Factors affecting biomass and wood extraction from coppices in Europe: Productivity models and influence of technological changes.

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EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

IUFRO 125th Anniversary Congress
18-22 September 2017, Freiburg, Germany
Session 82: Traditional coppice: ecology, silviculture and socio-economic aspects

BACKGROUND

Traditional coppices harvesting time studies compiled by the members of the European **COST Action EUROCOPPICE (344 comparable datapoints from 8 European Countries)**

Many of the time studies **only covered the felling and processing phases**

Regarding **extraction operations**, the data source → **128 comparable coppice harvesting data points from time-studies**

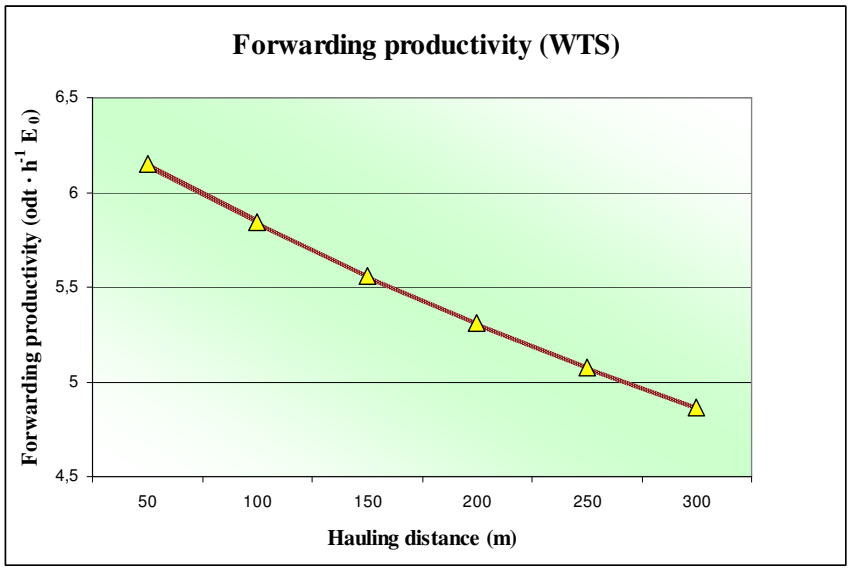
- **between 1975 and 2015**
- **in Italy (99), Spain (24) and the United Kingdom (5)**
- **Productivity most commonly studied variable → Volume per scheduled machine hour ($m^3 \cdot smh^{-1}$)** for the terrain transport of whole trees, logs and/or firewood from **traditional hardwood coppices (*Quercus* genus, beech and chestnut stands)**

GOALS

Main objective → to **deepen the study of the extraction phase in those coppice harvesting time studies**, in order to:

- **Develop productivity models, both general and specific for the different extraction means/systems**, identifying the main explanative factors to approximately estimate productivity.

- **Evaluate changes in productivity provoked by technological advances or differences in used machinery** along the time covered by the studies.



QUALITATIVE FACTORS

Factor	Value	Number	Frequency (%)
Felling type	Selective	61	49
	Clearcut	64	51
Mechanized bunching	Yes	18	14
	Not	107	86
Harvesting system	FireWood (FW)	19	15
	Cut-To-Length (CTL)	26	21
	Full Length (FL)	21	17
	Whole Tree (WT)	54	43
	Pruning Residues (PRES)	5	4
Extraction type	Ground skidding (SK)	49	39
	Forwarding (FW)	31	25
	Cable yarding (CAB)	33	27
	Animals (ANIM)	8	6
	Shovels (SHOV)	4	3

No significant differences in productivity among species, felling type (clearcut or selective) nor harvesting systems, possibly because of the wide range of studied cases and product types. **Only small significant differences among extraction types.**

Besides those factors, **the following variables were selected as possible explanatory** ones:

Independent Variable	Average value	Minimum	Maximum	Variation Coefficient
Maximum extraction distance, m	**395**	25	1500	96%
Average load volumen ($m^3 \cdot cycle^{-1}$)	**2,1**	0,06	10,6	138%
Average stem volumen ($m^3 \cdot tree^{-1}$)	**0,14**	0,002	2,03	167%
Average removal ($m^3 \cdot ha^{-1}$)	**107,3**	8	314	69%

Average values and ranges of the candidate explanative variables for all the coppice

Among simple combinations of the proposed explanatory variables, **the better relation found was among the productivity and the ratio**

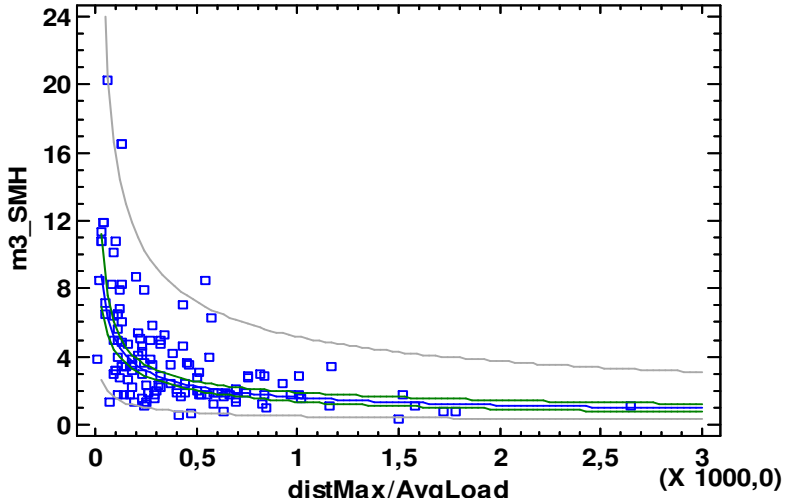
$$X = \frac{\textbf{Maximum extraction distance,m}}{\textbf{Average Load Size,m}^3 \cdot \textbf{cycle}^{-1}}$$

After the removal of three outliers from the analysis, besides the Italian riverbed cases, that showed a different behavior compared to the rest of the data, the fitted equation was:

$$\textbf{Productivity} = 46{,}39 \cdot X^{-0{,}49} \qquad [0]$$

with $R^2 = 0{,}42$.

The ANOVA and the analysis of the model showed **significant differences among the regression lines for each Extraction Type** (skidder, forwarding, cable, shovel and animals). The two last were **rejected, because of the weak fitting parameters and the small number of cases.**



Statistical summary for Productivity (m^3/SMH)			
	Riverbed cleaning	**Extraction with animals**	**Extraction with shovels**
Count	4	8	4
Average	3,17	1,79	3,82
Standard Deviation	3,57	0,40	1,19
Variation Coefficient	112,8%	22,6%	31,1%
Minimum Value	1,04	1,3	2,8
Maximum Value	8,5	2,7	5,38
Range	7,46	1,40	2,58
Standard Slant	1,60	2,06	0,72
Standard Kurtosis	1,58	2,70	-0,39
Slant and kurtosis show that the distribution does not correspond to a normal one.			

Statistical summary for Productivity in Italian riverbed cleaning operations, coppice extraction with animals and coppice extraction with shovels (out of the general model).

The remaining different extraction types FW (forwarding), SK (ground skidding) and CAB (cable yarders) were analyzed, **as a whole and separatedly**, using the nonlinear regression technique, with the base model:

$$\textbf{Productivity} = A \cdot \textbf{MaxDist}^{B} \cdot \textbf{AverLoad}^{C} + K$$

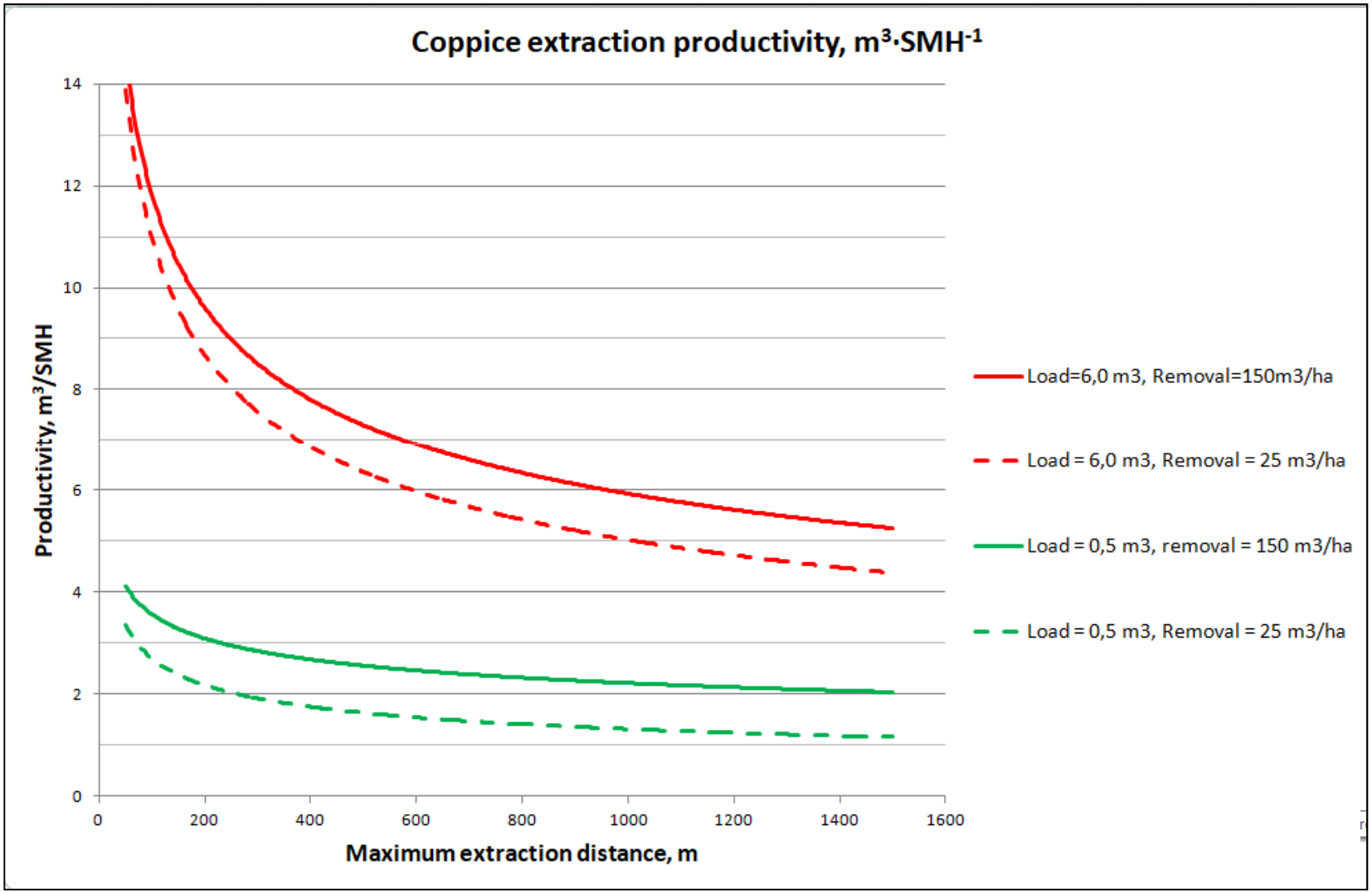
Average Stem Volume and **Average Removal** were considered again as linear addends.

The best result for all the data points with Extraction Types SK, FW and CAB:

$$\text{Productivity } (m^3/SMH) = 18{,}9 \cdot [\text{AvgLoad}(m^3)^{0{,}584}] \cdot [\text{MaxDistance}(m)^{-0{,}348}] + 0{,}0072 \cdot \text{Removal}(m^3/ha) \quad [1]$$

With an adjusted – by degrees of freedom - **R^2 = 64,5% and an average absolute value of the residuals of 1,2 m^3/SMH for the 108 included coppice extraction data points**, while the stem size coefficient and the constant K estimations were not significant, so they were rejected.

The general model [1] is depicted in the Figure:



Coppice extraction productivity equation for the Extraction Types Ground skidding, Forwarding and Cable Yarding.

Extraction Type	Productivity, m^3/SMH			Maximum Distance, m			Average load, m^3/cycle			Removals, m^3/ha		
	Aver	Min	Max	Aver	Min	Max	Aver	Min	Max	Aver	Min	Max
SK	2,8	0,54	8,5	302	30	1000	0,75	0,08	3,0	111	9	314
FW	6,4	1,8	11,9	672	50	1500	5,96	1,9	10,6	85	12	243
CAB	3,2	0,3	7,0	236	50	500	0,50	0,06	0,95	118	8	274

Average values and ranges for the Productivity and its explanative variables (skidding, forwarding and cable yarding extraction in coppices).

The resultant **new regression equations for Skidding and Cable Yarding were better than the global one**, looking at the average absolute values of the residuals, so they are recommended for using in the correspondent cases better than the model [1].

The skidding equation was:

$$\textbf{Productivity } (m^3/SMH) = 49{,}0 \cdot [AvgLoad(m^3)^{1{,}14}] \cdot [MaxDistance(m)^{-0{,}574}] + 0{,}0094 \cdot Removal(m^3/ha) \qquad [2]$$

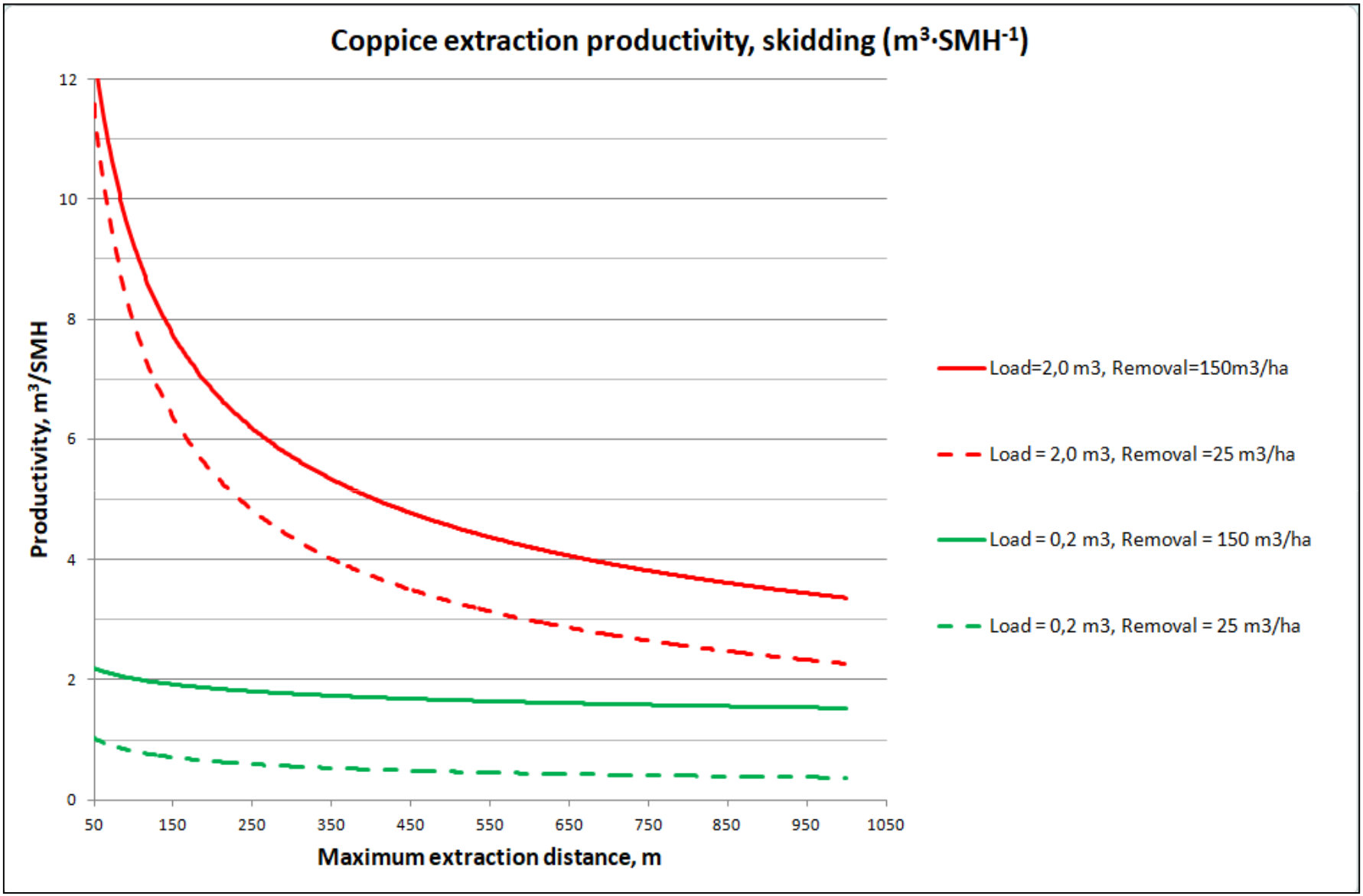
R^2 (adjusted by d.f.) = 52 **%**
Absolute average error = 0,87 (average absolute value of residues, m^3/SMH).

The **predictive equation for cable yarders**' group of extraction operations was:

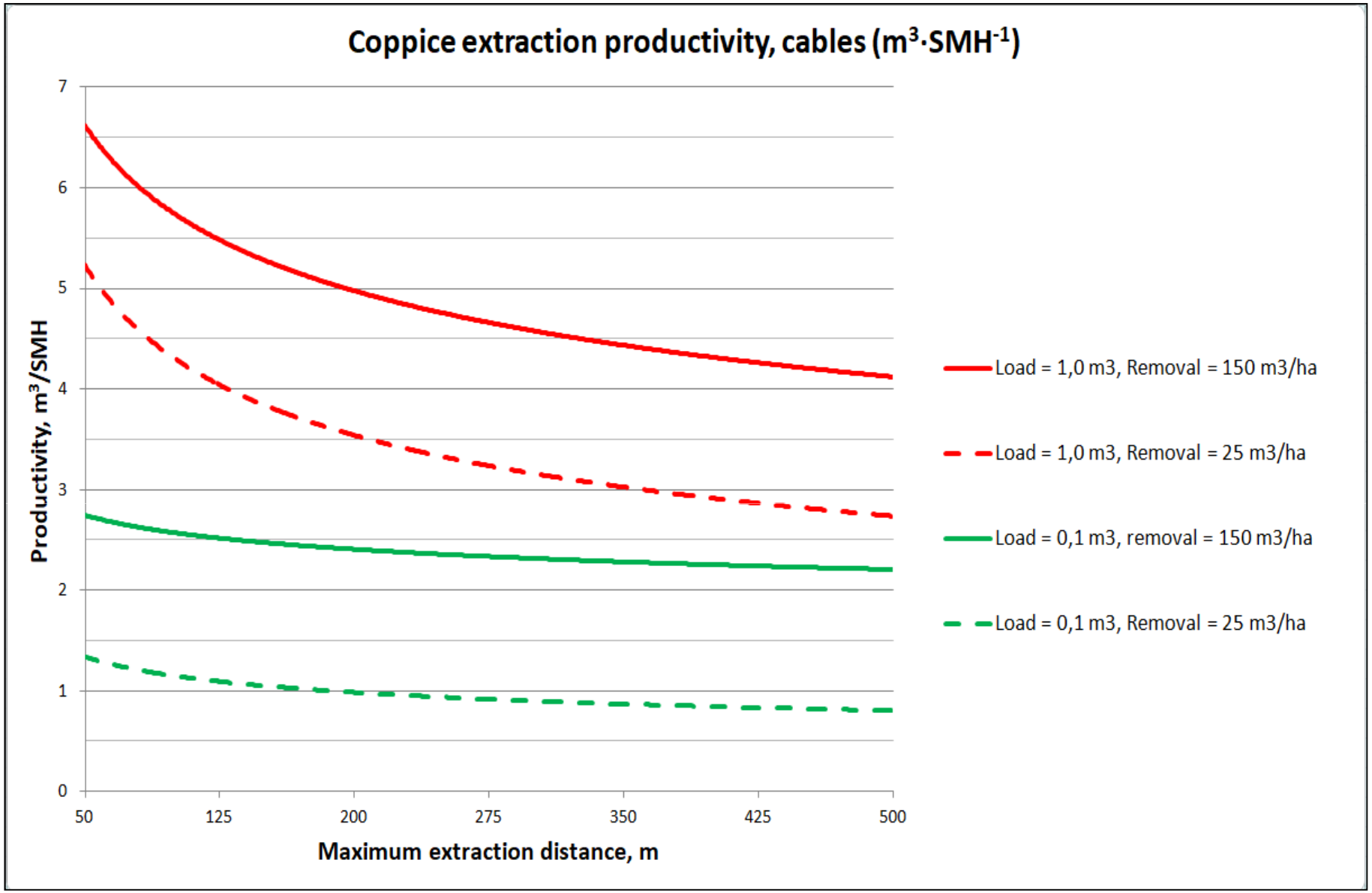
$$\textbf{Productivity } (m^3/SMH) = 16{,}3 \cdot [AvgLoad(m^3)^{0{,}699}] \cdot [MaxDistance(m)^{-0{,}304}] + 0{,}0113 \cdot Removal(m^3/ha) \qquad [3]$$

R^2 (adjusted by d.f.) = 50 **%**
Absolute average error = 0,80 (average absolute value of residues, m^3/SMH)

In both cases, the fitting quality was better than the for the global model [1]; although the value of adjusted R^2 is lower, **the average absolute value of errors is reduced from 1,2 m^3/SMH to 0,87 and 0,80**.



Coppice extraction productivity equations for the Extraction Type Skidding.



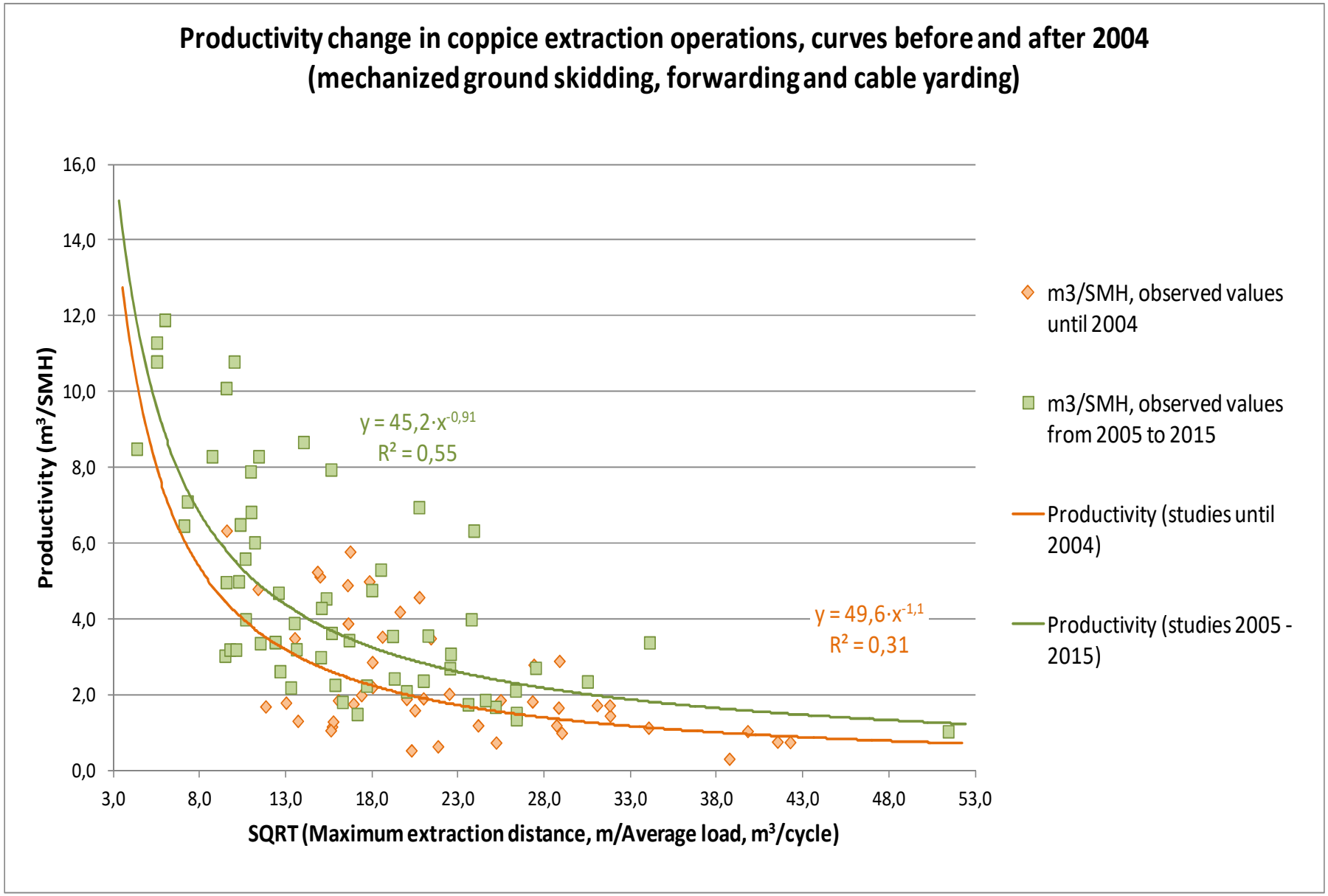
Coppice extraction productivity equations for the Extraction Type Cable Yarding.

To study the temporal changes in productivity, the last studies (from 2005) were compared to the former ones (enough subsample size, 47 until 2005 and 66 afterwards).

The difference in average productivity for all the extraction means was statistically significant (ANOVA). The recent value (5,3 m^3/SMH) more than doubles that from studies before 2005 (2,4 m^3/SMH).

The regression lines for productivity were also significantly different, but similar (See next Figure):
Probably, **data from the more simple extraction means were lost if only the more recent data were considered**.

The increase in average productivity is due to **technological changes in similar machines, but mainly to the use of more capable and powerful extraction vehicles**.



Curves showing the increase in productivity in the last decade.

CONCLUSIONS

- Productivity predictive equations have been fitted for extraction of whole trees, wood logs and firewood from traditional coppices, from more than 100 European time studies, mostly from the Mediterranean area, performed between 1975 and 2015.

- The general model predicts the productivity ($m^3 \cdot SMH^{-1}$) for extraction by mechanized ground skidding, forwarding and cable yarding, with R^2 = 64,5% and average absolute residuals of 1,2 $m^3 \cdot SMH^{-1}$.

- Particularized models have been obtained for mechanized ground skidding (skidders and similar adapted vehicles) and for cable yarders, mostly small-sized ones. For all the cases, the explanative variables were the maximum extraction distance (m), the average load ($m^3 \cdot cycle^{-1}$) and the felling intensity ($m^3 \cdot ha^{-1}$).

- The harvested species, the felling type (clearcut or selective), the harvesting system (whole trees, tree lenght, CTL or firewood) and the unit volume per tree have not been found as statistically significant factors.

- A relevant increase in the average productivity has been found between the extraction operations studied until 2004 and the cases studied from 2005 to 2015. The growth reflects the technological changes, although the main factor to explain it is the use of extraction means more powerful and capable.

AKNOWLEDGEMENTS

We are indebted to the **coordinating team and the rest of the members of the COST Action FP1301 (EuroCoppice),** and to the European Union as its funding organism. Particularly, **the memeers of its Work Group 3 provided the data to build the harmonized database** about coppice harvesting productivity.

The complete reference to the studies used to fit the models can be found in **SPINELLI, R.; CACOT, E.; MIHELIC, M.; NESTOROVSKI, L.; MEDERSKI, P. S.; TOLOSANA, E.; 2016. Techniques and productivity of coppice harvesting operations in Europe: a meta-analysis of available data. Ann. For. Sci. December 2016, Volume 73, Issue 4, pp 1125–1139.**

THANK YOU – ANY QUESTIONS?