Final Report- María Hernández Rodríguez

Cost Action: FP 1203 “European Non-Wood Forest Products Network”

STSM title: Predictive empirical models for mushroom production in *Cistus ladanifer* stands.

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Location: University of Eastern Finland, Joensuu, Finland

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Purpose of the STSM

Mushroom production has recently become a very important socioeconomic resource in depressed rural areas. *Cistus* species are broadly present in European forest ecosystems, mainly in the Circum-Mediterranean region. These scrublands can provide high production and diversity of mushroom species, despite being traditionally considered to be unproductive worthless ecosystems. Models based on empirical studies are a useful tool to integrate mushroom production in the management of these areas.

The purpose of the STSM was to develop predictive empirical models for mushroom production and diversity from data that have been collected in *Cistus ladanifer* stands of western Spain over the last four years. Thus, this STSM meets the scientific objectives of the Cost Action and contributes to the Working Group 1: Mushrooms and the Task Force 2: Data and Models.

Description of the work carried out during the STSM

During the three weeks of my STSM in the University of Eastern Finland (Joensuu) the work carried out consisted in the analysis of mushroom production and diversity data that had been previously collected in Spain.

The study area was located in Zamora province in North-western Spain. Plots for the study of mushroom production and diversity after total clearing were established in an area where vegetation was totally removed in 2002, and two areas (young 8-years old and overmature 22-years old scrublands) where total clearing was performed in 2010. Plots for the study of mushroom production and diversity after a fire have been established in two areas that were affected by fire in 1988 and 2002 respectively. These plots had been inventoried in a previous study and data for mushroom production and diversity from 2003 to 2006 were also available. Sampling plots consisted in transects of 2m x 50m, and three replicates were established in each area. All sporocarps were fully collected on a weekly basis during the autumn mushroom season from late October to late December from 2010 to 2013. The spring fruiting season was ignored because in this area it is characteristically very short and almost insignificant.

Fungal sporocarps were fully harvested, transported to the laboratory, identified and fresh and dry weights were measured. Shannon diversity index, based on dry weight of the fruiting bodies was calculated. Climatic data have been provided by the closest meteorological station (Spanish Meteorological Agency).

Vegetation structure of all the plots was measured in 2013. Shrub canopy cover was estimated using the line-intercept method and the mean height of the shrub layer was calculated as the mean height of the plants measured at meter intervals. Both measures were taken over transects' centerline.

During my STSM in Joensuu, we develop empirical models for total production (fresh weight, kg ha^{-1}) and diversity (Shannon diversity Index) for mycorrhizal and saprotrophic species, as well as for the production of the most economically important species: *Boletus edulis*. Two different management treatments were studied: burning and total clearing. In the first modelling approach, climatic variables and time after treatment were used as predictors.

In order to facilitate the practical implementation of the models by forest managers, we decided to fit more models including the structural characteristics of the vegetation (cover and mean height) instead of time after treatment. Thus, these models can be used from inventory data if managers do not know the time after fire or total clearing. Data for vegetation characteristics was not available for all the sampling years. Vegetation structure models for mean height and canopy cover were fitted from available data in order to predict missing values. Different growth functions such as Hossfeld I, Hossfeld I (modified), Smalian, Gompertz, Richard-Chapman and Van der Vliet were tested for mean height and canopy cover modelling. Final equations were selected based on fitting statistics and biological considerations.

Finally, we develop empirical models for mushroom production and diversity for mycorrhizal and saprotrophic species and for *Boletus edulis* production using climatic variables and vegetation characteristics as predictors.

All the models were fitted using nonlinear regression analysis and fixed-effects modeling approach with R software. Models were evaluated considering following criteria: (a) agreement with current biological knowledge, (b) logical behavior of the model set in extrapolations, (c) simplicity, (d) statistical significance (p-value < 0.05).

In the final part of the STSM, we have already started to write an article in order to publish the results of this work in a peer-reviewed scientific journal.

Description of the main results obtained

The main aim of this STSM has been fulfilled and all the planned models for mushroom production and diversity have been fitted in order to provide a useful tool for forest managers of these ecosystems.

Models for the mean height and canopy cover for *Cistus ladanifer* scrublands after fire and total clearing have been also fitted. Mean height growth for *Cistus ladanifer* did not show any significant difference between the two studied treatments. Gompertz equation was the most consistent from both biological and statistical points of view:

$$H = \exp(5.07553 - 3.33490 \cdot \exp(-0.34492\mathrm{Y}))$$

Where H is the mean height of *C. ladanifer* (in cm), and Y is the time after treatment (years). Residual standard error was 18.35.

Canopy cover was significantly different for the two studied treatments. After fire soil canopy cover is higher at younger ages than after total clearing. Thus, treatment was included in fitted model as a dummy predictor. Van der Vliet equation was chosen to fit canopy cover evolution over time for *C. ladanifer* scrublands, as it was the most biologically and statistically consistent:

$$CC = 79.7675 \cdot \left[1 - \left(1 + \frac{2Y}{2.7982 - 1.7610 \cdot TREAT} + \frac{2Y^2}{(2.7982 - 1.7610 \cdot TREAT)^2} \right) \cdot e^{-2Y/(2.7982 - 1.7610 \cdot TREAT)} \right]$$

Where CC is the canopy cover of the shrubland (%), Y is the time after treatment (years) and TREAT equals to 1 if the scrubland was established after fire and equals to 0 if the scrubland was established after total clearing. Residual standard error was 12.39.

Models for mushroom production and diversity for mycorrhizal and saprotrophic species and *Boletus edulis* production had been developed using both, time after treatment and vegetation characteristics as predictors. Thus, models for mushroom production and diversity can be applied from both, inventory data or management history data of the scrublands. Table 1 shows the model specification and the residual standard error for all the models fitted.

Table1: Predictive empirical models for mushroom production and diversity of mycorrhizal and saprotrophic taxa and for *Boletus edulis* production based on climactic data and using also time after treatment and vegetation variables as predictors.

	Predictive empirical models	Res. std. err.
Time after treatment	$P_{Myco} = \exp(-4.7588 + 2.4323 \cdot \ln(Tm\min_O) + 4.1331 \cdot \sqrt{Y} - 0.7497Y)$	135.60
	$P_{Sapro} = \exp(-4.90905 + 3.91042 \cdot \ln(Tm\min_{O+N}) - 0.08398 \cdot Y)$	57.33
	$H_{Myco} = \exp(-2.360987 + 0.048370 \cdot T\min_{S+O} + 0.004765 \cdot P_S - 0.185691 \cdot Y + 1.383084 \cdot \sqrt{Y})$	0.56
	$H_{Sapro} = \exp(-0.15733 + 0.03557 \cdot T\min_{O+N+D} - 0.06509Y + 0.4442\sqrt{Y}$	0.44
	$B.edulis = \exp(-17.09504 + 0.21615 \cdot T_{s+o} + 8.70958 \cdot \log(Y + 0.001) - 0.65478Y)$	14.22
Vegetation variables	$P_{Myco} = \exp(-9.44295 + 1.73855 \cdot Tm\min_O + 2.43656 \cdot \sqrt{H} - 0.12501 \cdot H)$	137.07
	$P_{Sapro} = \exp(-34.074016 + 12.503545 \cdot \ln(Tm\min_{S+O+N+D}) - 0.008145 \cdot H)$	55.73
	$H_{Myco} = \exp(-6.937640 + 0.117106 \cdot Tm\min_{S+O} + 0.004609 \cdot P_{A+S} - 0.041030 \cdot H + 0.922719\sqrt{H})$	0.46
	$H_{Sapro} = \exp(-0.025681 + 0.041956 \cdot T\min_{O+N} - 0.006450CC + 0.199355\ln(CC + 0.001))$	0.40
	$B.edulis = \exp(-1537 + 0.3669 \cdot Tm\min_{S+O} + 20.85\sqrt{H} - 0.8591H - 130.4\sqrt{CC} + 587.5\ln(CC + 0.001))$	12.48

P_{Myco}: production of mycorrhizal taxa (kg ha^{-1}); P_{Sapro}: production of saprotrophic taxa (kg ha^{-1}); H_{Myco}: Shannon diversity index for mycorrhizal taxa; H_{Sapro}: Shannon diversity index for saprotrophic taxa; *B.edulis*: *Boletus edulis* production (kg ha^{-1}). *Tmmin*: Mean minimum temperature, *Tmin*: Absolute minimum temperature; *P.* Monthly precipitation; *T:* Mean temperature. Subscripts *A, S, O, N, D* in climatic variables indicate the months included in these variables (August, September, October, November and December). *Y:* Years after treatment; *H:* Mean height of *C. ladanifer* (cm); *CC:* Canopy cover of *C. ladanifer* (%). Res. std. err.: residual standard error of the model.

No significant differences were found for the two studied treatments (forest fire and total clearing) in any of the models. The regression analyses showed that minimum temperatures were the most significant predictors in mushroom production and diversity. It is necessary to consider that, although precipitation was not present in most of the models, this does not mean that it has no influence in mushroom fructifications because it is correlated with the temperatures included in these models. Mycorrhizal taxa are influenced by earlier temperature (September and October) whereas saprotrophic taxa depend on later temperatures (October, November and December). In the case of *Boletus edulis,* which is the most economically valuable species in these ecosystems, it can be found from 5-6 years after treatment to the end of *C. ladanifer* life cycle. These models can be a useful tool for the optimal management of these areas in order to enhance fungal production while preventing forest fires.

Future collaboration with host institution

This STSM will allow to the two institutions, the Sustainable Forest Research Institute of the University of Valladolid and the University of Eastern Finland to collaborate in a continuous way in order to improve their knowledge of mushroom production models.

Foreseen publications/articles resulting or to result from the STSM

Work and results of this STSM will be published in a peer-reviewed scientific journal. This article has already been started and it will be submitted to a journal in the next few months.