FOREST HEALTH INDICATORS AS VALUABLE TOOLS FOR CLIMATE CHANGE ASSESMENT

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Abstract: Nowadays, the planet is in an unprecedented process of changing. This way, the theory that in the past century was known as “climate change”, has been completely accepted during this century. Society and politicians request information to scientist about the present position and future evolution of the world under this new scene. Whereby, we should develop and provide to forest managers with feasible and appropriate ecological indicators, i.e. indicators that are unambiguous and can be cost-effectively monitored.

Forests and in particular forest health are clear indicators of the effects of the climate change, and monitoring of forest health appears as a useful tool for screening climate change evolution. Since 1987 crown condition surveys (Level I) are carried out within the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forest (ICP Forest), and could easily be applied for monitoring climate change. However, its measurements (crown transparency and discoloration) and correlation with other factors that could show causes of forest decline (pests, pathogens, atmospheric pollutants, nutrient deficiencies, etc) is difficult.

In this study, we worked with ninety individuals of poplar (*Populus x euroamericana*, clon I-214), coming from thirty plantations with different quality sites, ages and forest management. In first place, we tuned up a methodology to objectively assess crown transparency and discoloration, using digital image analysis. Subsequently, relationships among foliar elements and dendrometric variables with crown transparency and discoloration index were assessed. Stress factors caused by climate change were proved to be causing variations in quality site and nutritional status, reflected in the variables crown transparency and discoloration. Thus, the use of these indicators of forest health as valuable tools for climate change assessment was validated.

Keywords: crown transparency, discoloration, indicator, climate change, CROCO.

1. INTRODUCTION

The Third Assessment Report of the Intergovernmental Panel on Climate Change concluded that the Earth is warming, and that some of this warming is due to the burning of fossil fuels and deforestation [15]. Thus, the society and politicians request information to scientist about the present position and future evolution, of the world under this new scene.

Up to now, climate change trends have been measured by means of environmental indicators, as precipitation or temperature, because it was easy to find information. However, these indicators can not explain for certain the future effect of the climate change on biological systems or on human communities. As forests are very stable ecosystems in time, a study of the evolution of the forests could help to understand the effects of climate change. In this sense, Holling [14] notes that an adaptive capability to climate change is a necessary component of sustainability, whereas other researchers have determined that forest health is very affected by environmental stress, as critical ozone levels, meteorological stress factor, air pollution stress, critical deposition level or nutrient deficiencies [5, 6, 11, 13, 19 & 36].

Therefore, we believe that indicators of sustainable forest management and forest health indicators could be used for climate change assessment. Provided that these indicators have some desirable characteristics as; their interpretation should be simple and unequivocal, should be reproducible and comparable, should have a standard measurement error, should have a low measurement error, should be acquired quickly and cost-effectively, should correlate with changes in processes, should be responsive to stressors for concern for management strategies, capable of measurement across large areas of forest, can integrate effects over time, can be related to the overall structure and function of ecosystem, information should be readily incorporated into GIS, developed for broader aims of forest management and should have an historical data base, or should be accessible data for development of a data base [8 & 28].

Crown transparency and discoloration are used as indicators of forest health [38]. Since 1987 crown condition surveys, are carried out within the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forest (ICP Forest, level I). These variables have been visually estimated by observers from the ground, so due to the subjectivity of the assessment, the data quality and comparability of assessments have been questioned [25]. The sources of error in assessments of crown condition are varied; each country has different methods, experience and personal “style” of the observers, weather condition, visibility of the crown, tree species, tree age and social position [10, 29, 32 & 37]. Such sources of error difficult making comparisons between data collected by different countries, different field crews, and even between assessments of the same observer. In the same way, subjective crown transparency and discoloration measurements can not be used to correlate possible causes of forest decline (pests, pathogens, atmospheric pollutants, nutrient deficiencies, etc.).

Researchers have tried to solve these problems; by combining field and control team assessments [9], using data from cross-calibration courses to estimate correction factors for the country differences [16], or by arranging annual training courses for observers and using reference photographs [32]. But all these attempts were not enough. That's why scientists have looked for others solutions by means of digital image analysis [2, 23 & 30] or remote sensing [3, 33, 34 & 35].

Particularly, Mizoue [23] developed a semi-automatic image analysis system, called CROCO, to assess crown transparency from photographs. CROCO calculates a measure of crown transparency (DSO), which is defined as the difference between the fractal dimension of the silhouette of a tree crown (Ds) and the fractal dimension of its outline (Do) [24]. CROCO uses Scion Image for Windows (free available at the http://www.scioncorp.com/) and the widely-used Adobe Photoshop.

Although discoloration has been a variable less studied than crown transparency, some research to eliminate or minimize its subjectivity has been published. So, Innes´ group [17] developed a method for the identification of trees with unusually coloured foliage, based on the use of Munsells’ plant colour charts. However, this method does not resolve entirely the problem of the subjectivity and only recognizes outliers, assuming that the majority of the population does not show discoloration. Therefore, this method cannot be used to obtain a quantitative discoloration index that could correlate with stress factor.

WinDIAS 2.0 (colour image analysis system) uses an image grabber card to offer fast image analysis for a wide range of applications that could need high colour discrimination, for example for plant pathology. WinDIAS can determine discoloration of leaves by means of a palette of colours (RGB; red, green and blue), and the total area of each RGB.

Taking into account that the purpose of this study is to find indicators of forest health that can be used to monitore climate change trend, we assess relationships among foliar elements and dendrometric variables with crown transparency and discoloration index. So we could estimate if variations in quality site and nutritional status of the trees, result from the stress factors caused by climate change, reflected in the variables crown transparency and discoloration. This would validate the use of these variables as indicators of the climate change.

2. MATERIALS AND METHODS

This study was carried out during 2005, over 30 plantations of poplar (*Populus x euroamericana*, Clone I-214) in Palencia (Castile and Leon province), northwest of Spain. A sub-sample of 90 trees was selected, exactly three trees per plantation (higher, medium and lowest visual crown transparency).

2.1. CROCO estimates

During the summer (first two weeks of July), the trees were photographed using a digital photo camera of 8 mega pixels (EOS 350D, Canon). The spacing of poplar plantation is 6x6 or 5x5 meters, enough to avoid crowns to overlap, and keeping norms that CROCO imposes; photographs must be taken with a camera angle lower than ca. 45 degrees and overlap rate with other trees must be lower than about 50 % of crown width [23 & 27].

The DSO values were calculated for each tree using CROCO as follows [25]. First, for all photographs a rectangular region of interest (ROI) was cut out, including the part of the crown exposed to sunlight, but excluding the parts overlapping with adjacent trees. At the same time, the overlap rate (OR) was categorized into 8 classes (no overlap, 25, 50, 75, 100 % overlap on one side of the crown and 25, 50, 75 % overlap on both sides). Second, an automatic thresholding algorithm was applied to the blue-filtered grey scale image to generate the crown silhouette image. Finally the DSO values were calculated from the silhouette images using fractal analysis [22]. Trees that overlapped have positively biased DSO values (underestimation of crown transparency), these were removed using the linear regression developed by Mizoue [23].

In other studies, the fit between crown transparency and DSO were carried out from reference photographs. In this case, there were no reference photographs for poplar, therefore seven photographs of different degrees of crown transparency were sent to one expert field observer of level 1 and 2 plots (European network), in order to assess their crown transparency.

2.2. WinDIAS estimates

Those 90 trees selected to evaluate crown transparency were also used to calculate the discoloration index with WinDIAS (colour image analysis system). So, during the first two weeks of September two entire main branches per tree were removed from the upper third of the canopy. In the laboratory, three terminal leaves were pruned and were analysed with WinDIAS, a mean RGB in function of the area of the different RGB were obtained for each leaf. Then discoloration index was calculated summing numerical values of red, green and blue. Finally, discoloration of each tree was calculated as the mean of those three leaves.

2.3. Foliar element analysis

On the same 90 trees, during the first two weeks of September, period in which the foliar nutrients are more stable in poplar [1], fifteen - twelve leaves were removed per tree, from two main branches of the upper third of the canopy. The oven-dried (60ºC) samples of the leaves were milled (0.25 mm) and digested with HNO3 in a microwave oven. Total carbon and N in milled foliar samples were analyzed by combustion, using a Leco analyzer (LECO, St Joseph, Michigan, EEUU).The total elements P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Ni S, Al, Cr, As, Mo, Cd, Co, Na and Pb in the digested foliar samples were determined by ICP-EOS (Perkin Elmer, Wellesley, MA, EEUU).

2.4. Dendrometric variables

During October dendrometric variables were collected from the study trees; diameter at breast height (Dn), total tree height (Ht), initial crown height (Hi) and crown diameter (Acrown). From these variables other three variables of growth were obtained; diameter at breast height per age (Dn/Age), total tree height per age (Ht/Age) and crown diameter per age (Acopa/Age).

2.5. Statistical methods

Logarithmic transformations were used to linearize the crown transparency and discoloration variables, calculated with CROCO and WinDIAS respectively. This transformation offers the possibility to make full use of the linearity of the predictor variables.

Statistical analyses were conducted in SAS v. 8 [31]. At first, we tried to choose the predictor variables carrying out a principal components analysis (rotation, normalized varimax), but the obtained models explained low variance. Finally, the analysis was conducted using multiple stepwise regression techniques. The fitted models were of the type of Eq.1. Where the foliar nutrients were C, N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Ni S, Al, Cr, As, Mo, Cd, Co, Na and Pb, and dendrometric variables were Dn, Ht, Hi, Acrown, Dn/Age, Ht/Age and Acopa/Age.

3. RESULTS AND DISCUSSION

3.1. Relationship between Crown transparency and DSO index

The values of DSO tended to decrease with increasing crown transparency, with DSO being close to zero at crown transparency (CT) =100% (Fig. 1). So, a fit using the values DSO obtained with CROCO and crown transparency was carried out, estimated by an expert field observer. The exponential function gave a very good fit with simple regression, R^2_{adj}=96.81 % and R^2_{adj} (adjusted for d.f.) = 96.18 %. This value is similar to those obtained for other tree species as; Norway spruce (95.4 %), Silver fir (97.1 %), Scots pine (95.1 %), Larch (92.8 %), Beech (99.9 %), Oak (99.3 %), Sycamore (98.8 %) and Ash (97.7 %) [26]. However, in broadleaves as poplars, many small branches with very little foliage are present and many parts of blight branches and foliage were converted to white in the black&white images, besides CROCO for windows (original version is for Macintosh) gives specially negative values (Mizoue, comm. pers.). For this reason, in trees with high crown transparency, the DSO index was negative, so was not possible use the logarithmic function $CT = a \ln(DSO) + b$ for the fit, as it has been used previously [22 & 25], and an exponential function $CT = a\, e^{b\ DSO}$ was applied.

This fit ratified that crown transparency could be assessed with CROCO from photographs taken in the field, besides it would not be necessary to use reference photographs for the fit. It agrees with the results obtained by Dobbertin´s group [7], who compared the scores given by field and slide assessment, with CROCO. They observed that correlation coefficients of CROCO with each of the field observers were larger than the median correlation coefficients between the field observers. In the same study, they observed that slide assessors significantly underestimated crown transparency in comparison with field observers, which could indicate that the values of crown transparency obtained in our study with CROCO could be a little bit underestimated, because our fit was carried out from photograph assessment. However, in our study it was not very important, since we were analyzing if crown condition reflected the climate change effects, therefore, it was more important to obtain an objective measurement than a perfect measurement (i.e. if the crown condition is a little bit underestimated, all trees would keep the same trend and no tree would be overestimated).

3.2. Relationship between foliar elements and dendrometric variables with crown condition

The results of the statistical analysis confirmed that crown transparency is highly influenced by foliar elements and age. So, the statistical model obtained for CT with all trees (global model) determined that with two foliar nutrients (N and 1/Ca), 47.42 % of the variance of Ht/Age and the age could be explained (Table 1). Age was the most influential variable, showing a negative effect on crown transparency, which agrees with previous studies [12 & 19]. On the other hand, N was positively correlated with CT, i.e. high concentration negatively affected forest health, and this could be due to higher concentrations than necessary. So, an excessive concentration of N may lead to an increased susceptibility of forests to natural stresses, such as fungal diseases, drought and frost [4]. However, mean N concentration of the 90 trees was 2,17% dry mass, similar or lower than foliar nutrient critical levels, 2 – 2.45 % dry mass, calculated from DRIS norms for *Populus deltoides* [20 & 21]. Could be that *Populus x euroamericana* needs less N concentration that *P.deltoides*.

Calcium mean concentration was 2.65 % dry mass, much higher than foliar nutrient critical level, 1.21-2.30 % dry mass [20 & 21], something natural since most of the stands had very basic soils. So could be that base cations neutralise acids that are important nutrient elements [36]. However, 1/Ca had a positive correlation with CT, i.e. an increment of Ca caused a reduction of CT. Finally, Dn/Age variable was correlated negatively with CT, however it is possible that Dn/Age was affected by CT and not the opposite, i.e. high CT index caused by other variables induced lower diameter growth.

Taking into account that age was the most influential factor in the TC, we developed two other statistical models; young trees (2-6 years old) and old trees (8-14 years old) (Table 1). This separation improved the model, increasing the explained variance on about 20 %, R^2_{adj}=68.33 % and R^2_{adj}=66.02 % (Table 1). Besides, tree age was not a predictor variable in the new models anymore, which showed that separation was right. These percentages of explained variance are a little bit higher than those obtained by Ke and Skelly [18], which were round of 34-67 %, although their models had 14 predictor variables. On the other hand, Hendriks´group [13] developed statistical models for the defoliation, using stand characteristics (tree species, provenance, tree density), site characteristics (soil type, nutrient availability), meteorological characteristics (drought, frost), air pollution and pest and diseases. But the variance percentages accounted for R^2_{adj} were 22.59, 33.73 and 23.85 % for Oak, Scots pine and Douglas-fir respectively. Besides, they needed 14, 25 and 9 different predictors respectively, against to 4-6 of our models.

Again, N was a very important variable in both models, keeping a similar performance on the global model. On the other hand, Pb, Na, Cr and As were negatively correlated with CT, which shows that there were no problems of toxicity by heavy metals in the stands (Table 1).

Discoloration model for all trees (global model) explained the 63.96 % of the variance, once divided in young and old, the explained variance was 75.5 and 64.92 %. This Increment was low because the age did not influence in a considerable way in the model (Table 2). These values were very similar to those obtained by Ke and Skelly [18], which were round of 61-77 %, although again their models had more predictor variables, exactly 13-15 against 4-6 of ours models.

Taking into account that the results of the neperian logarithms of values between 0-1 (foliar concentrations) are negative values, in the global model variables such as Cu, Fe, Na and Mn had a positive correlation with discoloration, this result could indicate that these nutrients were causing toxicity in the trees. Again N concentration was an important variable, however now N had a negative correlation with discoloration, contrary to what was seen for the CT models. Why high N concentrations increased the CT and decreased the discoloration, remains unexplained.

The high percentages of explained variance for our statistical models, from very few predictor variables, proved that the crown conditions are valid indicators to monitor possible changes in the quality site and nutritional status caused by climate change.

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Table 1: Relevant predictors explaining crown transparency with their parameter estimates and standardized coefficients.

Global model			Young model			Old model		
P.V	P.E	S.C	P.V	P.E	S.C	P.V	P.E	S.C
Intercep	-0,63002		Intercep	1,5301		Intercep	-1,54589	
N	0,0272	0,37164	Pb	-619,706	-0,56313	C	0,12809	0,39259
1/Ca	3,23055	0,27121	Ht/Age	-0,19687	-0,51491	Ln Na	0,39449	0,39083
AGE	0,06192	0,5253	Na	-3,32735	-0,39189	1/Mg	-2,32118	-0,62686
Dn/Age	-0,1449	-0,41646	N	0,03413	0,62851	Cr	-988,123	-0,3354
			As	-205,567	-0,48197	S	-0,43488	-0,69026
			Mo	120,28464	0,19525	N	0,06988	0,44046
R^2_{adj} = 47.42%			R^2_{adj} = 68.33%			R^2_{adj} = 66.02%		

P.V: Predictor variables. P.E: Parameter estimate. S.C: Standardized coefficients.

Table 2: Relevant predictors explaining discoloration with their parameter estimates and standardized coefficients.

Global model			Young model			Old model		
P.V	P.E	S.C	P.V	P.E	S.C	P.V	P.E	S.C
Intercep	2,06453		Intercep	2,22636		Intercep	2,56511	
1/N	0,49649	0,35938	Ln Cu	-0,03366	-0,57948	S	-0,042	-0,57948
Ln Mn	-0,0115	-0,27906	N	-0,00522	-0,31642	Na	-0,34742	-0,31642
Ln Fe	-0,01644	-0,19874	Ln Fe	-0,0215	-0,45899	N	-0,00273	-0,45899
Ln Ni	0,03061	0,21878	1/K	0,10267	0,28928	P	0,00649	0,28928
Ln Cu	-0,0537	-0,43483						
Ln Na	-0,01379	-0,17491						
R^2_{adj} = 63.96%			R^2_{adj} = 75.50%			R^2_{adj} = 64.92%		

P.V: Predictor variables. P.E: Parameter estimate. S.C: Standardized coefficients.

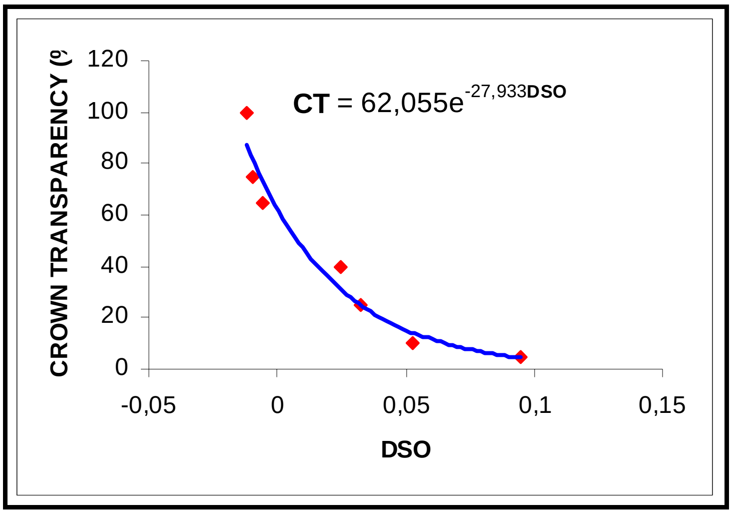

Fig. 1: Fit using the DSO values obtained with CROCO and crown transparency estimated by an expert field observer.

Log (CT or Discoloration) = f_1 (foliar nutrients) + f_2 (tree age) + f_3 (dendrometric variables)   Eq.1