Research Paper

ANALYSIS OF THE RECENT GROWTH TREND OF SILVER FIR (*Abies Alba* Mill.) IN THE CONTEXT OF CLIMATE CHANGE

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ABSTRACT:

Climate change is one of the major drivers of ecological dynamics and will positively or negatively affect the development of forests, depending on multiple factors such as growth dynamics and productivity. The present study aims to analyze the recent growth trend of *Abies alba* Mill. under the influence of climate change, as a main species with high importance for forest management and at an ecological level. The study was conducted in the Vosges mountains through a forest inventory of *Abies alba* over 16 pure and mixed plots, accompanied by coring and a dendrochronology analysis. For each plot, an index (independent of tree age) of mean radial growth (RI) was calculated. Resulting growth trends show that starting in 1999 and until present, the growth trend of *Abies alba* in comparison to the 20th century shifted, with a significant decline in radial indices. To explain this downturn, this study correlated growth trends with changes in climatic variables and found that temperature and radiation are significantly correlated to growth, with rising temperatures and higher radiation correlated to lower growth over the 1999-2020 period. Likewise, analysis of spatial data on environmental factors (altitude, trophic level and stand composition) revealed that these variables modulate growth in a complex and time dependent manner. Overall, the exploratory results add to existing observations of the downturns in growth in Western European forests, and contribute to providing causal explanations for this shift. Such knowledge will contribute to addressing the impacts of climate change on mountain forests in the future.

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Disclaimer
Although a lot of thought, effort and enthusiasm has gone into producing this paper, it remains the work of six students over a short period of time (6 weeks). Therefore, it is entirely possible that a few imprecisions or errors remain, which will hopefully be corrected and improved as this research continues through future projects. Thus, some caution is warranted when interpreting its results.

Overview

Abbreviations

RI = Radial Index
RW= Ring Width
CA=Cambial Age

INTRODUCTION

Roughly until the turn of the century, studies suggested that global changes were easing climatic constraints to growth, resulting in increases in tree's net primary production and changes in physiology (Francey, 1982; Lamarche,1984; Nemani *et al*, 2003; Boisvenue and Running, 2006). But since then, concerns about the effects of climate change on forest decline have grown. The number of studies documenting tree mortality is increasing (Michel and Seidling, 2018); and incremental temperatures and decreasing rainfall are leading to declines in growth (Taccoen, 2019). Today, forest dieback is widespread in Europe (Kowalski and Holdenrieder, 2009), and forecasts suggest this will continue, with impacts on forest productivity and biodiversity. It is essential to understand the causes of such changes in growth trends, but these are both complex and multifactorial (Piedallu *et al*, 2021; Huang, 2021; Sinclair, 1965).

Studying tree growth patterns at a regional scale will help to gain a better understanding of the changing patterns of tree growth. Accordingly, this study focuses on a region of high climatic, trophic and dendrological diversity, namely the Vosges mountains of northeastern France. Similarly to most mountainous zones in Europe, forests in the Vosges mountains are characterized by the widespread presence of silver fir (*Abies alba*), a species with high silvicultural and ecological value which is threatened by climate change (Rameau, 2001; Pinto, 2009; Mauri *et al*, 2016). Due to its importance, the research focuses on this threatened species.

The ecology of fir

Silver fir is a widespread, long-lived coniferous species frequently found with European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) throughout the mountains of Europe (Tinner *et al*, 2013). In France, analysis of National Forest Inventory (IFN) data suggests silver fir is present in zones with average annual temperatures ranging from 7°C and 10°C and with high moisture, with precipitation ranging between 700mm and 1800mm (Tinner *et al.,* 2013).

In the Vosges mountains, the ecology of silver fir has been studied extensively by Pinto (2006), who sampled 143 plots to assess the long-term survival, height growth and radial growth of fir and to link these parameters to interspecific competition and to climatic and nutritional gradients. Standing volume has an expected impact on radial growth, and spruce has a large impact on fir growth, according to Pinto.

Additionally, Pinto (2006) suggests that trophic levels have had a changing impact on growth, and that water availability impacts growth differently throughout the growing season, with primary growth occurring in spring periods of abundant water and secondary growth being limited by decreasing soil water stocks. In the Vosges mountains, the interaction of decreased interspecific competition, of winters which aren't yet too cold and of higher precipitation mean that the ideal altitude for silver fir is 700m.

With climate change, Pinto (2006) predicts a shift in silver fir distribution, and hydric stresat low attitudes. Indeed, concern about silver fir decline in the Vosges mountains began as early as the 1980s (Becker et al, 1989). Today, the species is under threat of dieback, which has already begun in some zones such as the Doller valley in the Southern Vosges (GMN, 2019; GMN 2020; FEN 2019). Because of the social, ecological and economic importance of fir, information on such declines - why it is occurring, to what extent, and whether it will persist - is urgently needed. This study thus focuses on characterizing and explaining changes in silver fir growth since the mid 20th century.

Methods used to assess tree growth

Modeling of spatio-climatic variables is frequently used to identify the causes of growth decline. For example, Trostiuk *et al* (2020) used a vegetation based dynamic model to assess the spatial impact of seasonal environmental constraints on tree growth for seven species, including silver fir. Likewise, Taccoen (2019) developed mortality models including variables related to tree status, stand characteristics, stand management, soil properties, climate conditions and climate change to evaluate the impact of climate change on mortality. Focusing on fir in the Vosges mountains specifically, Piedallu et al (in press) built a modeling approach combining remote sensing images, photo-interpretation and models describing environmental conditions.

In parallel to models of spatial-climatic variables, **dendrochronology** can also be a valuable method for the characterization of growth patterns and mortality. The values and uses of tree ring analysis are well documented (Spieker, 2002; Bréda and Badeau, 2008), allowing for the retrospective quantification of radial growth trends in trees at annual and seasonal scales (Fritts, 1976). Dendroecological studies have contributed to the understanding of the temporal and spatial impact of climate gradients and competition on tree growth (Schurman *et al*, 2020; Ponton, 2018). With respect to climate change, Jump *et al* (2006) used dendrochronology to document climate change related growth decline at the southern range edge of beech, Rozenberg *et al* (2020) assessed the impact of climate change on larch (*Larix decidua*) along an elevational gradient, and Bosela *et al* (2021) investigated the climate sensitivity of Norway spruce (*Picea abies*) along geographical gradients. Dendrochronology studies on fir specifically include Pretzsch *et al* (2020)'s study of elevation-specific growth changes in mixed mountain forests. They also include Pinto (2006)'s joint analysis of the impact of competition and of ecological factors on silver fir's growth in diameter.

Dendrochronology, silver fir and declines in growth: the relevance of this study

Although several studies focus on silver fir tree ring growth, few studies use dendrochronology to assess the impact of climate change specifically on fir growth. Ols *et al* (2020) use tree ring data from the French National Forestry Inventory (IFN) to evaluate the impact of forest heterogeneity and thermal and water constraints on growth. Gazol *et al* (2020) analyze trends in radial growth related to defoliation and dieback to determine the impact of drought stress on Pyrenean silver fir.

It is hoped that this study will contribute both data and analysis to these works. By working from the research done by Pinto (2006) and adding an updated assessment of the impact of climate change on fir in the Vosges mountains, the results presented aim to characterize and explain recent changes in growth trends of *Abies alba* in the Vosges mountains related to climate change.

More specifically, the aim of this study is to answer two incremental questions:

1. Has the growth trend in Abies alba changed since the turn of the century and if yes, how?
2. What variables explain or modulate these changes in growth trends ?
   - 2.1. Over time: what climatic factors can explain these changes?
   - 2.2. Spatially: Is this reversal of trend occurring across the entire elevation gradient, nutritional levels and stand types ?

It is hypothesized that

1. Growth has changed, more specifically, it has declined since the turn of the century
2. This is correlated to climatic and spatial factors
   - 2.1. Increasing temperatures and radiation are correlated to reduced growth
   - 2.2. Spatial data is correlated to growth:
     - 2.2.1. Declines in growth are lesser at higher altitudes
     - 2.2.2. Trophic level is no longer a limiting factor for growth
     - 2.2.3. Declines in growth are lesser in mixed stands

To test these hypotheses and answer these questions, this study resamples plots selected by Pinto et al (2006), conducting both inventories and coring on a subset of selected plots. It then links resulting calculated radial indices - standardized indicators of growth - with climatic and spatial data to explain changes in growth trends. The results and analysis serve exploratory purposes: they indicate directions for future studies, rather than being absolute and certain.

MATERIALS AND METHODS

Study Area & Baseline dataset

The Vosges mountains

The study focuses on the Vosges mountains in the north-east of France, one of the most densely forested areas of the country. The boundaries of the Vosges used here are those defined by Gégout (1995) and used by Pinto et al. (2006), encompassing an area of 6 800km² with altitudes ranging from 300m to 1400m (Figure 2). In terms of climate, annual precipitation in the Vosges varied between 580 and 2400mm and mean annual temperatures ranged from 5.5°C and 10.5°C over the 1961-2020 period (Figure 2). Geologically, the Vosges are characterized by granitic rocks in the central southern zone and acidic sandstones in the north and west (Piedallu et al, *in press*). Topographically, the west of the Vosges mountains comprise gentle slopes, whereas the eastern side has more abrupt slopes. In terms of vegetation, silver fir (*Abies alba*) is the most present species, followed by beech (*Fagus silvatica*) and spruce (*Picea abies*). There is also some sessile oak (*Quercus petraea*), Scots pine (*Pinus silvestris*) as well as maples (*Acer pseudoplatanus*) (Pinto, 2006) (Figure 3). The distribution of these species changes with altitude, with a majority of oak and beech below 400m, of beech and fir between 400m and 1100m, and of beech above 1100m with grassland on summits (Pinto, 2006, Dion, 1985, Rameau, 1985).

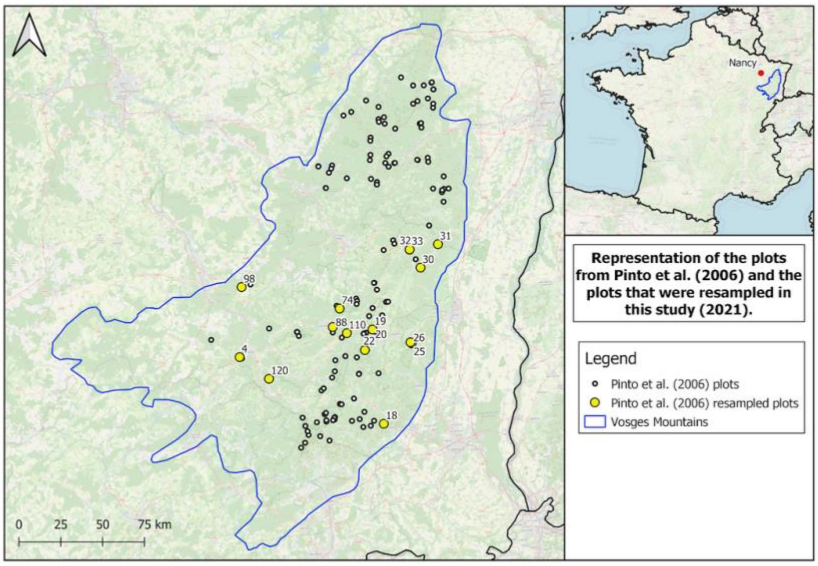

Figure 1: Representation of the Pinto et al. (2006) plots in the Vosges Mountains.

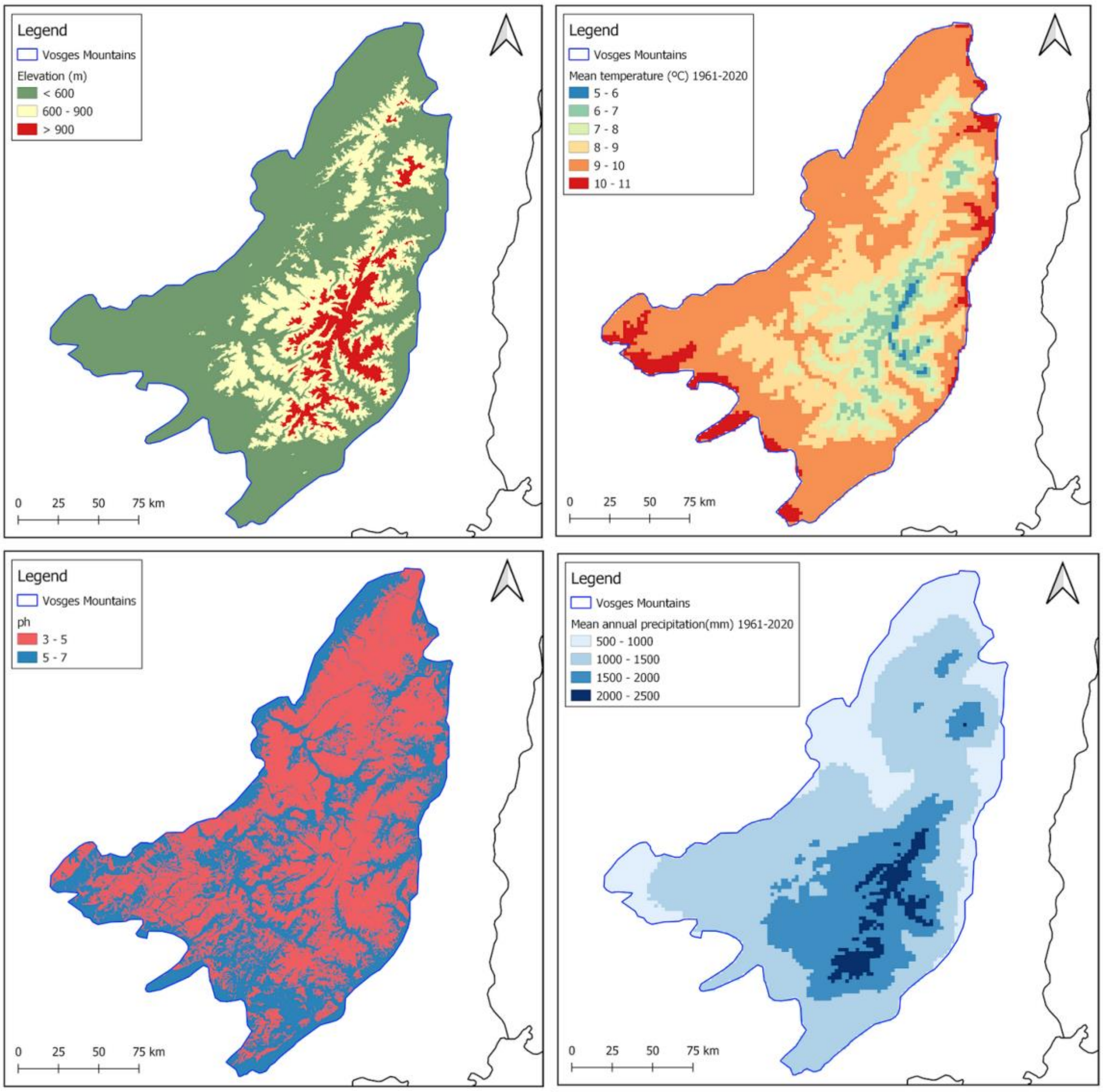

Figure 2: Distribution of the variables elevation, mean temperature, pH and mean annual precipitation in the Vosges Mountains.

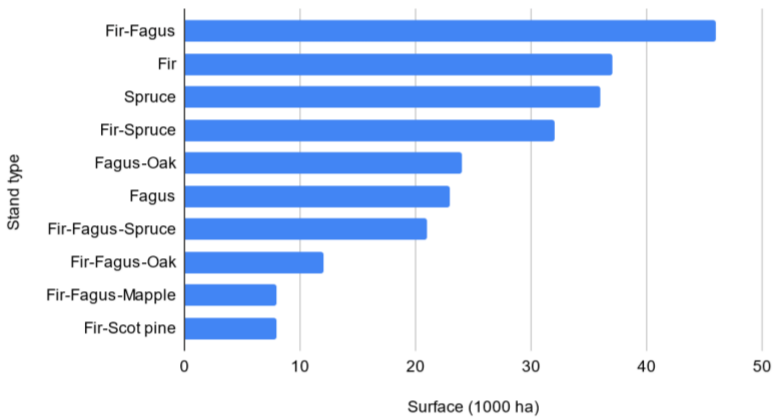

Figure 3 : Surface of the different stand types in the Vosges Mountains

Our baseline dataset

This study works from Pinto's (2006) baseline dataset, based on samples obtained from 143 plots in 2002 (Figure 1). Pinto's sampling strategy centered around fir and is based on data from the National Forest Inventory (Table 1). It focuses on mixed stands, in which the relative homogeneity of ages and heights of dominant trees allows for the study of interspecific relationships. Pinto defines 45 strata distributed along 7 types of stands (pure *Abies alba* (Aa) stands and six types of mixed stands - *Abies alba-Fagus sylvatica* (Aa-Fs), *Abies alba-Picea abies* (Aa-Pa), *Abies alba-Fagus sylvatica-Picea abies* (Aa-Fs-Pa), *Abies alba-Fagus sylvatica-Quercus petraea* (Aa-Fs-Qp)**,** *Abies alba-Fagus sylvatica-Acer pseudoplatanus* (Aa-Fs-Ap) and *Abies alba-Pinus sylvestris* (Aa-Ps)) and 9 ecological categories combining 3 altitude classes (<600m, 600m<...<900m and >900m) and 3 trophic levels (eutrophic, mesotrophic and oligotrophic).

Table 1: Stratification of Pinto's (2006) plots. Aa = *Abies alba*, Fs = *Fagus sylvatica*, Pa = *Picea abies*, QP = *Quercus Petraea*

	altitude<600 m				600 >altitude< 900 m				altitude> 900 [m]				Total
Type de peuplement	eutrophe	mesotrophe	oligotrophe	sous-total	eutrophe	mesotrophe	oligotrophe	sous-total	eutrophe	mesotrophe	oligotrophe	sous-total	placettes réalisés
Aa	3	3	3	9	3	3	4	10	3	3	3	9	**28**
Aa-Fs	3	3	6	12	3	3	3	9	3	3	3	9	**30**
Aa-Pa	3	3	3	9	3	3	4	10	3	3	3	9	**28**
Aa-Fs-Pa	3	3	3	9	3	3	4	10	3	3	3	9	**28**
Aa-Fs-Ap				0	4	3		7	3	3		6	**13**
Aa-Fs-Qp	3	3	3	9				0				0	**9**
Aa-Ps			4	4			3	3				0	**7**
sous-total	15	15	22	52	16	15	18	49	15	15	12	42	
Total													**143**

Data collection

Photo-interpretation

Photo-interpretation was the first step of the sampling strategy and aimed at removing harvested plots from the plot selection and conducting a preliminary assessment of dieback. Three potential sources of aerial imagery were considered: Bing aerial images, Google Earth aerial images and IGN (National Institute of Geographic and Forest Information) orthophoto imagery. The analyses showed that these IGN images were the most recent, dated in the year 2018. They were therefore retained. In each of the 143 plots the condition of the crown of some trees was analyzed to assess if some trees were dead or not and if the plot had been harvested. Harvested plots were removed from the selection of plots, leaving 125 plots.

Selection of plots

The aim of this study being to resample Pinto's (2006) plots to assess the impact of altitude and stand composition, the sampling strategy stratified all non harvested plots in terms of altitude (<600m, 600m to900m, and >900m) and stand composition (pure/mixed), resulting in a total of 6 strata (3*2). For practical purposes, the Southern region of the Vosges mountains was selected as the area of work, and thus 72 plots were retained by removing northern plots. Excel was used to successively generate random numbers. For each plot corresponding to a generated number, the strata was retained. The first three plots were retained within each strata as selected plots, and the subsequent three as supplementary plots should it be impossible to access or analyze the selected plots. A set of 18 points and 18 supplementary points were selected . During a first field campaign, six of these 18 points were inventoried.

However, practicalities during the second field campaign prevented us from sampling the remaining plots. Because of the snowy weather conditions, the study focused on the lower limit of the *Abies alba* range, which is of analytical value because it is also where the species is most vulnerable to climate change. The study focused on plots which were under 900m of altitude in the Southern side of the Vosges mountains. 16 points were sampled (Figure 1).

Fieldwork

Once each plot was reached using Iphigénie and Google Maps , data collection began with determining the plot center based on environmental and topographical information recorded by Pinto (2006) and based on the presence of at least 3 dominant individuals of each species within the 1000m² plot. This was followed by conducting a complete inventory of the plot: for each tree whose Circumference was superior to 23.5cm, location information (azimuth, distance from the center of plot) and tree-specific information (diameter at breast height, species, health status) was recorded, as were stumps (see protocol in Annex for more detail). Dominant trees were then ranked. It is recommended that the health status of the 6 largest trees be recorded, as well as any other tree which was cored. The protocol includes details on how to conduct fieldwork, including suggestions based on the learnings of this study: it is in and of itself a result of this study and can be considered as such.

Data from cores

Ranks were used to select the trees to core. Trees of ranks 1,5 and 9 were selected. In mixed plots, trees closest to ranks 1,5 and 9 were cored for each species. A thermal core drill was used to extract one or two cores from each tree (depending on how close the first core was to the pith). Cores were labeled.

Following data collection in the field, cores were prepared for analysis: they were first flattened with a scalpel and then marked with a microscope. Following this, each core was scanned using Windendro, an image analysis system for tree-ring analysis. Notable years were recorded for quick interdatation. However, a full interdatation was not committed due to time constraints. It is recommended that future projects interdate cores to decrease errors in tree ring assessment.

Data on climatic and environmental variables

On the field, a quick characterization of soil and humus was conducted, using a spade to analyse the horizons of humus.

Using ArcGIS, geospatial data and climatic data (from Digitalis v3), a subset of environmental, climatic and topographical variables were selected and extracted for each sampled point. Additionally, National Forest Inventory (IFN) data on the temperatures and presence of *Abies alba* all over France data was used to obtain information on the range of temperatures in which the species was present in the Vosges and Nationally.

Data analysis

Forest Inventory data

Basal Area, Basal Area/hectare, Dominant Height and the Basal area for the whole dataset and for *Abies alba* was calculated and grouped by each plot. Then, R studio (RStudio team, 2020) was used to calculate the confidence intervals for the variables of interest. the basal area is calculated as follows :

$$\boldsymbol{Basal\ area}\ (\boldsymbol{m^2})\ = \boldsymbol{\frac{\pi}{4}} * \boldsymbol{Dbh^2} \quad \textbf{(1)}$$

where Dbh is the Diameter at breast height in cm.

Cores: Tree ring width data

For each plot, cores were prepared following dendrochronological techniques. (Stockes & Smiley, 1968). The cores were shaved with a scalpel in order to have a flat surface to scan the samples. The samples were processed on WinDendro. Each ring width of all cores was measured with a precision of 0.01mm. Following the way the literature treated the rotten trees, 79% (42 trees) of the 54 trees sampled were successfully aged. The remaining 21% had a rotten center. (Thomas et al, 2014)

In order to remove the age effect, a reference curve was modeled using a second-degree polynomial using the RWi values of Pinto's (2006) research. The model was applied to the data to calculate the estimated ring width.

$$RWi^* = a + b * CA + c * CA^2 + e \quad (2)$$

The radial index was then calculated for each annual ring as the ratio:

$$RI = RWi / RWi^* \quad (3)$$

Where RWi is the ring width i and RWi* is the modeled **expected** width.

Overall analysis

The radial indices per year are at the basis of the analysis of growth patterns. The *ggplot2* and *ggforce* functions in the "ggplot" package of R were used to plot radial indices according to years. This plot (presented in the results - Figure 8) showed a clear inflection point at the year 1999: before 1999, the general trend was to an increase in radial indices. After 1999, the general trend was to a decrease in radial indices. This observation informed the choice of periods of analysis: 1977-1999 and 1999-2021, two periods of 22 years each.

The curves of radial indices were then linked to temporal climatic and environmental data. For environmental data, this involved separating out the data into classes (for altitude, >900m and <900m; for nutritional level, eutrophic, oligotrophic, mesotrophic) and plotting the radial indices of trees in each class to identify trends. For climatic data, this involved first plotting the curve of radial indice with variations in climatic variables to visually start identifying key variables. The *rcorr* function of the "Hmisc" package was then used to build a correlation analysis matrix with p values and correlation coefficient values, then the "corrplot" package was used to map data.

RESULTS

Forest Inventory

16 plots of 1000 m² were measured in total during the field phase, from altitude levels that range between 410 to 1010 meters. pH values of the plots range from 3 to 5,7 with a mean of 4,1. An average of 40 trees with a mean diameter of 35,9cm was found per plot. The mean total basal area per hectare was 42,91 ± 4,7 m² (Table 2).

Table 2 : Forest inventory results, where x: latitude, y: longitude, dbh: diameter at breast height, G: basal area(m2), Gha: Basal area (m2/ha), Aa: Abies alba, Hdom: Dominant height (m).

Plot_number	x	y	altitude_m	peuplement	pH	Niveau_trophique	Total_trees	meandbh_cm	TotalG_m2	Gha_m2	AaTotalG_m2	AaGha_m2	Hdom_m
100004	965310	6773197	565	Aa-Pa	3,55	1	70	21,5	3,456	34,6	2,295	22,95	25,0
100018	954461,83	2324127,45	460	Aa-Fs-Qp	4,53	2	46	31,6	4,490	44,9	1,530	15,30	25,9
100019	10001186	6780431	540	Aa	3,91	2	35	40,2	5,977	59,8	5,864	58,64	35,9
100020	951343	6780389	540	Aa-Pa	3,87	1	27	50,3	5,607	56,1	2,061	20,61	35,1
100022	999641	677475	600	Aa	5,20	3	11	58,0	3,284	32,8	3,266	32,66	40,2
100025	1012470	6746593	490	Aa-Fs	5,76	2	22	44,6	3,880	38,8	2,396	23,96	34,3
100026	1012120	6776793	440	Aa-Fs-Qp	5,36	2	39	36,6	4,928	49,3	1,497	14,97	31,0
100030	1015060	6797242	610	Pa-Fs	3,85	3	24	44,9	4,208	42,1	2,210	22,10	33,1
100031	1019880	6803620	440	Aa	3,58	2	32	29,4	2,671	26,7	2,392	23,92	15,6
100032	961534,12	2371874,79	590	Aa-Fs-Qp	4,97	3	60	26,6	3,975	39,8	1,798	17,98	22,6
100033	1012100	6802243	589	Aa-Fs	4,59	3	39	37,7	4,811	48,1	3,731	37,31	26,0
100074	992812	6786199	980	Aa-Fs-Pa	3,43	2	36	34,5	4,626	46,3	0,990	9,90	33,1
100088	990879	6781159	1010	Aa-Pa	3,38	1	90	19,4	4,164	41,6	2,091	20,91	23,6
100098	966003	6792311	410	Aa-Fs-Pa	3,43	3	35	27,8	3,226	32,3	1,093	10,93	30,8
1000110	994735	6779454	990	Aa-Pa	3,00	1	33	43,9	5,226	52,3	0,671	6,71	25,4
1000120	973280	6767132	800	Aa	3,12	2	46	27,4	4,097	41,0	3,955	39,55	27,6

From the evaluated plots, 4 correspond to *Abies alba* pure stands. Meanwhile, the rest of the plots belonged to mixed stands composed of species such as *Picea abies*, *Fagus sylvatica* and *Quercus petraea.* Among the measured plots, *Abies alba* represents a high dominance within the stands, as can be seen in the diametric and basal area distributions as follows:

A B

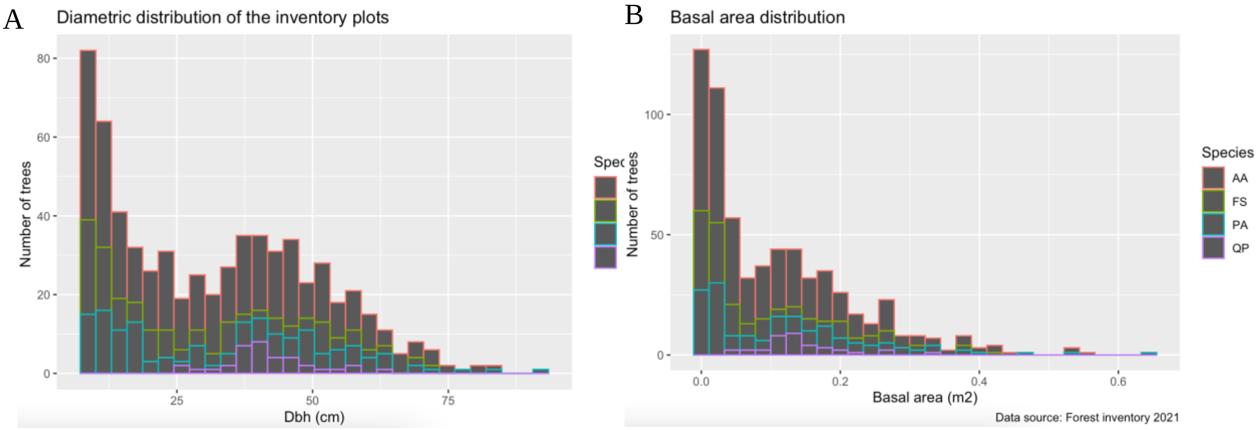

Figure 4: In A Diameter at breast height (Dbh, cm) and in B Basal area (m2) Distribution of the inventoried trees within the whole set of plots. where AA: *Abies alba*, FS: *Fagus sylvatica*, PA: *Picea abies*, QP: *Quercus petraea*

As seen in figure 4, the distribution of dbh and basal area values highlight the dominance of *Abies alba* in comparison to the species found in the study. Of the total basal area found, *Abies alba* represents 29,8 ± 8,9 m2/ ha (almost 60% of the total basal area per hectare).

Results of the photo interpretation

Figure 5 illustrates the results of the photo interpretation done before field work (figure 5.1, left) vs the number of plots which were assessed to be in dieback on the field (figure 5.2 right). The percentage of matches above the total cases indicate a range between 25%-37% of matches between those interpreted by aerial photographs and what was evidenced on the field.

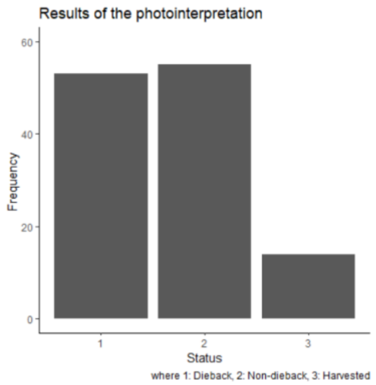

Photo Interpretation	Field Interpretation	Count	Percentage
Dieback	Dieback	4	0,25
Non dieback	Dieback	6	0,37
Dieback	Non dieback	2	0,13
Non dieback	Non dieback	4	0,25

Figure 5: Comparison of dieback by photo interpretation and the identified on field. On the left, the results of photo interpretation. On the right, a comparison of field interpretation and photo interpretation.

Health status of cored trees

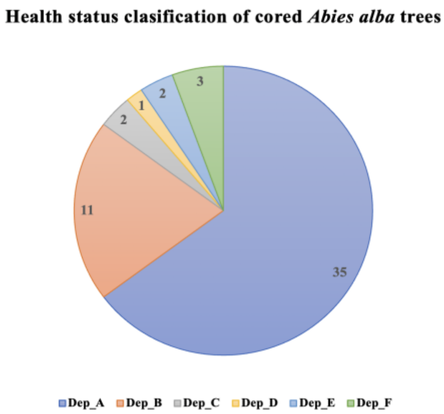

Figure 6: Deperis protocol classification of Abies alba trees

According to the Deperis protocol classification (See Annex), the trees selected for being cored were classified according to their health status (Figure 6). 35 trees correspond to healthy trees under category A (64,8%), 11 trees under category B (20,3%), meanwhile the resulting 14% of the trees belong to the categories C, D, E and F.

Tree radial growth

Growth trend of Abies alba

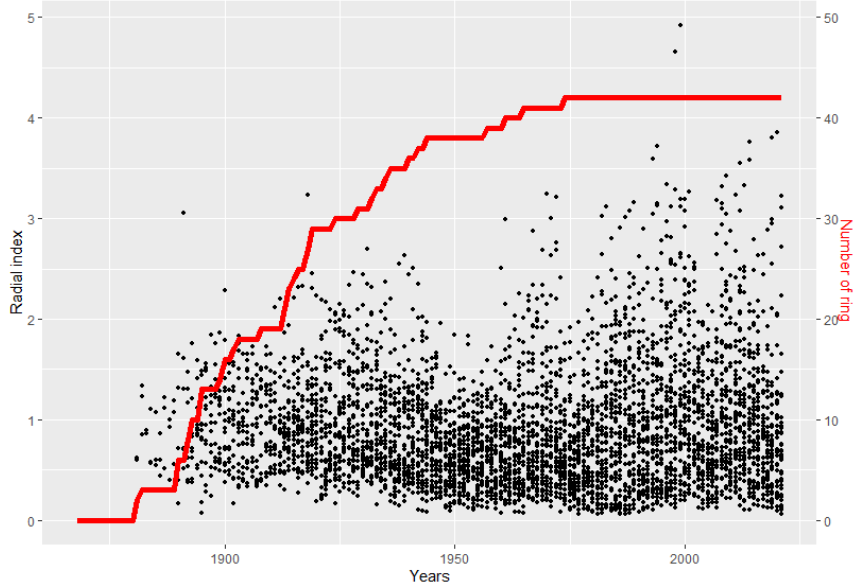

Figure 7 : Number of rings (mm) per year (1868-2021). where the red curve is the sum of the number of IR data points in each year.

Figure 7 illustrates the cloud of dots represents the complete dataset, while each dot represents one radial index. The red curve shows the amount of rings measured for each year. From 1975 to 2021, 42 values are available for each year, which means the result will be more accurate than before 1975 where there are less measured values.

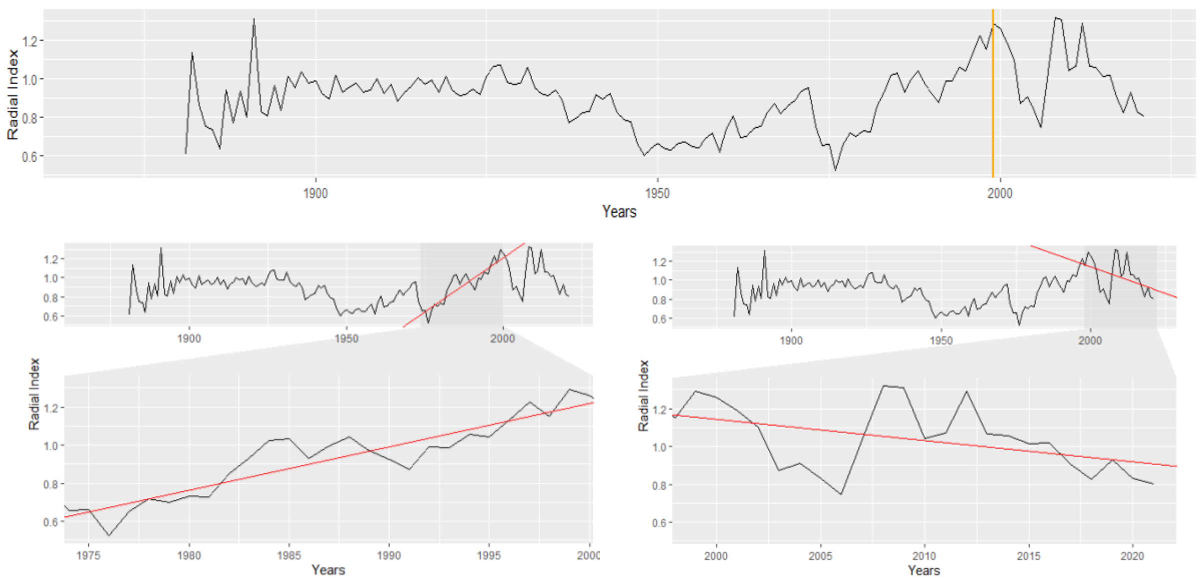

Figure 8 : Growth trend of *Abies alba*. A : Zoom in the period 1975 - 1999. B: Zoom in the period 1999 - 2021
In red: the regression line of the model used..

Figure 8 illustrates the general growth trend of *Abies alba* in two periods. On graph A (1975-1999), the RI trend increases each year whereas on graph B (1999-2021) the growth trend starts to decrease gradually with a -0.011232 slope. During period A (1976-1999), growth trends increased, with episodes of decline as in 1976, 1977. For period B (1999-2021), the trend seems to be reversed with a declining growth trend. Pronounced declines are observed after 2003 and 2018. The results compiled in Table 3 thanks to a linear regression model confirm these observations, The linear regression modeling period A has a positive slope of 0.022778 while the slope for period B is negative: -0.011232 .

Table 3: Matrix of correlation of RI against years.

RI VS YEARS			
Period	**Slope**	**p-value**	**R squared**
A 1978-1998	0.022778	4.581e-09	0.7874
B 1998-2021	-0.011232	0.04299	0.142

Explaining the changes in the growth trend

Climatic variables (time series)

Radial Index was described along with the trajectory of the mean annual temperature and radiation across the selected time period (1977-2021) (Figures 9 and10).

Many variables were used, to assess which variables were significant. Then the study was narrowed down on specific variables, and focused mainly on the spring and summer months. These were the ones that showed significance. October was also included, following Trostiuk *et al* (2020) observation of October temperatures which are significant for growth. Here, the results which are consistent and significant are included.

Temperatures

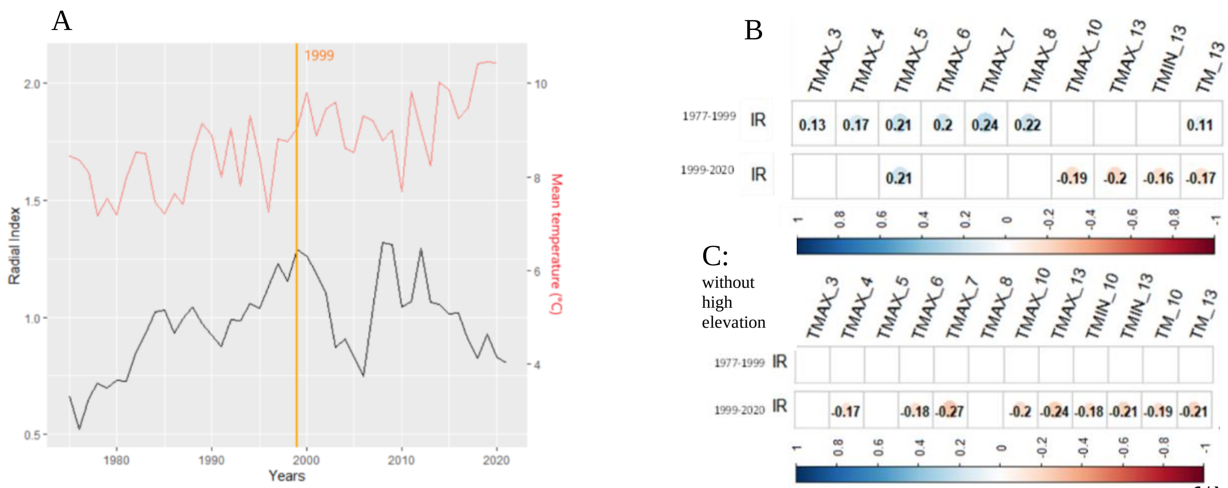

Figure 9. A Radial index and Mean temperature ; B: Correlation analysis of RI **of all plots** with Temperature variables. C : correlation analysis of RI **of low and medium altitude plots only** with temperature variables. TMAX_3 : maximum temperature of March, , TMAX_4: of April, TMAX_5: of May, TMAX_6: of June, TMAX_7: of July, TMAX_8: of August; TMAX_10: of October, TMAX_13: an average of the maximum temperatures of each month ; TMIN_13: an average of the minimum temperatures of each month, TM_13: TM is the mean annual temperature.

The variation of the mean temperature represents a gradual increase of the temperature where it reaches temperatures above 10°C for 2020. Before 1999 temperature and growth were increasing and the table shows that the growth trends were positively correlated with temperature from march to august when high altitude plots are included.

After 1999, temperatures kept increasing whereas the growth trends began decreasing. Here, maximum temperatures in the months of the growing season **stop being** positively correlated to growth. When high altitude plots are excluded, maximum temperatures in April, June, July, October, all become negatively correlated to growth. Moreover, for all plots, maximum temperature in the months of October and annually, as well as annual average minimum temperature all become negatively correlated to growth. For mean annual temperature, whilst it used to be positively correlated to growth, it became negatively correlated to growth.

Radiation

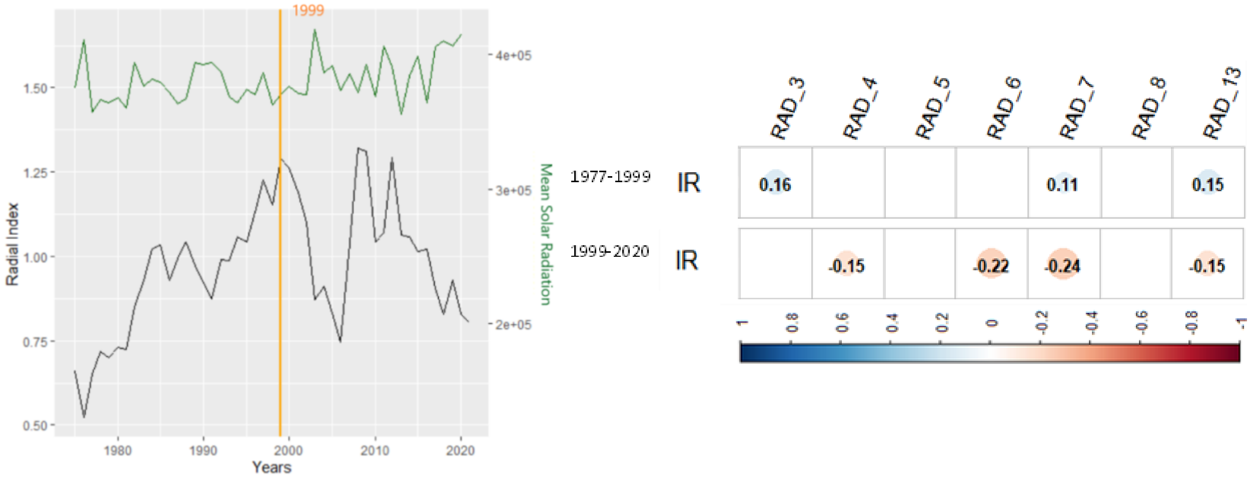

Figure 10. *Left: Radial index and Mean Solar radiation ; Right: Correlation analysis of RI with Radiation variables, where RAD_3, RAD_4, RAD_5, RAD_6, RAD_7, RAD_8, are the radiations for the months of March, April, May, June, July and August respectively, and RAD_13 is the total sum of the annual radiation.*

Although annual radiation itself looks like it did not vary significantly over the study period (Figure 11, left), its significance changed significantly when the two periods are compared. During the first period, radiation of the months of March, July, and total annual radiation were all significantly positively correlated to growth. In contrast, during the second period since 1999, the months of April, June, July and annually are all negatively correlated to growth, and increasingly so as the growing season progressed. This represents a clear shift in the importance and impact of radiation.

Altitude:

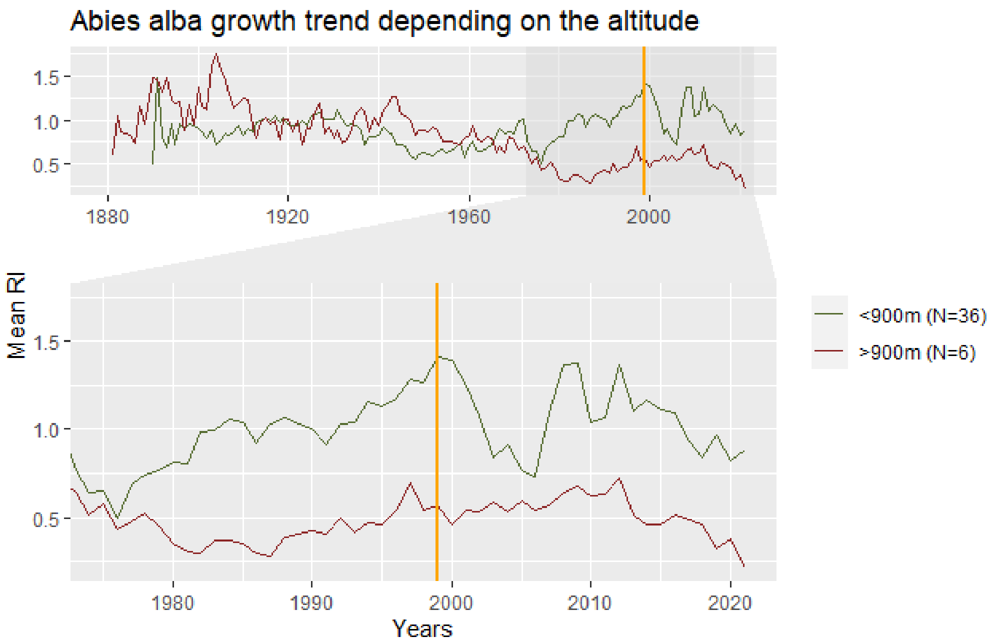

Figure 11: *Growth trend of* Abies alba *from 1868-2021 in terms of the Altitude. The blue curve represents the trend for trees in low altitude (under 600m), the green curve represents the trend for trees in medium altitude (between 600 and 900m) and the red curve represents the trend for trees in high altitude (higher than 900m). N is the number of trees used to create the curve.*

Before 1950 trees in high altitudes had RI more important than trees in medium and low altitudes (Figure 11). And globally medium trends are under lower trends. After 1950 the growth trends of trees in high altitudes started decreasing compared to low and medium altitudes. There is an important decrease of the RI after 2003 for the trees located under 900m whereas nothing like that happened for the trees above 900m.

Trophic level:

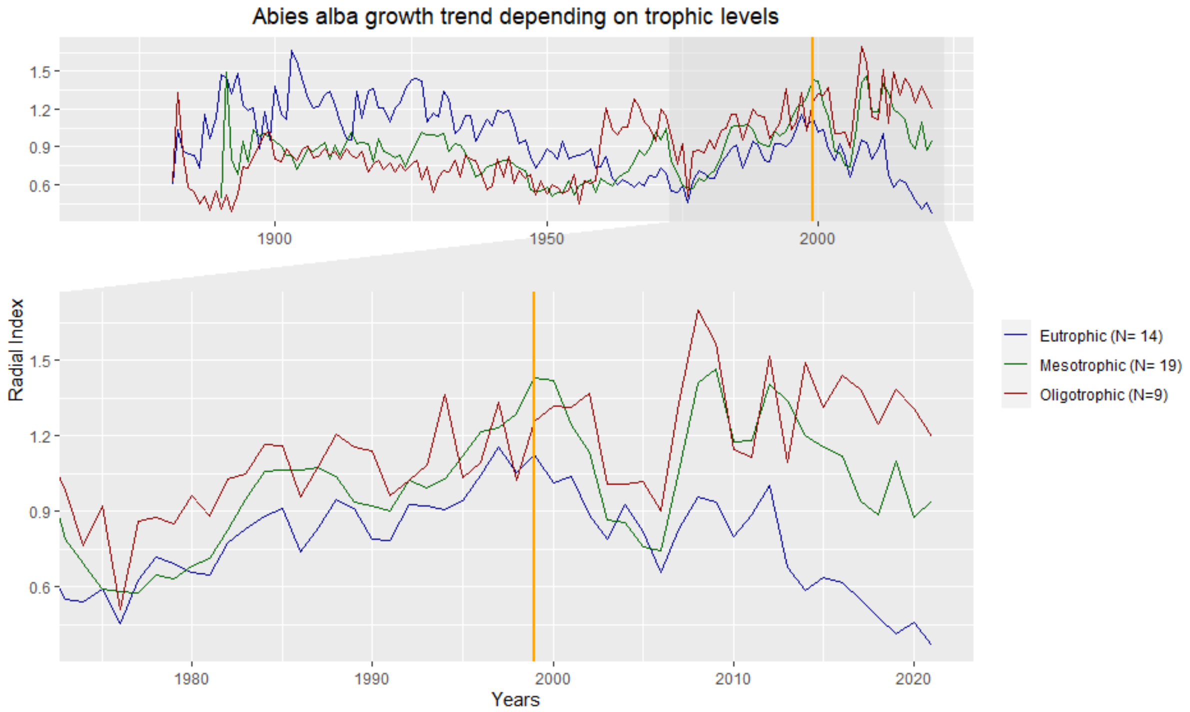

Figure 12: *Growth trend of* Abies alba *from 1868-2021 in terms of trophic level. The blue line represents eutrophic conditions, in green the mesotrophic conditions and in red the oligotrophic conditions. N represents the number of trees used to create the curve.*

Trees in eutrophic conditions grew better than those in mesotrophic and oligotrophic conditions before 1950 (Figure 12). After 1950 there was a reversal of the situation: trees in oligotrophic conditions were growing better than the other ones. In 2000 all growth trends declined for all trees regardless of their trophic level. Around 2005 all growth trends reached 0,6After 2005, the growth of trees in eutrophic conditions declined a lot compared to the other ones. Trees in oligotrophic conditions nowadays grow better than the ones in mesotrophic conditions which grow better than the ones in eutrophic conditions.

pure vs mixed composition of the stands:

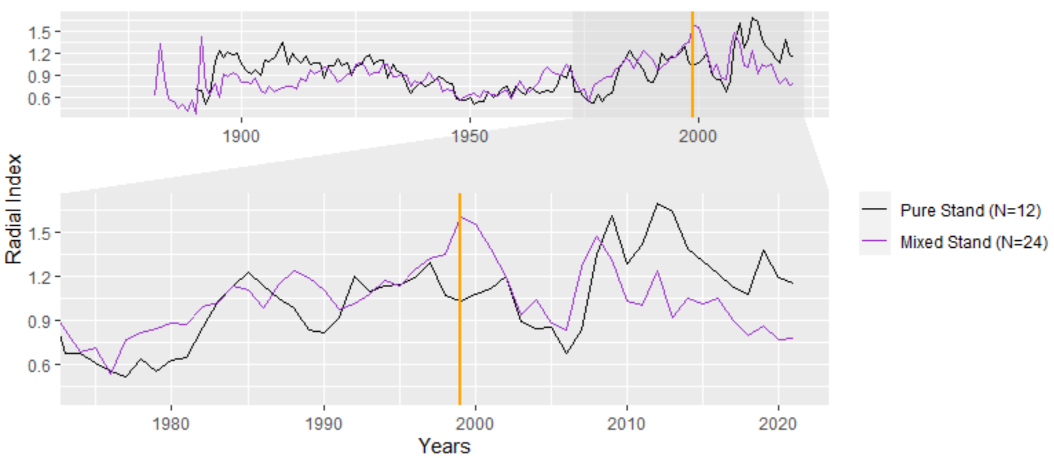

Figure 13*: Growth trend of Abies alba from 1868-2021 in terms of the Stand composition. N is the number of trees used to create the curve.The orange lines highlight the year 1999.*

The growths in the two stand types intersect from the beginning of the chronology. Towards 2008 a difference becomes apparent: growth in mixed forests decreases more strongly than growth in pure *Abies alba* forests (Figure 13).

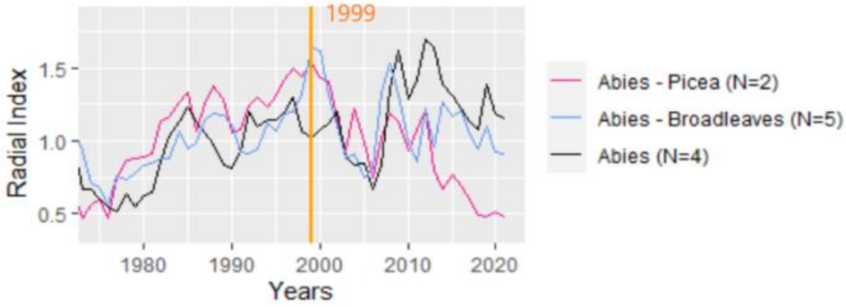

Figure 14 : *Growth trend of* Abies alba *from 1975 to 2021 showing the different trend with the type of mixture : only coniferous (Abies - Picea) and abies with broadleaves. Here broadleaves trees are* Fagus sylvatica *and* Quercus. *N = the number of tree*

First, although this graph must be interpreted with caution because of the low sample size, it shows a clear difference for growth depending on which species *Abies* is mixed with. The growth trend of *Abies alba* was better with *Picea abies* before 1999. After 2012 the growth trend decreased a lot more when *Abies alba* grows with *Picea abies* than when it grows with broadleaves.

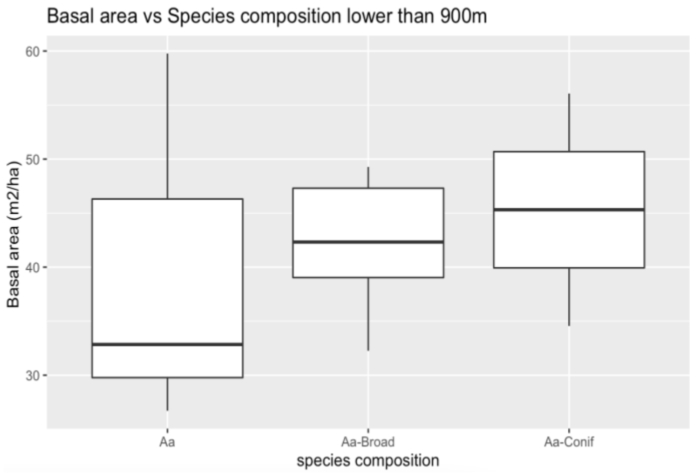

Figure 15. Comparison of basal areas for pure *Abies alba* plots and for mixed plots, *Abies* and broadleaves on the one hand and *Abies and coniferous* on the other

Second, Figure 15 shows a clear difference in basal area depending on stand composition. Pure silver fir plots have a lower basal area than mixed plots on average. Again such results must be interpreted with caution because of the relatively low number of plots in each category.

DISCUSSION

Has the growth trend in Abies alba changed since the turn of the century, compared to the 20th century ?

The hypothesis here was that g*rowth has changed, more specifically, it has declined since the turn of the century.*

Results from the present study provide insight into how changes in the climate can influence forest growth. The trend of silver fir growth illustrates the changes of the RI through the years. The resulting growth trend shows that starting in 1999 and until present, the growth trend of Abies alba in comparison to the 20th century shifted towards a decline in growth. In Becker's (1989) view, precipitation and temperature are climatic variables that can be used to describe conditions under which trees might thrive, where the most adverse conditions can eventually affect the health of forests. Then, the dendrochronological analysis expresses with fidelity the registration of climatic events as mentioned by Schweingruber (1996); Latreille *et al*, (2017).

A decline in the growth rate was evident from the fact that temperatures had continued to rise until 2021. In addition, the ability to observe a clear shift in the growth trend by Becker (1989) also suggested that environmental factors might correlate with the retention of needles of Abies alba, which, under healthy conditions, can retain needles for up to 12 years. It is of note that the largest proportion of healthy trees (64%, Figure 6) was chosen to build the mentioned growth trend.

What is the direction of the change?

During the first period (Figure 8) the RI increases over the years. The consequences of the drought of 1976 can be observed with a sudden decline of the RI. But as the slope is positive the overall growth trend is increasing. Then during the second period the regression line's slope is negative. Decline after years 2003 and 2018 could be explained by severe drought that occured in the Vosges mountain (Breda et al, 2006). The second period shows a decreasing growth trend in the Vosges mountains for the *Abies alba.*

How does dendrochronology contribute to explaining this change?

Time series climatic variables : temperature and radiation

The hypothesis here was that *increasing temperatures and radiation are correlated to reduced growth.*

Changes in the influence of temperature on growth are clear, consistent and directional. Before (during the 1977 - 1999 period), higher temperatures were generally correlated to higher growth, especially in plots of high altitude (the significance of maximum temperature disappeared when these plots were removed). High temperatures were therefore a boosting factor. This is matching the previous studies that found temperature was the limited climatic factor for radial growth in mountainous regions. (David W. & David L.,1994; Mäkinen *et al*, 2002; Jovic *et al*, 2019).

In contrast, since the turn of the century, annual maximum, minimum and average temperatures overall became negatively correlated to growth. This suggests high temperatures have become a limiting factor for radial growth and the effect is even clear in the low and medium altitudes. Such results are consistent with recent years observations of the impact of climate change on radial growth in mountainous areas of Abies alba (Mihai *et al*, 2021; Subotić *et al*, 2020), and may validate the hypothesis.

In terms of radiation, the results are again consistent. Radiation shifts from being positively correlated to growth to being negatively correlated to growth. Thus, although some authors like Hilmers *et al*,(2019) show that southern slopes for fir at European scale are related with more productive sites, in this case, since the turn of the century, higher radiation was correlated with lower growth. This is consistent with the modeling studies of Piedallu *et al* (in press) and of GMN (2020), who find that southern exposed slopes and edges are more vulnerable to climate change. Additionally, the negative correlation of radiation with growth since the turn of the century is more pronounced as the growth season progresses, with higher correlation in July than in April. This suggests radiation has a stronger negative effect during summer. These results corroborate the hypothesis of the growing importance of radiation.

Spatial data

Altitude

The hypothesis here was that *declines in growth are lesser at higher altitudes.* This is because literature suggests that trees at low altitude will experience reduced growth because of climate change, whereas trees at high altitude will experience increased growth because cold temperatures will cease to be a limiting factor of growth. Indeed, growth of trees at high altitudes was limited by cold temperatures, which slows the metabolism (Rolland, C et al, 1999; Bert,D, 1992). However, warmer temperatures and a decreasing rate of snow cover (meaning earlier availability of water in its liquid form) (Way and Oren, 2010) may have been beneficial to high altitude trees in recent years and in the future. Such results were found for *Larix decidua* by Rozenberg et al (2010).

The results of this study show that whilst trees at high and low altitudes had similar growth until roughly 1976, high altitude trees have experienced lower growth since, which runs counter to the formulated hypothesis. Such results can be further broken down into 3 periods: (1) 1976-2003, (2) 2003-2012 and (3) 2012 to 2020.

(1) Between 1976 and 2003, high altitude trees did not experience increases in growth in the same way as low elevation trees between 1976 and the turn of the century, which explains their lower relative growth rates.

(2) In 2003, trees under 900m suffered from the drought and took several years to recover, until roughly 2012, whereas trees in high altitude were not affected by the drought of 2003. This is perhaps because increased drought temperatures at high altitudes did not result in conditions different from the ecological niche of the fir tree. Slight increases in growth for high elevation during the 1976-2012 period may result from climate change induced warmer temperatures and decreased snow cover as expected in the hypothesis.

(3) However, since 2012, roughly, declines in growth have been similar for both high and low elevation trees, unlike what was expected in the hypothesis. Thus, the exploratory results of this study suggest that differences in altitude do not contribute to an explanation of overall decreases in *Abies alba* growth since the turn of the century. Rather, the results presented above that increasing temperature and radiation are both negatively correlated to growth may explain declines in growth at both high and low altitudes since 2010.

Trophic levels

The hypothesis for the trophic level is that the *nitrogen input is no longer a limiting factor for growth*.

The results observed in Table 12 are consistent with the literature. During the first half of the 20th century, nitrogen was a limiting factor and trees grew better on eutrophic soils (Vitousek & Howarth, 1991). From the 1950s onwards, prevailing northerly winds brought nitrogen deposits from industrialized regions in the form of rain. (Galloway et al, 1995) The soils were enriched by these deposits and growth increased from the 1950s to the present. Nitrogen is no longer a limiting factor.

For the second period: In the Vosges mountains, the trend is reversed: trees grew better on oligotrophic soils and less on eutrophic soil. The growth trend is not explained by the trophic level. One hypothesis for this lower growth would be the negative effect of pollutants like aluminum. (Pinto et al 2007).

Is there any difference in growth between pure and mixed stands of *Abies alba*?

The hypothesis here was that *declines in growth are lesser in mixed stands.*

Before 2008, growth was roughly similar between the two types of stand. Since 2008, however, visual assessment suggests that the type of stand has had an importance for the growth of *Abies alba,* with better growth for pure stand (Figure 13). This invalidates the hypothesis and runs counter to existing literature on the benefit of species mixtures for climate change (Lebourgeois *et al,* 2013). It suggests instead that competition between two species on the same plot may have had an increasing impact since trees started to suffer from temperature increases. However, further exploratory analysis nuanced such results and conclusions.

First, it was tested whether the species mixed with *Abies alba* can influence its growth. Here, visual assessment suggested that mixed stands of *Abies alba* and broadleaves (*Fagus sylvatica* and *Quercus)* showed a lesser growth decline than mixed stands of *Abies alba* with the other coniferous *Picea abies* (Figure 14). An explanation of this could be that during early spring, *Abies alba* takes advantage of the increasing temperature and radiation with a larger part of its crown when the leaves of the broadleaves trees are still in the bud (Lebourgeois, 2013, *et al*). Moreover, previous studies show that the presence of *Fagus sylvatica* decreased *Abies alba* sensitivity to exceptional drought (Lebourgeois, 2013, *et al*), which could again explain a lesser decline for *Abies* and broadleaves.

Second, basal areas were compared to test whether differences in growth decline between stands of different compositions could result from differences in inter-tree competition rather than from interspecific competition. Here, a higher basal area for mixed stands compared to pure stands confirms that inter-tree competition may indeed be confounding results of stand composition. Higher declines in growth could result from higher density of mixed stands rather than from interspecific competition. Such results and interpretations are exploratory – with only 2 to 5 trees per type of stand – but give directions for future study.

CONCLUSIONS

1. Growth trends of silver in the Vosges mountains show that starting in 1999 and until present, the growth trend of *Abies alba* in comparison to the 20th century shifted. Indeed, following increasing radial indices over the second half of the 20^{th} century, the turn of the century saw the beginning of a significant decline in radial indices.
2. Temperature and radiation are significantly correlated to this decline, with rising temperatures and higher radiation correlated to lower growth over the 1999-2020 period.
3. Analysis of spatial data concerning environmental factors (altitude, trophic level and stand composition) revealed that these variables modulate growth in a complex and time dependent manner
4. Overall, these exploratory results add to existing literature documenting warming induced stress causing tree growth decline. They confirm downturns in growth in some Western European forests and contribute to providing causal explanations for this shift. Such knowledge will contribute to addressing the impacts of climate change on mountain forests in the future.

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ANNEXES

Annex 1: Protocol

Field work protocol
For the analysis of the recent trend growth of *Abies alba* under the context of climate change

This protocol is designed to obtain data on the relationship between tree growth (assessed from tree rings), forest stand characteristics, climate change and silver fir dieback, working from a previous field campaign conducted by Paulina Pinto in 2002. The protocol was in part inspired by that of FEN students' fir dieback study in 2019.

The implementation of this protocole and subsequent analysis of results resulted in ideas concerning how to improve the protocol. What is below is therefore not a strict description of *what was done*, but rather includes our learnings to propose a method for *what can be done.*

The protocol was designed and tested by 6 FEN students (Clémence Anderhuber, Emma Antoine, Luigui Ramirez, Pengcheng Lai, Jose Porto and Sydney Vennin), one professor (Paulina Pinto) and three technicians (Lukas Putigny, Erwin Thirrion, Sophie Lorentz). On the field, this group was separated into two groups of 4. Barring any abandonment of plots, it was roughly possible to do two plots per day (one pure and one mixed).

The protocol is split into three chronological sections: preparing for fieldwork, conducting fieldwork and analysis of data from the field.

Preparing for fieldwork

- Procurement of the **dataset with results of Paulina Pinto's 2002 field campaign:**
    - Familiarization with this dataset:
        - How the 143 plots were selected
        - What site characteristics were sampled
        - tree inventory information

- **Use of GIS to conduct photointerpretation of the 143 plots:**
    - Use of IGN aerial photographs accessible via ArcGIS.
    - For each plot, assessment of:
        - Whether it had been harvested (1 if yes, 0 if no)
        - Whether there were grey or brown tree crowns, a sign of dieback (1 if yes, 0 if no)

- **Classification plots according to:**
    - whether they have been harvested. Removal of plots which were harvested
    - whether they have dieback or not
    - whether they are pure or mixed
    - their attitude class
    - the trophic level of the soil

- **Selection of plots which will be resampled:**
    - Theoretically
        - Use of Excel to conduct a random selection of plots according to altitude and trophic level
        - Location: focus on the Southern part of the Vosges mountains due to time constraints
        - Assignment of each randomly selected plot to one or both of the questions
            - supplementary points
    - *Nb - this selection was not followed because of logistical constraints related to weather*

- **Preparation of the equipment and tools needed for fieldwork:**
    - Draft of a list of necessary equipment
    - Preparation of data forms
    - For selected plots: extract key characteristics necessary to identify the plot from Excel

- **Loading of points onto IPhiGénie and Google MyMaps:**
    - Conversion of points' coordinates to GPS references using ArcGIS
    - On IPhiGénie
        - loading the 143 points
        - Downloading the immediate zone of selected points at scales 1:12500 for IGN map and 1:6000 (?) for orthophotos. This makes these points available offline.
    - On Google MyMaps
        - Loading the 143 points as one layer
        - Loading the selected points as another layer and assigning a different colour to them

Conducting fieldwork

- **Getting to the plot by car**
    - Use of Google MyMaps to navigate to the road closest to the point by car. Double check Google MyMaps forest roads with IGN map, which has more thorough information on type of road and can help assess whether it is practicable by car.

- **Calibration of the vertex**
    - Use of measuring tape to measure 10.0 m exactly between the transponder and the Vertex front
    - Use of the "calibrate" function in the menu to calibrate the vertex

- **Identifying the center of the plot**
    - Use of IPhiGénie to reach the center of the plot as determined by its GPS coordinates
    - Because of imprecisions in GPS coordinates and to confirm location:

- Use of the identified characteristics of the plot during the 2002 field campaign to confirm the exact center:
  - **Slope**: measurement with clinometer.
  - **Exposition**: with back to the slope, use compass
  - **Confinement**: clinometer
  - **Elevation**: use altimeter
  - **Topographic position** : cf Figure B

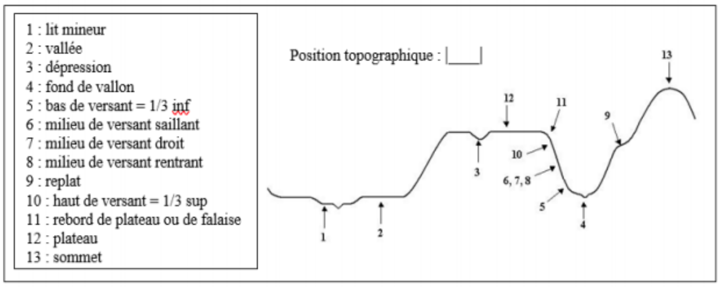


Figure B: Diagram of the different topographic position possibilities

  - **Species**: check the plot has at least 3 dominant fir trees. If it is a mixed plot, there must be 3 dominant trees of the other species present as well.
- Once measures of slope, exposition, elevation, confinement and topographic position match those identified in the 2002 field campaign, the main determinant of the center of the plot will be the presence of dominant trees of present species within the plot
- Once center is selected, transponder is placed on it

- **determination of the diameter of the plot:**
  - The plot has to be 1000m2 by horizontal projection: if there is no slope, its radius is 17.84m. If there is a slope, a larger diameter is necessary. A table is then used to correct the slope and determine the exact diameter of the plot.

- **Conducting of the inventory.** This requires 3 or 4 people: 2 going between trees and 1 or 2 measuring azimuth and recording values
  - **For standing trees**
    - The field workers going between trees start at azimuth 0 (full north with respect to the center of the plot) and proceed clockwise, going up in azimuths
    - For each tree whose Diameter at Breast Height (DBH) is superior to 23.5cm, record:
      - Its distance to the center of the plot (in meters). Use the "DME" function of the vertex and place it at the level of the center of the trunk.
      - Its diameter at breast height
      - Its species
      - Its azimuth
      - For dominant trees, spray paint their inventory number at base on side facing center
  - **For stumps:**
    - Use dedicated data form (*annex #...)*, which requires input about the position of the stump, its diameter and its level of decay

- **Ranking** of trees from largest to smallest, possible to stop ranking at tree number 11

- **Selection of trees to core**
    - If the plot is a pure fir stand:
        - Select trees of ranks 1, 5 and 9
    - If the plot has mixed species
        - Select trees of rank number 1, 5 and 9
        - *Then* for each species, and for each rank (1, 5 and 9)
            - *Either:*
                - The selected tree of a given rank is of the species – keep it
                - The selected tree of a given rank is not of the species: select the tree of the species which is closest to the rank. If both trees of the required species are at equal distance to the rank (e.g. if trees number 4 and 6 are of the species of interest), select the larger tree (see Table X)

Rank	Species	Circumference
1	Spruce	224,5
2	**Oak**	203,6
3	**Beech**	199,8
4	**Beech**	198
5	Oak	176,2
6	**Spruce**	169,2
7	Oak	158,1
8	**Spruce**	150,4
9	Beech	148,9
10	**Oak**	134

Figure 1 An illustration of the process to select trees which will be cored in a mixed plot. The trees of ranks 1, 5 and 9 are selected (red frame), then for each species, those closest to the rank if the rank itself is not of the species (bold)

        - for a plot with three species, obtention of 9 trees to carrot

- **Tagging** of trees which will be cored with a ribbon

- **Coring**
    - There are two instruments to make cores:
        - A manual pressler drill
        - A thermal core drill
    - If there is a slope and if it is possible, core trees parallel to the slope (rather than upslope or downslope) to avoid compression wood
    - if the first core is far from the pith, make another one.
        - If the core shows that the inside of the tree is rotten and it will be impossible to analyse tree rings, select instead a tree of the same species which is closest to 1st/5th/9th ranking tree, depending on which rank the rotten tree occupied.
        - If the tree has a diameter superior to 80cm, a larger core drill will be needed. Return to plot with larger core drill

- Fill holes in trunk with antifungal pegs and with wood filler
- Label cores with a grease pencil: *1000XX-Sp-YY-Z,* with
  - 1000 = code of field campaign
  - XX = number of the plot
  - Sp = species (Aa : *Abies alba,* Fs: *Fagus sylvatica*, Pa: *Picea Abies,* Qp: *Quercus petraea*)
  - YY= number of the tree in the inventory
  - Z= number of the core (1 or 2)
- Store cores in dedicated box, also labelled
- Fill in dedicated form with information on cores (if on pith, if broken or not)

- Measuring **height of cored trees**:
  - Identify two locations at least 30m away from the tree where the crown and base are both visible
  - Use of the vertex
    - place the transporter on the trunk at 1.30m
    - go to point at least 30m away
    - select the programme for height measurement
    - looking into vertex measure distance to transponder: once this, is done, the red cross in the vertex viewpoint will blink
    - still looking into the vertex, slide up to the top of the crown and press three times, to obtain three assessments of height. Take the average of these
  - Measure height from two different viewpoints, then record average of the two averages

- Assessing **health status of fir trees**
  - selection of trees: assess the health status of the 6 largest (i.e. highest ranking) fir trees, and of any cored fir tree which is not included in these 6 trees
    - In a mixed stand, this may mean assessing the health status of fir trees which are not ranked in the top 10 in terms of size
    - In a pure stand, this will mean assessing the health status of the six largest trees *and* of the tree ranked #9 (because it is cored)
  - For selected trees, assessment according to DEPERIS protocol designed by the Ministry of Agriculture and Food (DSF). Two criteria are assessed qualitatively : needle loss and branch mortality. For each, observers give a score between 1 and 5 (see Table A). They should only look at the functional crown (that which is not affected by competition with neighbour trees).

Grade	**Intensity**	**Frequency**	**Number**	**Indicator(%)**
0	Null to very low	Null to very low	Null to rare	0-5%
1	Low	Low	Rare to few	6-25%
2	Quite strong	Moderate	Few	26-50%
3	Strong	High	Many	51-75%
4	Very strong	Very high	A lot	76-95%
5	Total	Every part is concerned	Total	96-100%

Table A (from Fir dieback in Doller valley *FEN report, 2019)*

- As per table B, attribution of an alphabetical score based on numerical scores of branch and needle mortality
- declining trees are trees of scores D, E and F
- Declining stand are stands with more than 20% declining trees

		Lack of Needles					
		0	1	2	3	4	5
Mortality of branches	0	A	B	C	D	E	F
	1	B	B	C	D	E	F
	2	C	C	D	D	E	F
	3	D	D	D	E	F	F
	4	E	E	E	F	F	F
	5	F	F	F	F	F	F

Table B: the transformation from numerical scores for branch and needle mortality to alphabetical scores for dieback (from Fir dieback in Doller valley *FEN report, 2019)*

- Quick **characterization of soil and humus**:
  - Fill in relevant form
  - Analyse the horizons of humus
    - OLn: plant remains whole
    - OLv: plant remains, poorly fragmented, discolored
    - OF horizon: partly decomposed litter, mainly from
    - transformed leaves/needles, recognizable to the eye, combined with aggregates of fine organic matter volume.
  - Use spade to identify the A horizon

Analysing cores :

- **Preparation** of cores with scalpel : flattening in the transversal direction (*i.e.* perpendicular to the rings, on the side on which rings are most visible)
- **Marking** every 10 tree rings with a microscope, lamp and pencil
- **Marking tree rings using Windendro**
    - Use of scanner
        - Core placed in vise, then vise placed on scanner
    - launch Windendro on computer
        - Launch the scan
        - Mark the path from the pith to the bark
        - label the scan
        - year of the last ring: 2021
        - confirm that in "*paramètres*": "*detection des cernes*" is on "*tangente*"
    - 3 red lines appear: mark rings by clicking on the central one, shift and click to adjust inclination and/or position of ring
    - A txt file will automatically be filled. **Do not modify the txt file.**
    - If core not on pit, use transparent calibration chart to calculate number of missing tree rings

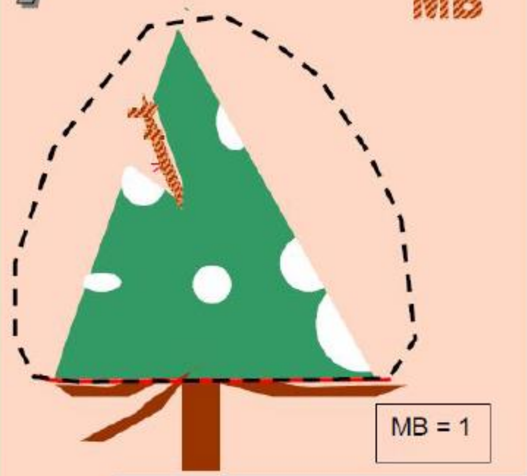
- Filling in Excel spreadsheet with information on analysis:
    - Code of core, operator, date, presence of bark, presence of pith, estimated distance to pith, estimated number of missing cores, difficulty of measurement

- Placement of core in paper accordion, labelled with code (*1000XX-Sp-YY-Z*) and fix it with tape, then once all cored are analysed place accordion in cardboard box

Annexe 2 : Deperis Protocol translated

For softwood

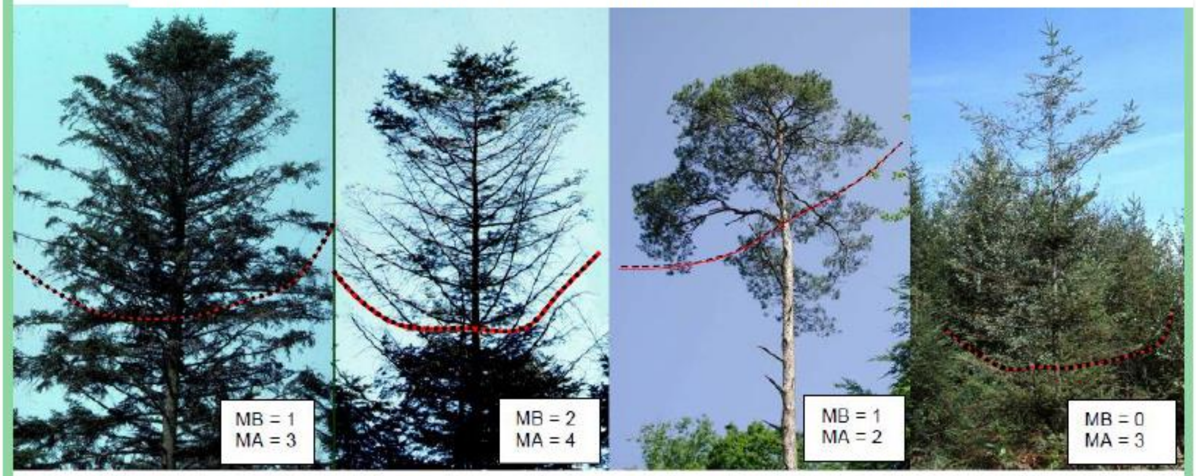
1 Assessment of branch mortality
Qualitative score from 0 to 5



2 **Lack of needles** (notches, windows, abnormal holes, insufficient number of needle years, abnormally small needles, red needles... in the living part not affected by MB)

Qualitative score from 0 to 5

Damage by biotic agents is integrated into MB and MA (MA rust, MA sphaeropsis)



These scores can be assessed in all seasons and are qualitative

3 The DEPERIS summary note

DEPERIS = [((5 - MB)/5)* MR ou MA)] + MB

- A dying tree = D, E, F
- A declining stand = more than 20% of trees in severe decline

		Manque de Ramification (feuillus) Manque d'Aiguilles (résineux sauf mélèze)					
		0	1	2	3	4	5
Mortalités de Branches	0	A	B	C	D	E	F
	1	B	B	C	D	E	F
	2	C	C	D	D	E	F
	3	D	D	D	E	F	F
	4	E	E	E	F	F	F
	5	F	F	F	F	F	F

To possibly complete the diagnosis

4 - observation in detail to determine the identified problems

Cockchafer, processionary caterpillar   Oidium, rust disease   Grade from 0 to 5

5 Foliar deficit (used for RS and Renecofor): includes ALL deficiencies (branch mortality, loss of branching, missing or abnormally pale leaves, insect defoliation...). 5% class