Using A Ceptometer to Validate A Visual Evaluation of the Degree of Defoliation of Holm and Cork Oak Trees

Margarida Tomé and Maria Vasconcelos

Abstract.— The study presented in this paper is part of a project to monitor the defoliation degree of cork and holm oak trees in stands with signs of "decline," after application of different amounts of Aliette, a product specific for *Phytophotora cinnamonii*, one of the possible causes of the "decline." The specific objective was to validate a qualitative classification of the degree of defoliation of cork and holm oak trees. This qualitative classification, visually assessed by an operator, is based on the degree of defoliation of tree crowns according to the EU Regulation nº 1697/87. Two quantitative variables were also used to evaluate the defoliation degree of 210 trees in each of three sites and therefore to validate the subjective classification: percentage of radiation (PAR) that is not intercepted by the crown ($\%rad_{nint}$), and leaf area factor (*kL*), an estimation of the product of leaf area and the extinction coefficient. The percentage of radiation non-intercepted by each crown was evaluated with the Sunfleck ceptometer by measuring the radiation under the tree crown and outside the canopy. Analysis of variance and the median, the Kruskal-Wallis test, and the Kolmogorov-Smirnov test were used to determine if there were significant differences between the values of these quantitative variables for trees classified in different defoliation classes. These analyses showed that, generally, there are significant differences for $\%rad_{nint}$ and *kL* across different defoliation classes, therefore giving some confidence to the subjective classification. It was also shown that the accuracy of the operator improved with practice.

Cork oak (*Quercus suber*) stands are among the more important forest types in Portugal, in terms not only of area but also of the economic value of cork and the importance of the ecosystem cork oak represents. Of the 3.4 million ha of forests in Portugal, 720,700 ha (21 percent of total forest area) are cork oak stands (DGF 1998). These stands produce 123,000 t of cork per year (mean for the years 1988/93); cork products account for 26 percent of the total forest products exported from Portugal (CESES 1996). Although economically not as important as cork oak stands, holm oak (*Quercus ilex* spp. *rotundifolia*) stands, with a total area of 475,700 ha (DGF 1998), are also of great environmental importance in a large area of regions with a semi-arid climate. The apparent "decline" of some cork and holm oak stands in Portugal has been one of the worries of the landowners, and several studies are being carried out on the subject. According to the survey that is being conducted in Portugal following the International Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP), the maximum levels of defoliation occurred in 1991 and 1992, with, respectively, 36.6 and 29.2 percent of the sampled trees with signs of defoliation (Barros and Rodrigues 1994). *Phytophotora cinnamonii* has been claimed as one of the possible causes for the "decline."

Between December 1992 and March 1993, the company Rhône-Poulenc Agro established some trials in cork and holm oak stands to monitor the effect of the application of different amounts of Aliette, a product specific for *Phytophotora cinnamonii*, on the vegetative situation of the oak trees with signs of "decline." Monitoring of these trials was based on an operator's observation and visual classification of the degree of defoliation of each individual tree crown into five defoliation classes, according to the EU regulation No 1697/87 (CEE 1987). The objective of the study reported in this paper was to evaluate the accuracy of the operator in visually assessing the degree of defoliation of the oak trees.

METHODS

Experimental Design

The trials designed to monitor the effect of the application of different amounts of Aliette on the vegetative situation of the oak trees with signs of "decline" were established on 18 sites. Aliette is a fungicide of Rhône-Poulenc origin with 80 percent of fosetil (in the form of fosetil of aluminum) that is used in other *Quercus* to fight

Associate Professor, Departamenta de Engenharia Florestal, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal, and Agronomist, Rhone-Poulenc Agro Lda, Av. Duque de Avila, 185, 3°D, 1050 Lisboa, Portugal, respectively.

Phytophotora cinnamonii. Two of the trials were established in holm oak stands; the remaining ones in cork oak stands. These trials included, in each location, seven large stand areas (4 ha for the aerial and 7 ha for the terrestrial treatments) to which the following treatments were randomly assigned:

- 2 applications of 5 $kg.ha^{-1}$ (aerial treatment)
- 3 applications of 5 $kg.ha^{-1}$ (aerial treatment)
- 2 applications of 5 $kg.ha^{-1}$ (terrestrial treatment)
- 3 applications of 5 $kg.ha^{-1}$ (terrestrial treatment)
- 2 applications of 7.5 $kg.ha^{-1}$ (terrestrial treatment)
- 4 applications of 5 $kg.ha^{-1}$ (terrestrial treatment)
- control

The trials, established between December 1992 and March 1993 by the company Rhône-Poulenc Agro, were visited four times between the time of establishment and July 1994. All the trees inside each plot were observed, and the respective defoliation degree qualitatively assessed by the same operators. Three out of the 18 sites, Palma, Freixo, and Catapereiro, were selected for the validation of the subjective classification using a ceptometer, a device that measures incident photosynthetically active radiation (see below). The Palma and Catapereiro sites are cork oak stands and the Freixo site is a holm oak stand. Some years ago the acorns of the oaks were considered an economically important product and the trees used to be pruned to increase fruit yield (fructification pruning). This practice is still used by some farmers that associate this type of pruning with tree vigor and cork yield. Tree crowns in the Palma and Catapereiro sites had signs of previous pruning, particularly the Palma site, while tree crowns in the Freixo site were clearly unpruned. In each of the seven plots from each site, 30 trees, 10 in each of three defoliation classes (1, 2, and 3), were selected for measurement of non-intercepted radiation with the ceptometer. This quantitative evaluation of the degree of defoliation was made on two dates, July 1993 and July 1994. A total of 210 trees were measured at every site on each of the two evaluation dates. At the same time, the same operator qualitatively evaluated the degree of defoliation of these trees.

Evaluation of the Degree of Defoliation

Qualitative Evaluation of the Degree of Defoliation

The degree of defoliation of every tree was assessed by the same operator and put into one of the five classes defined according to the EU regulation nº 1697/87 (CEE 1987):

1. healthy tree, less than 10 percent defoliation;
2. light defoliation, 11-25 percent;
3. medium defoliation, 26-60 percent;
4. heavy defoliation, higher than 60 percent;
5. dead tree.

Quantitative Evaluation of the Degree of Defoliation

The Sunfleck ceptometer (Delta-T devices, undated) is usually used for indirect evaluation of leaf area index. Model SF-80 was used in this study. It has 80 light sensors for photosynthetically active radiation (PAR) placed at 1-cm intervals along a probe. When this probe is inserted under the canopy, a microprocessor scans the 80 sensors. In sample mode, as it was used in this study, the ceptometer displays a reading (an average of the readings of all the sensors) each time the sample button is pushed, and the operator chooses when to average accumulated readings and store them in memory. The percentage of radiation non-intercepted by each crown was evaluated with the Sunfleck ceptometer by measuring the radiation under the tree crown and the radiation above the canopy. Radiation under each tree (rad_{und}) was evaluated by the average of eight measurements with the ceptometer radially placed under the tree crown (center at the stem) at 45º angle intervals. Radiation above the canopy (rad_{abv}) was measured outside the canopy before every fifth tree, using a similar procedure (eight measurements at 45º angle intervals). The mean of radiation measured outside the canopy just before and after each group of five trees was used as the radiation value for these five trees. All the measurements with the ceptometer were made in the 2-hour period around solar midday and cloudy days were avoided. The trees selected for this study were of similar size. This ceptometer is not designed for measurements under individual trees, because it also measures lateral radiation. However, it was assumed that it was convenient for the present work because it was intended here for comparative purposes. Another problem related to the use of the ceptometer is the fact that it relies on the assumption that the canopy elements are randomly dispersed in space (Delta-T devices, undated). This is not true for the crowns of cork and holm oak trees if they have been severely pruned as is the case at two of the sites, as previously mentioned.

Quantitative evaluation of the degree of defoliation took place on two evaluation dates, June/July 1993 and July/August 1994.

Two quantitative variables were used to evaluate the defoliation degree of each tree to validate the subjective classification:

- Proportion of total radiation that is not intercepted by the crown ($\%rad_{nint}$)

$$\%rad_{nint} = rad_{und}/rad_{abv}$$

where rad_{und} and rad_{abv} are, respectively, the radiation under and above the crown. The greater the value of $\%rad_{nint}$, the higher the degree of defoliation.

- Leaf area factor (kL)

$$rad_{und} = rad_{total} \, e^{-kL}, \qquad (kL = -log(\%rad_{nint})$$

where k is the extinction coefficient, L is leaf area, and other symbols are as before. The leaf area factor is an estimate of the product of leaf area and the extinction coefficient. The smaller the value of kL, the greater the defoliation degree.

Statistical Analysis

To assess the effectiveness of the operator's visual assessment of every tree and placement into one of five defoliation classes, the mean and median values of $\%rad_{nint}$ and kL were computed for each site and evaluation date, by defoliation class. On the second evaluation date, there were a few trees in defoliation classes 0 and 4, but the frequency in classes 0 and 4 was very small. Therefore, only three defoliation classes were considered: (1) light defoliation, <25 percent; (2) medium defoliation, 26-60 percent; (3) heavy defoliation, >60 percent.

Statistical tests were selected to determine if there were significant differences in the values of $\%rad_{nint}$ and kL between trees classified into different defoliation classes. Analysis of variance, the median test, and the Kruskal-Wallis test (e.g., Conover 1980) were used to test if the distribution of the quantitative variables had the same location parameter across the different defoliation classes. Analysis of variance is a parametric test and tests equality of means, while the others are non-parametric tests that analyze the equality of medians. The last are expected to be less sensitive to non-characteristic values of non-intercepted radiation that can be registered under tree crowns highly influenced by previous pruning. These tests are intended to be sensitive to differences in means and medians of the various populations tested, but they may be insensitive to other differences, in particular differences in variance. In fact, a wide disparity of variances may tend to hide the differences in means (Conover 1980). The Smirnov-type tests were therefore also selected to test if the distribution of the quantitative variables ($\%rad_{nint}$ and kL) was the same across the defoliation classes. According again to Conover (1980), these tests are not as sensitive to differences only in means, but they are consistent against a wider variety of differences and, therefore, are often more powerful if the differences in means are accompanied by differences in variances and other differences. Smirnov tests on more than two independent samples may be applied only to samples of equal size, because the tables for the case of unequal sizes have not yet been developed (Conover 1980). To avoid this problem, the two-sample Kolmogorov-Smirnov test was used to compare the distribution of the quantitative variables $\%rad_{nint}$ and kL for defoliation class 1 and a class combining defoliation classes 2 and 3.

RESULTS AND DISCUSSION

Table 1 shows, for each site in each evaluation date, the mean and median values of $\%rad_{nint}$ and kL computed by defoliation class. Figures 1 and 2 illustrate the relationship between the median value of these two quantitative

Table 1.—*Mean (median) values for $\%rad_{nint}$ and kL and respective number of observations (nobs) by defoliation class in 1993 and 1994*

Defoliation class	nobs	June 1993 $\%rad_{nin}$	June 1993 kL	nobs	June 1994 $\%rad_{nint}$	June 1994 kL
			Catapereiro Site			
1	56	0.189(0.155)	1.832(1.867)	122	0.168(0.123)	1.972(2.097)
2	65	0.161(0.141)	1.967(1.960)	63	0.212(0.173)	1.664(1.756)
3	68	0.198(0.180)	1.715(1.716)	4	0.396(0.399)	0.956(0.920)
			Freixo Site			
1	66	0.124(0.099)	2.281(2.308)	124	0.112(0.095)	2.343(2.356)
2	68	0.158(0.143)	1.966(1.943)	32	0.171(0.136)	1.900(1.994)
3	26	0.222(0.190)	1.611(1.662)	4	0.201(0.194	1.644(1.640)
			Palma site			
1	69	0.252(0.183)	1.633	132	0.229(0.195)	1.597(1.636)
2	70	0.271(0.240)	1.457	63	0.283(0.240)	1.383(1.429)
3	70	0.264(0.224)	1.514	14	0.328(0.305)	1.196(1.188)

Figure 1.—*Median values of percentage of non-intercepted radiation ($\%rad_{nint}$) for the three defoliation classes: (1) light defoliation, <25 percent; (2) medium defoliation, 26-60 percent; (3) heavy defoliation, >60 percent.*

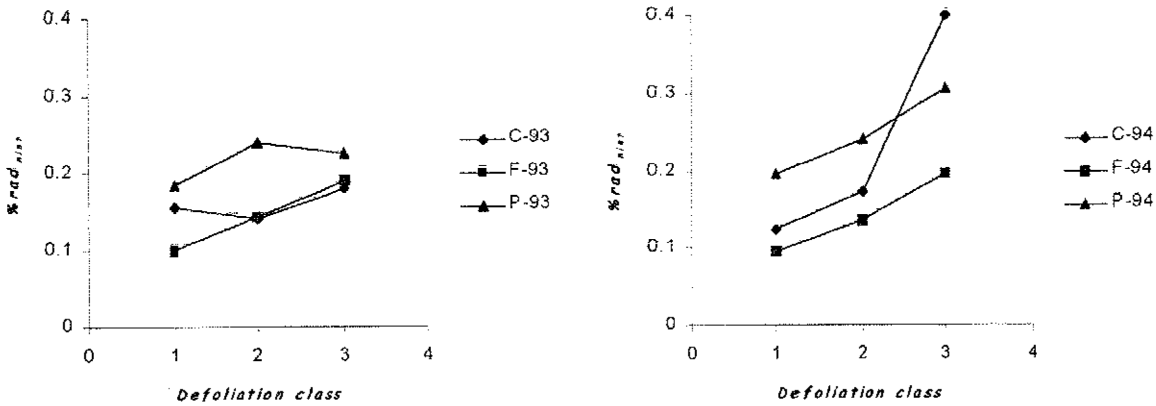

Figure 2.—*Median values of the product of extinction coefficient and leaf area (kL) for the three defoliation classes: (1) light defoliation, <25 percent; (2) medium defoliation, 26-60 percent; (3) heavy defoliation, >60 percent.*

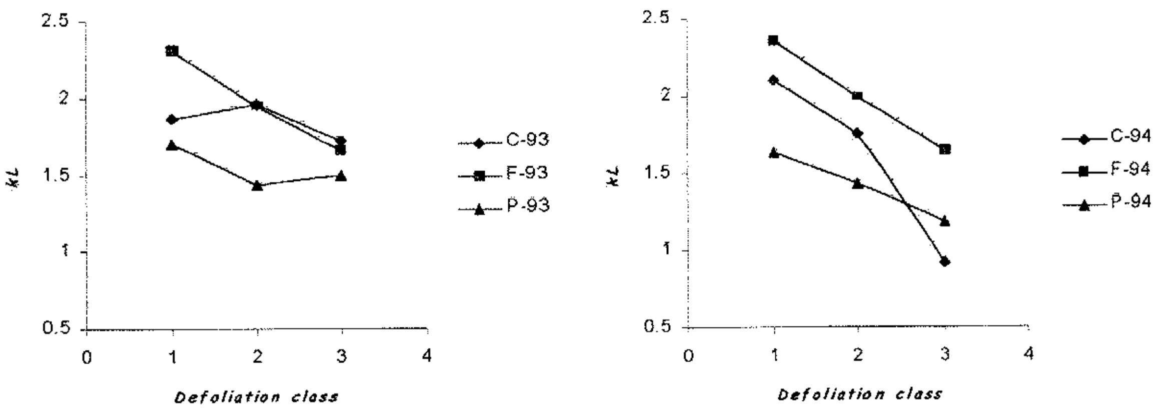

Table 2.—*Probabilities associated with the values obtained for the statistical tests to compare* $\%rad_{nint}$ *and* kL *for different defoliation classes*

	Catapereiro		Freixo		Palma	
	Jul93	**Jun94**	**Aug93**	**Jun94**	**Jul93**	**Jun94**
			%rad_{nint}			
Analysis of variance	0.1078	0.0007	0.0001	0.0005	0.8477	0.0024
Kruskal-Wallis	0.0127	0.0001	0.0001	0.0001	0.2110	0.0015
Median test	0.0099	0.0001	0.0001	0.0005	0.0206	0.0044
Kolmogorov-Smirnov	0.8618	0.0001	0.0001	0.0002	0.0265	0.0046
			kL			
Analysis of variance	0.0194	0.0001	0.0001	0.0001	0.2370	0.0011
Kruskal-Wallis	0.0127	0.0001	0.0001	0.0001	0.2103	0.0016
Median test	0.0155	0.0001	0.0001	0.0005	0.0143	0.0060
Kolmogorov-Smirnov	0.8619	0.0001	0.0001	0.0002	0.0265	0.0511

variables and the defoliation class. As can be seen, there is a reasonable correspondence between the qualitative classification and the mean (median) values of the two variables. The ranking of the mean values of $\%rad_{nini}$ and *kL* for the three defoliation classes is almost always logical, only with two inversions for the Catapereiro and Palma sites in the first evaluation date (1993). The greater agreement between the qualitative classification and the quantitative variables observed in 1994 might reflect an improvement in the ability of the operator to visually assess the defoliation degree. These inversions, however, are not very important as they correspond to very similar mean values for adjacent defoliation classes. They may also be the consequence of one or two abnormally high values for non-intercepted radiation measured under a tree affected by previous pruning. Note that at the Freixo trial, established in a holm oak stand without signs of pruning, there is no inversion in the ranking of the mean values of quantitative variables. The results of the statistical tests (table 2) confirm the significance of the differences between the values of the selected quantitative variables for the three defoliation classes. The median test, less sensitive to abnormal values registered under pruned crowns, suggests significant differences for the three sites on the two dates, confirming that the mean may not be an appropriate statistic if there are pruned trees among the data set. From the two quantitative variables used, the leaf area factor (*kL*), an estimation of the product of extinction coefficient by leaf area, was more in accordance with the visual qualitative classification. This makes sense because this variable integrates two parameters that are greatly related to the degree of defoliation, the extinction coefficient and the leaf area.

CONCLUSIONS

The results obtained in the study reported here gave confidence to the operator who was in charge of the visual evaluation of the degree of defoliation, and the analysis showed also that visual assessment improved with training. The quantitative evaluation of defoliation degree through the measurement of non-intercepted radiation proved to be very useful for the validation of visual assessments. It can also be very important to train an evaluation team, guaranteeing homogeneity of classification. These conclusions are important, because for practical reasons, defoliation degree of individual trees in large areas has to be visually evaluated.

ACKNOWLEDGMENTS

The following people reviewed this manuscript: José A. Tomé, Teaching Assistant in the Department of Forestry, Instituto Superior de Agronomia, Lisboa, Portugal, and Klaus VonGadow, Professor, University of Göttingen, Germany.

LITERATURE CITED

Barros, M. da Conceição; Rodrigues, J.M. 1994. Evolução da vitalidade da floresta portuguesa desde 1988. III Congresso Florestal Nacional, Actas II: 62-79.

CEE. 1987. Jornal Oficial das Comunidades Europeias. Regulamento CEE nº 1696/87 e 1687/87 do Conselho, 10 de Junho de 1987. L 161, 22 de Junho de 1987, 28 p.

CESES. 1996. O sector florestal português. Conselho Ensino Superior-Empresa, Portugal.

Conover, W.J. 1980. Practical non-parametric statistics, 2nd ed. New York: John Wiley &Sons, Inc.

Delta-T devices. undated. Sunfleck Ceptometer. User manual. Delta-T devices. 27 p.

DGF. 1998. Resultados preliminares da 2ª fase da 3ª revisão do Inventário Florestal Nacional. Web site of DGF: http://www.dg-florestas.pt.