Temporal Analysis of Sweet Chestnut Decline in Northeastern Portugal Using Geostatistical Tools

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Keywords: aerial photography, *Castanea sativa*, kriging interpolation, *Phytophthora cinnamomi*, *Cryphonectria parasitica*, Portugal

Abstract

The rising demand for sweet chestnut (*Castanea sativa*) in Portugal and elsewhere in Europe has led to more intensive management practices to increase nut production. This intensification has potentially increased the widespread of ink and chestnut blight diseases, causing decline in sweet chestnut orchards health and production and limiting the establishment of new planted areas. In this study we estimated chestnut decline along the last twenty years (1986 to 2006) in the northern part of Portugal using 1986, 1995 and 2006 aerial photography to quantify the damage at the tree level within fixed sample plots according to a categorical scale. Mean damage and damage variance in each date, however, were not significantly different. Geostatistical analyses indicated, however, changes in the spatial distribution of damaged and undamaged areas over time. The spread of decline in the region of study was estimated using Kriging based on the spherical model. During the examined period we observed spread of chestnut decline and increasing damage levels in regions where damage is systematically high. The chestnut productive surface in the region has increased in the last twenty years because new plantations exceeded mortality areas. The spatial analyses applied here have made clearer the relations between the spread of chestnut decline and geographical variables.

INTRODUCTION

Chestnut ink disease caused by *Phytophthora cinnamomi* Rands is a major threat to the sustainability of chestnut agro-ecosystems in the northern part of Portugal where many stands contain clusters of dead and dying trees interspersed with healthy trees (Fonseca et al., 2004). As symptoms, trees exhibit root-rot, necrotic inner bark lesions in the collar region. In the summer, trees may die suddenly with brown leaves and burrs attached to their branches while others remain alive in a declining condition for several years. In northern Portugal, chestnut trees are grown in mountain areas from 600 to 1000 m a.s.l., with rye and potatoes as understorey crops. Soils are usually shallow with high acidity and low organic matter content, as well as low extractable phosphorus and exchangeable bases (Portela et al., 2003, 1999). Soil compaction and root damage from wheel traffic and equipment associated with tillage are common (Fonseca et al., 2004).

The increased demand for chestnut has been satisfied by expanding the area in production, increasing the use of nitrogen, and intensifying management practices such as manuring. New plantations have been used to reduce the negative socio-economic impacts of mortality caused by ink disease and also by chestnut blight (*Cryphonectria parasitica* (Murr.) Barr), a recent pathogen in the region. However, the large scale incidence of sweet chestnut diseases and the factors affecting their spread as well as the spatial and temporal dynamics of mortality and new plantations are not well understood.

Monitoring chestnut health requires expedite methods for damage evaluation because, under favorable conditions, diseases rapidly spread by zoospores and chlamydospores through water and movement of soil particles (Zentmyer, 1980). The control of ink disease is based on preventive measures that should be applied at a regional scale to be effective. As a consequence, an efficient monitoring system able to provide information on number and size of infected foci is necessary (Vannini et al., 2005).

Aerial photography has proven useful in detecting chestnut blight foci (Bissegger and Heiniger, 1994; Ambrosini et al.,1997; Martins et al., 2005, 2007, 2008) in Portugal.

Geostatistical methods, developed in the 1960s for mining and oil prospection (Krige, 1951), can be used to analyze and predict the spread of natural phenomena with spatial variability, like environmental sciences, ecology, forestry and also in plant pathology (e.g., Diggle, 2000). We used conventional aerial images and geostatistical methods to analyze the spatial distribution of chestnut disease affected areas over time and to monitor and evaluate chestnut decline since 1986.

MATERIAL AND METHODS

This study was conducted in the Padrela Mountain region (12,162 ha), Trás-os-Montes region, Northeastern Portugal, where sweet chestnut is a crucial resource. It comprises the parishes of Carrazedo Montenegro, S. João Corveira, Padrela, Tazem, St Ribeira Alhariz, Serapicos and Curros.

We used aerial photography from 1995 (infrared false color) to exhaustively map sweet chestnut orchards in the study area. The accuracy assessment of the photointerpretation was made by Cohen’s kappa index of agreement with ground truth data (Cohen, 1960; Congalton, 1991). Distribution of chestnut orchards in 1986 and 2006 was estimated based on sampling over the same area (see below) using a 1986 panchromatic aerial coverage and a 2006 true color composite. The coverage from 1986, the only not already orthorectified, was orthorectified with PCI – OrthoEngine software.

A random sampling scheme was defined in a GIS (ArcGis 9.2). Circular 20-m radius sampling plots (1,256.6 m^2) were established in the corresponding locations. Within these plots we evaluated tree health condition visually on-screen based on a five level categorical scale (1 - healthy to 5 - decrepit) in each of the dates. This classification has been used before in this and other regions of Portugal and the ground truth tested by Martins et al. (2001, 2007). Within the same plots we evaluated also tree mortality and recruitment (new plantations).

We used variography to analyze the spatial dependence of disease incidence data of the health assessment process above. The semivariogram is a graphical representation of similarity (semi-variance) of data pairs, in this case the health condition of a pair of trees, as a function of the lag distance (h), i.e., the distance between each data pair. As paired data values become less similar, the semivariogram increases in value (Isaaks and Srivastava, 1989). The spatial dependence can be classified assuming the nugget as a percentage of the sill: <25% (strong), between 25 and 75% (moderate), and >75% (weak spatial dependence) (Cambardella et al., 1994). A mathematical function is empirically chosen to fit the semivariogram. The ordinary kriging leads to a prediction map of the tree health condition evaluation. The best fit should minimize the prediction errors, i.e., the difference between known (At) and interpolated locations (Ft), but also should make sense in terms of the natural process to be analyzed (Soares, 2000).

RESULTS AND DISCUSSION

Chestnut orchards in 1995 covered 2,234 ha (18.4%) of the study area (Cohen’s kappa index of agreement K=0.904) (Table 1). In 2006 the total area was 2,562 ha (21.1%). The health condition was constant in the lower classes from 1986 to 1995 but we noticed a slight increase in classes 3 and 4 in the same period. In 2006, class 5 (decrepit) was much higher, but also class 2 was higher than in the previous period
(table 2; Fig. 1). These frequencies were reflected by a general increase in the mean value of chestnut disease incidence during the period of analysis. Differences in disease incidence mean and variance between 1986 and 1995 were not significant (P=0.6465; P=0.4838). From 1995 to 2006, however, we observed a significant increment in the global level damage (P<0.0001***; P=0.0016**). The coefficients of variation calculated for 1986, 1995 and 2006 (32.7%, 30.2%, and 32.7%, respectively) showed a moderate variability (12 to 60%) pattern of the categorical evaluation (Warrick and Nielsen, 1980).

Plantations have exceeded mortality in the study area (Table 3). The chestnut area increased 147±6.1% in the study period but higher spread of chestnut decline rate was observed in 2006, particularly in areas where soil tillage is more frequent. Those practices have been considered as the main causes of transport of soil infested with chlamydospores and other inocula of *Phytophthora* species (Abreu, 1992; Martins et al., 1999). The more severe chestnut decline observed in 2006 is probably a consequence of chestnut blight incidence. The higher mechanization and also the very dry and hot summers between 1995 and 2006 may have caused the observed higher tree mortality. Probably as a consequence of these factors, in 2006 the disease incidence level increased. In these areas, the clustering effect is more evident in the damage level prediction maps of 2006 but it was already present in 1995 and 1986 (Fig. 2). The spatial distribution of decline (darker tones in Fig. 2) indicated that there is a tendency for higher levels of disease incidence in the same places (e.g., North of Carrazeda de Montenegro, Padrela, and Tazem).

Variograms indicated a moderate dependence degree of 1986, 1995 and 2006 health condition data (Table 4; Fig. 1). The coefficients calculated by cross-validation indicated good prediction: prediction errors near zero, RMSSE and absolute difference between ME and RMSE near one, and low values of MAE, MPE and MAPE. The prediction maps obtained from ordinary kriging (

Fig. 2) were, therefore, a valuable estimation of spatial distribution of disease incidence in the region.

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Tables

Table 1. Chestnut area in the study area by parish.

Parish	Total area (ha)	Sweet chestnut area					
		1986		1995		2006	
		(ha)	(%)	(ha)	(%)	(ha)	(%)
Car. Montenegro	2 865.0	547.0	18	701.7	24	804.7	28
S. João Corveira	1 836.1	463.6	24	594.7	32	682.0	37
Padrela e Tazem	2 841.5	360.9	12	462.9	16	530.8	19
St Ribeira Alhariz	1 457.0	210.6	14	270.1	19	309.7	21
Serapicos	1 162.9	106.5	9	136.6	12	156.6	13
Curros	2 000.0	52.9	3	67.9	3	77.9	4
TOTAL	12162.5	1741.5	13.8	2233.9	18.4	2561.7	21.1

Table 2. Descriptive statistics for damage at the plot level evaluated based on a categorical scale (1 - healthy; 5 - decrepit) for 1986, 1995 and 2006.

	1986	1995	2006
Number of plots	124	139	148
25% Percentile	2.00	2.00	2.20
Median	2.19	2.38	2.64
75% Percentile	2.85	2.88	3.41
Mean	2.33	2.37	2.87
Std. Deviation	0.762	0.717	0.936
Std. Error	0.0684	0.0608	0.0770
D'Agostino & Pearson normality test (P value)	0.4251 ns	0.5924 ns	0.0156*
Passed normality test (alpha=0.05)?	Yes	Yes	No
Coefficient of variation	32.68%	30.20%	32.66%
Skewness	0.280	-0.104	0.598
Kurtosis	-0.109	-0.348	-0.133

Table 3. Chestnut area dynamics since 1986 to 2006.

± Sampling Error (%)	1986	1986-1995		1995	1995-200		2006
		Plantations	Mortality		Plantations	Mortality	
TOTAL (ha)	1741.5			2233.9			2561.7
Area dynamics (%)				28.3			14.7
Area dynamics (ha)		1680.5	-588.3	492.4	1171.3	-472.3	327.8
Sampling Error (%)	10.1	14.3	23.5	6.9	20.2	30.3	6.1

Table 4. Variogram parameters and estimation coefficients obtained after cross-validation of the prediction (1986, 1995 and 2006).

Variogram parameters				Estimation coefficients			
	1986	1995	2006		1986	1995	2006
Lag size	425	425	425	ME	0.002	-0.002	-0.001
Num lags	12	12	12	RMSE	0.757	0.984	1.048
Partial sill	0.455	0.760	0.871	ASE	0.754	0.840	0.976
Nugget	0.490	0.594	0.813	MSE	0.001	-0.002	-0.002
Sill	0.945	1.354	1.684	RMSSE	1.005	1.172	1.073
DD	52%	44%	48%	MPE	-11%	-17%	-13%
	Moderate	Moderate	Moderate	MAPE	27%	36%	29%
Model	Spherical	Spherical	Spherical	Samples:	1140	1105	1097

Dependence Degree (DD), Mean Error (ME), Root-Mean-Square (RMSE), Average Standard Error (ASE), Mean Standardized Error (MSE), Root-Mean-Square Standardized Error (RMSSE), Mean Percentage Error (MPE), Mean Absolute Percentage Error (MAPE)

Figures

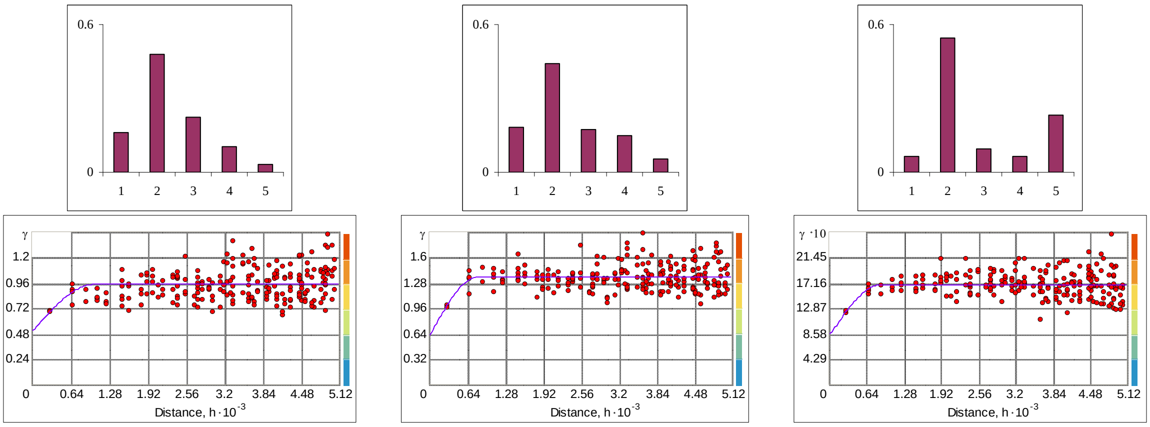

Fig. 1. Histograms of relative frequency of damage evaluated based on a categorical scale (1 - healthy; 5 - decrepit). Top: Left: 1986; center: 1995; right: 2006. Semivariograms for health condition data in the Padrela Mountain. Bottom: Left: 1986; center: 1995; right: 2006.

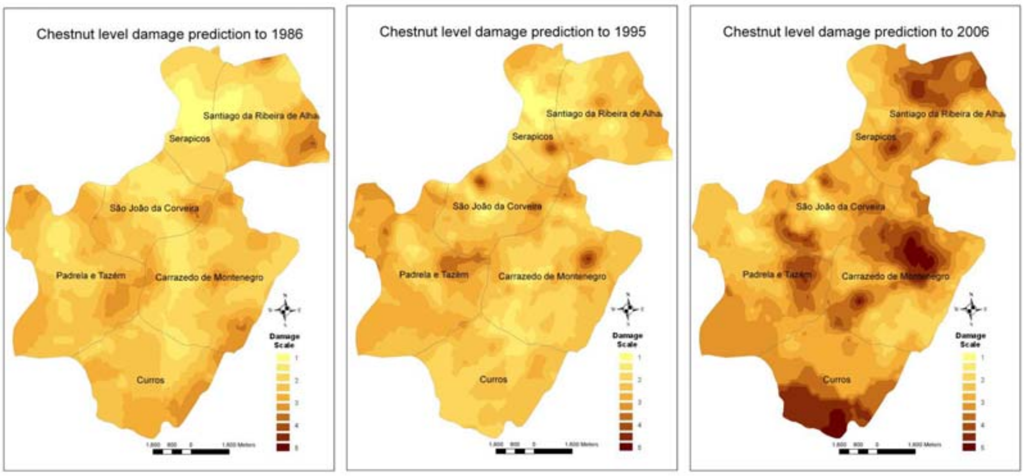

Fig. 2. Ordinary Kriging Prediction maps for 1986, 1995 and 2006.