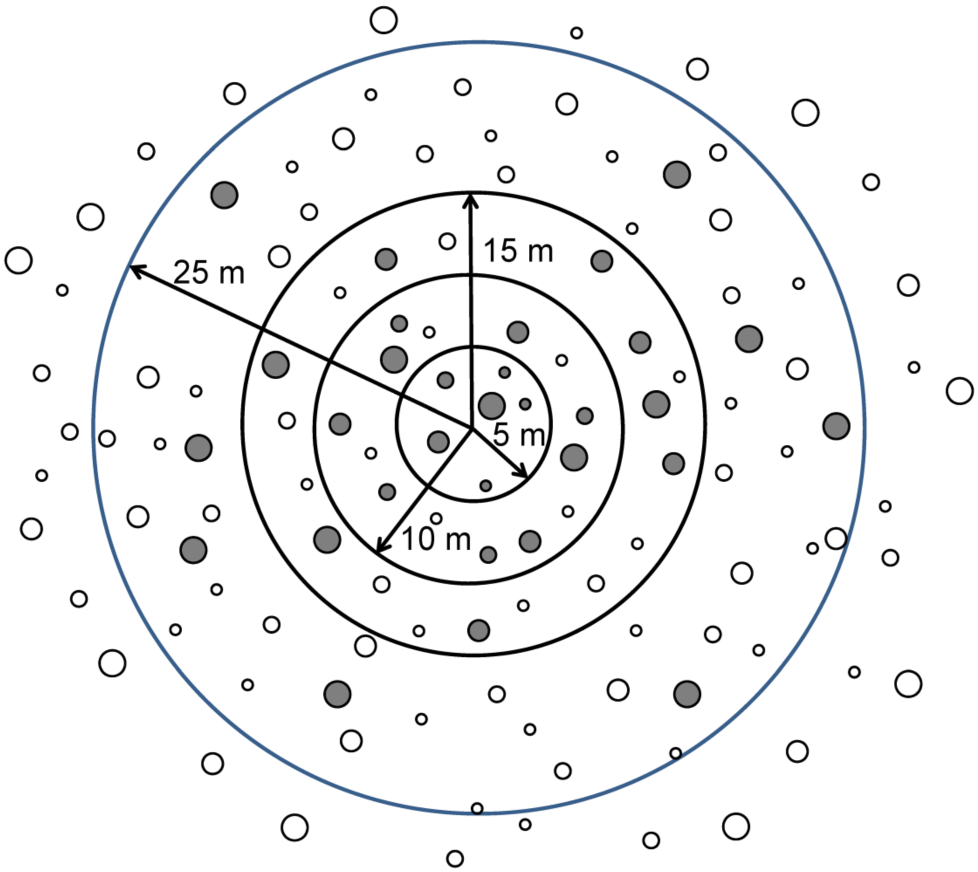
Data from IV National Forest Inventory (2009-2010) were used.

Selection criteria:
$N_{pine} \geq 90\%$
$G_{pine} \geq 90\%$

A total of 110 sample plots were selected.

MATERIAL AND METHODS

Field data



- Sample plots consist of 4 circular concentric subplots of radii 5, 10, 15 and 25 m.
- Diameter at breast height (d) and tree height (h) are measured in trees selected on the basis of their diameter and distance to the plot centre:

d ≥ 42.5 cm for the 25-m radius;
d ≥ 22.5 cm for the 15-m radius;
d ≥ 12.5 cm for the 10-m radius and
d ≥ 7.5 cm for the 5-m radius.

MATERIAL AND METHODS

Field data

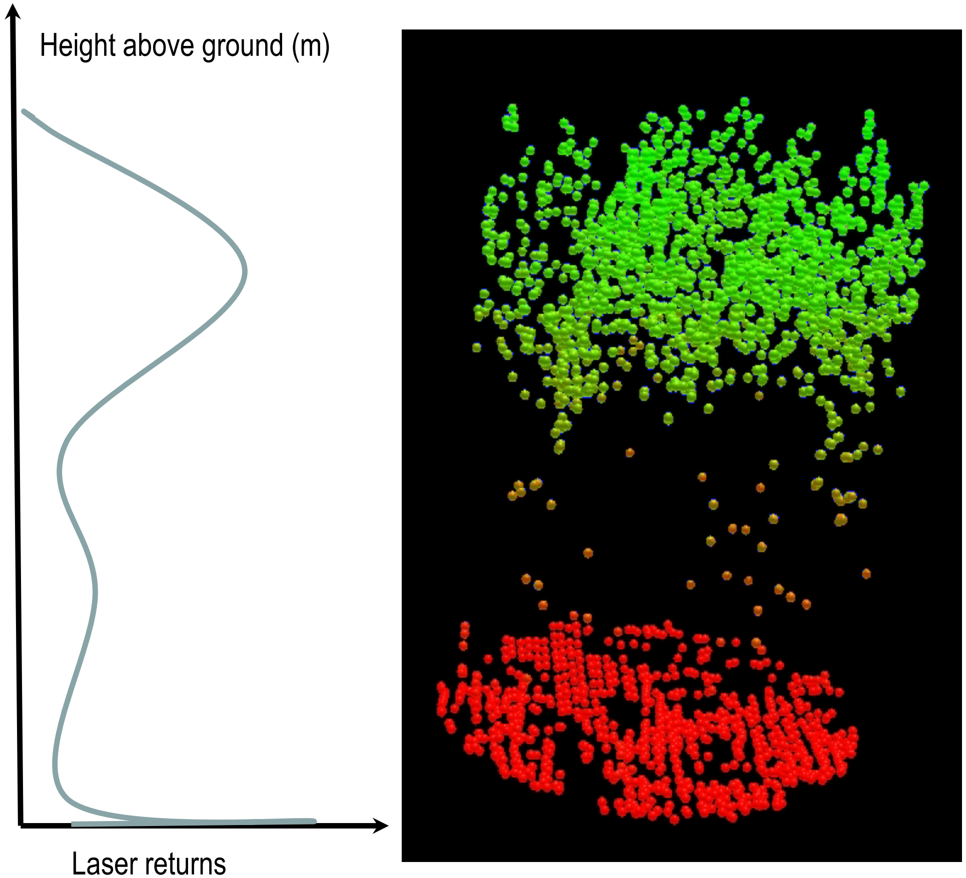
Mean, Minimum, Maximum and standard deviation of the main stand variables.

Statistics	*d* (cm)	*h* (m)	*N* (stems ha^{-1})	*dg* (cm)	*G* (m^2 ha^{-1})	*H* (m)
Minimum	7,5	2,2	42	8,8	0,98	4,2
Maximum	58,8	25,2	3.063	35,2	73,98	22,6
Mean	21,9	12,5	857	19,8	25,43	12,1
Std. Dev.	6,8	4,1	552	5,7	15,40	4,3

d = diameter at breast height; *h* = total tree height; *N* = number of stems per ha; *dg* = quadratic mean diameter; *G* = stand basal area and *H* = dominant height (defined as the mean height of the 100 thickest trees per ha)

MATERIAL AND METHODS

Airbone Laser Scanning data



- LiDAR data were acquired for the PNOA project in autumn 2009 and autumn 2010 (corresponding with NFI measurements).
- A maximum of 4 returns per pulse were registered, with a theoretical laser pulse density of 0.5 returns m^{-2}.

MATERIAL AND METHODS

Airbone Laser Scanning data

Potential independent variables related to height distribution and canopy cover.

Variables related to height distribution (m)	Description
h_{max}	maximum
h_{mean}	mean
h_{mode}	mode
h_{median}	median
h_{SD}	standard deviation
h_{CV}	coefficient of variation
h_{skw}	skewness
h_{kurt}	kurtosis
h_{ID}	interquartile distance
h_{AAD}	average absolute deviation
$h_{MADmedian}$	median of the absolute deviations from the overall median
$h_{MADmode}$	mode of the absolute deviations from the overall mode
$h_{L1}, h_{L2},\ldots, h_{L4}$	L-moments
h_{Lskw}	L-moment of skewness
h_{Lkur}	L-moment of kurtosis
$h_{05}, h_{10}, h_{20},\ldots, h_{90}, h_{95}, h_{99}$	percentiles
h_{25} and h_{75}	first and third quartiles

MATERIAL AND METHODS

Airbone Laser Scanning data

Potential independent variables related to height distribution and canopy cover.

Variables related to canopy cover (%) Variables related with height (i)	Description
PFR_{Ahmean}	ratio of the number of the first laser returns above h_{mean} to the number of first laser returns for each plot
PFR_{Ahmode}	ratio of the number of the first laser returns above h_{mode} to the number of first returns for each plot
PAR_{Ahmean}	ratio of the number of the all laser returns above h_{mean} to the number of all laser returns for each plot
PAR_{Ahmode}	ratio of the number of the all laser returns above h_{mode} to the number of all laser returns for each plot
PFR_{A4}	ratio of the number of the first laser returns above 4 m height to the total number of first laser returns for each plot
PAR_{A4}	ratio of the number of the all laser returns above 4 m height to the total number of first laser returns for each plot

MATERIAL AND METHODS

Modelling approach

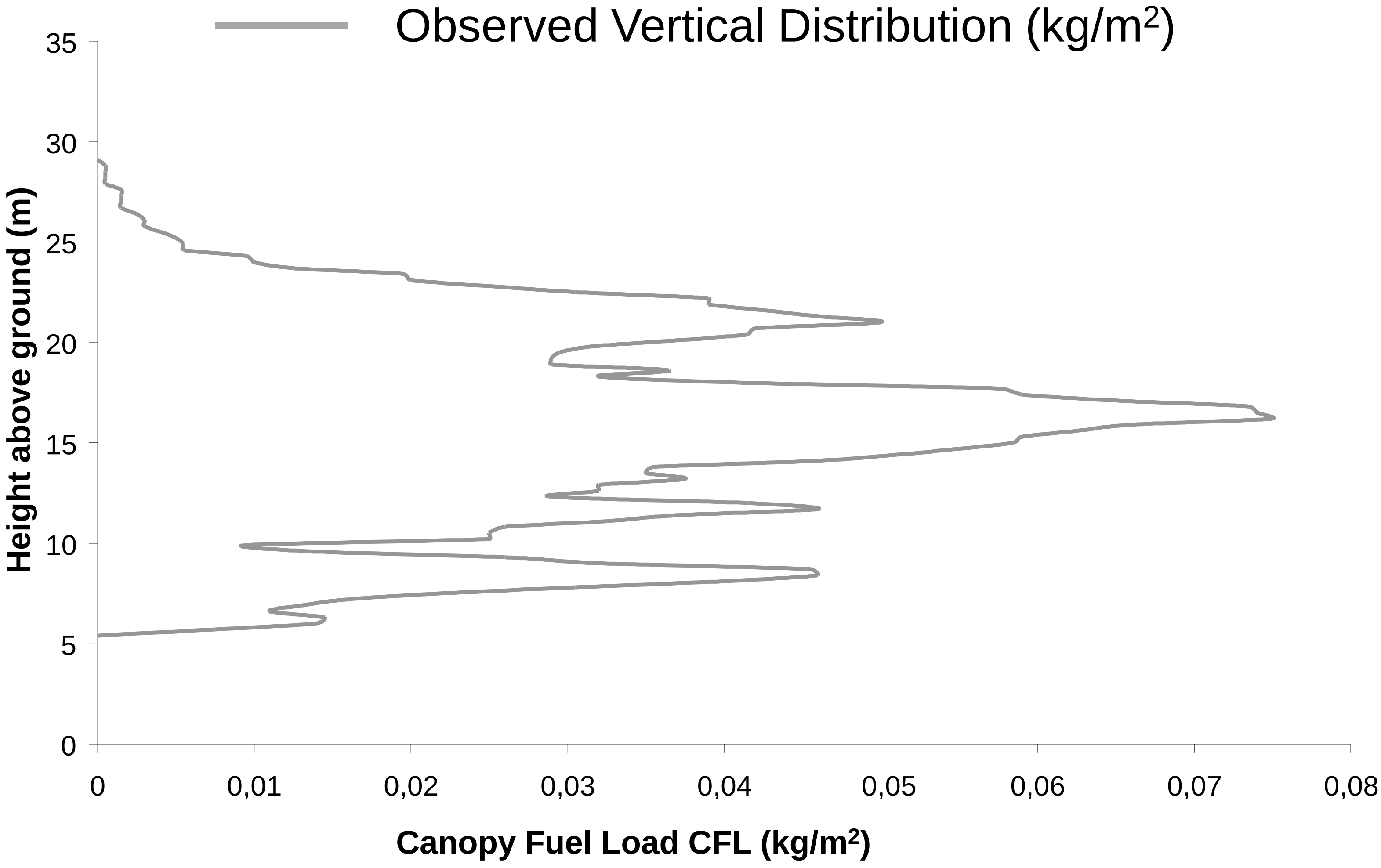
- The **observed** vertical canopy fuel profiles of each sample plot were constructed by:

    1. Calculating the values of fine fuel load of each tree for 0.3-m horizontal layers from the ground to the apex by combining estimates from individual-tree crown profile models and from a system of biomass models.

    2. Summing the available fuel weight in 0.3-m vertical layers across all trees and dividing by the plot area.

MATERIAL AND METHODS

Modelling approach



MATERIAL AND METHODS

Modelling approach

- The **estimated** vertical canopy fuel profiles were modeled by:

1. Characterizing the observed vertical profiles using the three-parameter **Weibull density function**

$$CFL_i = CFL\left(\frac{a_3}{a_2}\right)\left(\frac{CL_i - a_1}{a_2}\right)^{a_2-1} e^{\left(\frac{CL_i - a_1}{a_2}\right)^{a_3}}$$

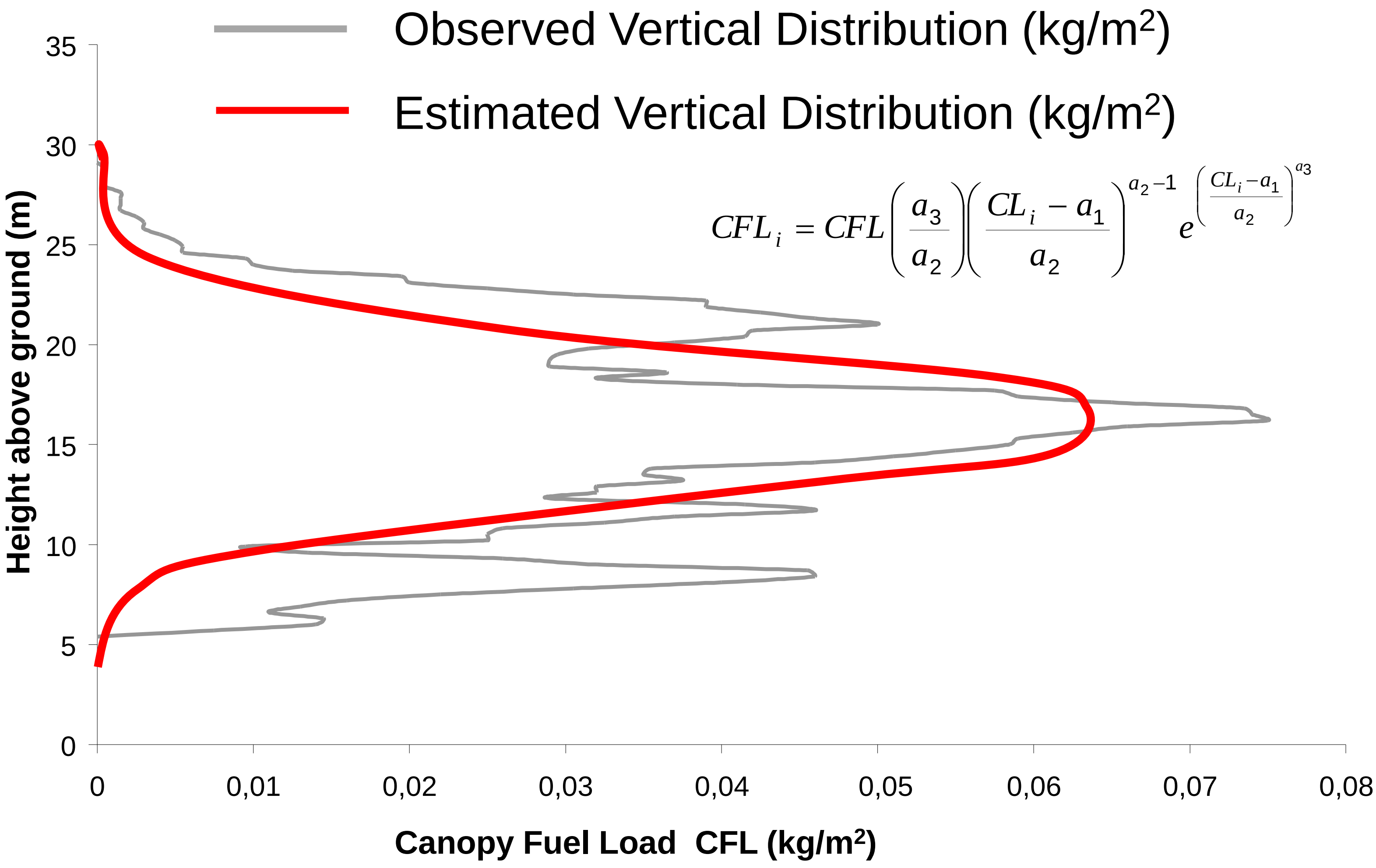
where parameters a_2 and a_3 were estimated from the first and second moments of the observed vertical profiles (m_1 and m_2)

$$m_2 = \frac{(m_1 - a_1)^2}{\Gamma^2\left[1+\frac{1}{a_3}\right]} \cdot \left(\Gamma\left[1+\frac{2}{a_3}\right] - \Gamma^2\left[1+\frac{1}{a_3}\right]\right) \qquad a_2 = \frac{m_1 - a_1}{\Gamma\left[1+\frac{1}{a_3}\right]}$$

2. Fitting four models to estimate *CFL* and the Weibull parameters from LiDAR metrics.

MATERIAL AND METHODS

Modelling approach



$$CFL_i = CFL\left(\frac{a_3}{a_2}\right)\left(\frac{CL_i - a_1}{a_2}\right)^{a_2-1} e^{\left(\frac{CL_i - a_1}{a_2}\right)^{a_3}}$$

MATERIAL AND METHODS

Modelling approach

- Model fitting was carried out in two steps:

  - First, the set of predictors for each dependent variable was selected by using the stepwise variable selection method. To avoid multicollinearity, predictors with a condition number above 30 were disregarded.

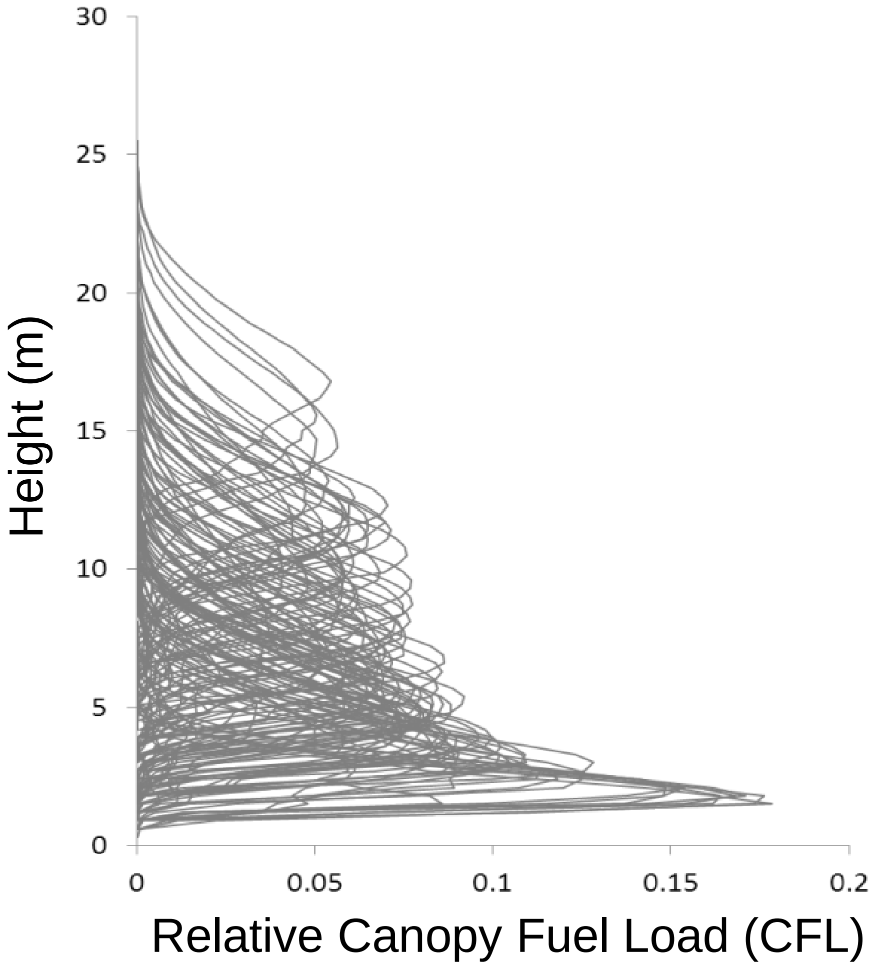
  - Second, the four selected models for each dependent variable were fitted simultaneously because the values of the four dependent variables were estimated for each sample plot from the same vertical profile, and the residuals are therefore expected to be correlated.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n-p}} \qquad \mathrm{ME} = 1 - \frac{(n-1)\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n-p)\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

MATERIAL AND METHODS

Modelling approach

Observed vertical canopy fuel profiles of *Pinus sylvestris*



RESULTS

Modeling the vertical distribution of fine canopy fuel

Parameter estimates and goodness-of-fit statistics for the system of models fitted.

Low density LiDAR (0.5 pulses/m²)

Dependent Variable	Model	$\hat{b}_0$	$\hat{b}_1$	$\hat{b}_2$	*ME*	*RMSE*
Canopy Fuel Load *CFL* (kg m^{-2})	$C\hat{F}L = \hat{b}_0 + \hat{b}_1 h_{70} + \hat{b}_2 FR_{A4}$	0.4657	0.0566	0.0048	0.2698	0.5480
a_1	$\hat{a}_1 = \hat{b}_0 + \hat{b}_1 h_{\mathrm{mean}}$	0.7684	0.3863	---	0.3608	1.6108
a_2	$\hat{a}_2 = \hat{b}_0 + \hat{b}_1 h_{\mathrm{max}}$	1.5015	0.2500	---	0.4614	1.5227
a_3	$\hat{a}_3 = \hat{b}_0 + \hat{b}_1 h_{\mathrm{max}}$	1.9709	0.0484	---	0.2396	0.5025

where h_{70} is the height of the 70th percentile of ALS returns; h_{mean} and h_{max} are the mean and maximum heights of ALS returns and FR_{A4} is the percentage of first returns above 4 meters.

The system of four models was used to estimate the vertical distributions of CFL for each sample plot. The profiles obtained explained **41%** of the observed variation with a RMSE value of 0.3273 kg m^{-2}.

CONCLUSIONS

- The accuracy of the system of models proposed is not high, specially compared to other similar systems of equations using field measurement stand variables as predictors. However, the proposed system could be used to predict the vertical distribution of CFL over the entire area of the ALS data coverage. Therefore,

- The proposed model could also be used to evaluate the effects of different forest management alternatives for reducing crown fire hazard. Maps representing spatially explicit data layers of CFL can be obtained and used as inputs for fire behaviour simulators to evaluate the effect of thinning and pruning treatments to yield stand structures more resistant to the initiation and spread of crown fire.

- Other important areas of forest research such as carbon accounting, selective biomass estimation from silvicultural treatments, ecological modelling of the light regime within the crown and canopy photosynthesis would also benefit greatly from better knowledge of vertical distribution of tree crown biomass.

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