Assessment of Chestnut Ink Disease Spread by Geostatistical Methods

University of Trás-os-Montes and Alto Douro
CEGE, Apartdo 1013
5001-911 Vila Real
Portugal

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Abstract
Chestnut ink disease of chestnut associated with the soil-borne pathogen Phytophthora cinnamomi Rands, is observed in single trees as rarefied foliage and general dieback which begins at the branch tips. These conditions can be detected by satellite images with high spatial resolution or by large format aerial photography. However, capturing those images frequently over small sampling areas is very expensive. This study presents an alternative method to evaluate chestnut health using lower cost technology: Small Format Aerial Photography (SFAP), of ground plots taken from light aircrafts. Normal colour and infrared SFAP from 2000 and 2001 were compared with on-the-ground evidence of chestnut ink disease. The spatial variability of health conditions of chestnut plots was adjusted in experimental semivariograms, using a spherical model. The spread of ink disease was then interpolated by ordinary kriging. Different vegetative conditions were detected using SFAP, in 2000 and 2001, showing, respectively, 5.6% and 11.1% of dead chestnut trees. The geostatistical interpolation of the study area (460 ha) found a critical cluster where chestnut decline had increased.

INTRODUCTION
Chestnut ink disease in Northeast Portugal has a widespread distribution. Affected trees can be located near healthy trees and also grouped in clusters away from healthy plants. The factors that affect the dispersion of the disease can be assessed in a regional context, if those factors have a geographical distribution. This variation can be estimated by spatial interpolation methods, namely by geostatistical ones (Webster, 1998). Sustainable chestnut productivity requires easy assessment methods of the disease spread on a regular basis. Remote sensing can be used to collect data on the soil-borne P. cinnamomi, because this pathogen associated to ink disease causes symptoms well observed on images: yellowish, sparse foliage, dieback of branches and gradual decline on infected trees. Early detection of the visible effects on the canopies of affected trees is possible using large-scale aerial photography (Warner et al., 1996; Ambrosini et al., 1997). For this reason, Small Format Aerial Photography (SFAP) techniques are useful in monitoring the disease due to their relatively low cost and chromatic quality (Abreu et al., 2000; Martins et al., 2001).

In the present study SFAP was used to monitor chestnut decline. The results produced in true colour films (2000) and infrared colour films (2001) are compared. The spread of ink disease between 2000 and 2001 evaluated by ordinary kriging and the factors that could affect the spread of the oomycete pathogen on a global scale are discussed.

MATERIAL AND METHODS
A study site from the “Castanha da Padrela” region (Northeast Portugal) was selected due to its high incidence of chestnut ink disease. The site has 460 ha of orchards with chestnuts of different ages, as well as newly planted trees. Conventional aerial photography obtained in 1995 by the “Instituto Português de Cartografia e Cadastro” was used to select the chestnut orchards.

In 2000 colour SFAP were obtained from a Cessna 152 aircraft, using the camera door-mount described by Martins et al. (2001). In order to assess the level of damage...
induced by ink disease, 32 chestnut plots were evaluated and 30 independent plots (1000 m²) were also evaluated via ground survey, using the diagrammatic scale for visual analysis, according to Martins (1997).

Another aerial reconnaissance over the study area was made in 2001. A camera rig was adapted on a Cessna 172 aircraft to support a 35 mm reflex camera (Nikon SLR). That platform was assembled near the right hand door, on the wing structure (Fig. 1). The reflex camera, equipped with a standard 50 mm lens and a yellow filter (Kodak Ektachrome # 12), was loaded with Kodak Ektachrome Professional Infrared Film (CIR). The camera was oriented in a transversal direction i.e., the 24 mm frame edge was parallel to the flight path. The equipment was so mounted in order to provide better accuracy on flight lines (Fig. 1).

Seven flight lines, referenced on the WGS 84 system and at an average flying height of 430 m, were made over 27 circular chestnut plots. The flight lines were controlled by a Global Position System (Garmin Etrex) connected to the MapSite™ software, running in a laptop computer. An electronic intervalometer was adjusted to take aerial photographs with a 60% overlap.

The CIR aerial photographs were processed by the E6 system in a commercial lab. A total of 270 chestnut trees were evaluated by visual interpretation on screen images according to their structural and chromatic characteristics. Five levels of damage (0-4) were defined for the interpretation (0 = healthy; 1 = slightly damaged; 2 = moderately damaged; 3 = heavily damaged; 4 = dead).

Thirty independent plots (1000 m²) were also observed by ground survey, using a diagrammatic scale for visual analysis (Martins, 1997). For each level of damage, a t-test for discrete distributions was undertaken (Snedecor and Cochran, 1982).

The chestnut health data observed in 2000 and 2001 were introduced into a Geographic Information System with a Portuguese grid. The health condition data variability was defined by an experimental semivariogram (Formula 1) and adjusted to a spherical model (Formula 2), where: \( n(h) \) is the number of samples for each lag distance \( h \); \( Z(x) \) is the health condition for each geographical position; \( a \), is the longer distance explained by the model (Soares, 2000).

\[
y(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(x_i + h) - Z(x_i)]^2 \quad (1) \\
\lambda(h) = \begin{cases} 
1.5 \frac{h}{a} - 0.5 \left( \frac{h}{a} \right)^3 & \text{when } h \leq a \\
\frac{C}{h} & \text{when } h > a 
\end{cases} \quad (2)
\]

The spread of ink disease was interpolated by ordinary kriging, according to the following Formula (3):

\[
\mathbf{Z}(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad (3)
\]

RESULTS AND DISCUSSION

The use of SFAP and light aircraft reconnaissance has shown its effectiveness in monitoring chestnut health condition. The convenience of easy control of externally mounted cameras overcomes some of the difficulties imposed by the restricted space in the Cessna 152 or 172 cabins. This kind of camera rig can also be adapted to many types of light aircraft (Long et al., 1986).

The number of chestnut trees sorted by level of damage is shown in Table 1. The five levels of damage observed on colour SFAP are not significantly different from the results of the ground survey according to a one-sided t-test with 95% of significance.

Between 2000 and 2001 an increase of mortality was observed (Table 2). The higher mortality in 2001 was confirmed by interpretation of CIR film (11.1%) and by ground observations (13.0%).

The kriging interpolation found a critical cluster and an increase in chestnut
The most affected area was confirmed by ground observations. The higher incidence of ink disease was near water lines and in soils with bad drainage. The main direction of the disease spread (NW) was also an indicator of the higher dispersion of the disease along water streams (Fig. 2).

The high nugget effect of the adjusted spherical semivariograms ($C_0 = 0.454$ in 2000 and $C_0 = 0.857$ in 2001) shows the high variability of the chestnut health condition on a small scale. This is evidence of the overall distribution of the disease in the study area.

**CONCLUSIONS**

With the methodology used, aerial photography can be obtained easily in a short time period. Also, the cost of SFAP is low; its interpretation is easy and accurate. This makes the regular aerial surveying possible for monitoring the health conditions of chestnut orchards. The cost of each aerial survey flight described here was near 300 Euro in 2000 and 350 Euro in 2001. This is approximately 15% of the cost of a conventional photographic survey. Colour and CIR aerial images provide accurate information on ink disease of chestnut. On CIR photographs, developed by the E6 process, the level 3 of damage was significantly different from the ground survey due to the high magenta colour intensity on declining trees (Table 2). For this reason, in future studies, it will be preferable to use the AR5 process, because the quality of CIR images will be improved (Lillesand and Kiefer, 2000).

The success of geostatistic methods resulted from the need to evaluate recoverable land information (Goovaerts, 1999). In assessing the spread of ink disease, the usefulness of those methods was proved on this particular study area. The disease spread obtained by ordinary kriging can be related to the proximity of water lines and soils with poor drainage. By SFAP and geostatistic interpolation, the most affected areas in Northeast Portugal can be identified easily and, preventive measures can be applied to avoid the spread of the disease.

**Literature Cited**


### Tables

Table 1. Average levels of damage assessed using colour photographs and ground survey showing significant differences with t-test for discrete distributions.

<table>
<thead>
<tr>
<th>Average level of damage</th>
<th>35 mm colour photographs</th>
<th>Ground survey</th>
<th>t-test</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of chestnut trees</td>
<td>p₁</td>
<td>Number of chestnut trees</td>
<td>p₂</td>
</tr>
<tr>
<td>0</td>
<td>17</td>
<td>0.053</td>
<td>28</td>
<td>0.096</td>
</tr>
<tr>
<td>1</td>
<td>102</td>
<td>0.318</td>
<td>84</td>
<td>0.288</td>
</tr>
<tr>
<td>2</td>
<td>116</td>
<td>0.361</td>
<td>88</td>
<td>0.301</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>0.212</td>
<td>64</td>
<td>0.219</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>0.056</td>
<td>28</td>
<td>0.096</td>
</tr>
<tr>
<td>Total</td>
<td>321</td>
<td>1.000</td>
<td>292</td>
<td>1.000</td>
</tr>
</tbody>
</table>

p₁ = proportion of chestnut trees with levels of damage 0-4 in the colour photographs; p₂ = proportion of chestnut trees with levels of damage 0-4 in the ground survey; n.s. = no significant difference

Table 2. Average levels of damage assessed using infrared photographs and ground survey showing significant differences with t-test for discrete distributions.

<table>
<thead>
<tr>
<th>Average level of damage</th>
<th>35 mm infrared film</th>
<th>Ground survey</th>
<th>t-test</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Number of chestnut trees</td>
<td>p₁</td>
<td>Number of chestnut trees</td>
<td>p₂</td>
</tr>
<tr>
<td>0</td>
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<td>0.167</td>
<td>41</td>
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<tr>
<td>1</td>
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<td>0.504</td>
<td>128</td>
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</tr>
<tr>
<td>2</td>
<td>54</td>
<td>0.200</td>
<td>67</td>
<td>0.223</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>0.019</td>
<td>26</td>
<td>0.086</td>
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<tr>
<td>4</td>
<td>30</td>
<td>0.111</td>
<td>39</td>
<td>0.130</td>
</tr>
<tr>
<td>Total</td>
<td>270</td>
<td>1.000</td>
<td>301</td>
<td>1.000</td>
</tr>
</tbody>
</table>

p₁ = proportion of chestnut trees with levels of damage 0-4 in the infrared photographs; p₂ = proportion of chestnut trees with levels of damage 0-4 in the ground survey; n.s. = no significant difference; * = significant
Figures

Fig. 1. Camera rig mounted on a Cessna 172 aircraft wing structure, carrying a 35 mm reflex camera (Nikon SLR).

Fig. 2. Spread of ink disease between 2000 and 2001 made by kriging interpolation. The arrows show the main direction of the experimental model. The spatial resolution of both images is 50 x 50 m.