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Thomas Bogensperger
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PS1-01: Strength / grading

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Session Abstract

The papers presented in this session deal with mechanical properties of timber. The focus is on structural application, design and experimental study. This includes contributions on experimental quantification of structural characteristics.

Presentations

Physico-mechanical properties, durability and treatability of Pinus Uncinata from the Pyrenees

E. Correal-Mòdol[1], M. Vilches-Casals[1], P. Langbour[2], M.-F. Thevenon[2], J. Gérard[2], D. Guibal[2]
[1]Wood Catalan Institute, Spain; [2]CIRAD, Spain

Pinus uncinata is a native pine from the mountain zones of Spain and of the centre and west of the Alps. Since centuries, it has been known that this species presents an excellent structural competence and his heartwood is perceived as highly durable. Nevertheless, its properties have not been studied in depth. The timber characterized comes from the French and the Spanish Pyrenees. The study analyses the mechanical and the physical properties of the clear wood, as well as the durability and the treatability. All the tests were done according the European standards. Pinus uncinata is soft, lightweight and not as stiff as the native pines of southern Europe. The natural durability was evaluated and the mountain pine was classified as non-durable. The sapwood wood is treatable while the heartwood is little or non-treatable.

Timber moisture content influence on non-destructive local measurements

D. F. Llana[1], G. Iñiguez-Gonzalez[1], E. Hermoso[2], V. Maynou[1], F. Arriaga[1]
[1]Universidad Politecnica de Madrid, Spain; [2]INIA-CIFOR, Spain

When assessing existing timber structures it is not possible to obtain density as the ratio mass/volume, so nondestructive probing methods are very useful tools to predict density. As in other nondestructive techniques, moisture content influences measurements. The goal of this paper is to study the influence of timber moisture content on two nondestructive probing techniques (penetration resistance and pullout resistance). 25 specimens of Scots pine (Pinus sylvestris L.) from Spain were tested. The moisture content ranged from 46.5% to 10.0%.

Results obtained show that penetration depth decreases and screw withdrawal strength (pullout resistance) increases, when moisture content decreases, below the fiber saturation point. There are lineal tendencies in both techniques. Above the fiber saturation point influence of timber moisture content is much lower than below. Moisture content correction factors of the measurements, below fiber saturation point, are proposed for this species.

Experimental characterization of Gaboon species under cyclic compressive loading

S. Ikogou[1], C. F. Pambou Nziengui1[1,2,3], R. Moutou Pitti[2,3,4], S. Ekomy Ango[4]
[1]Ecole Nationale des Eaux et Forêts (ENEF), Gabon; [2]Université Blaise Pascal (UBP), France; [3]Centre National de la Recherche Scientifique (CNRS), France; [4]Centre National de la Recherche Scientifique et Technologique (CENAREST), Gabon

In this paper, the stress-strain tests are performed on Gaboon (Aucoumea Klaineana Pierre) specie in room temperature and humidity. This specie is used, in major part, in collective, individual and industrial construction, in timber structure and also in the fabrication of paper and veneer wood products in Europe. In first, 15 samples have been tested under monotonous loading and 6 others in 5 cycles compression loading with different levels. According to the typical load stress-strain curve, the elastic moduli are obtained and the comparison between envelope of the cyclic load curve and the monotonous loading curve is achieved. The evolution of continuous displacement versus number of cycles shows three different zones representing the mechanical behaviour of the specie. The obtained results are in accordance with these proposed in the literature and the European code and bring important informations to the Gaboon's timber building. At the end, different test have been also performed on 7 samples under various internal moisture content of wood. The results show that the modulus of elasticity decrease with humidity but after one cycle the modulus of elasticity amount with the intensity of loading independently of moisture content of sample tested.

Effects of tree height and diameter on mechanical properties of structural lumber sawn from Japanese larch selected plus trees

T. Takeda[1], Y. Hosoo[1], T. Hashizume[2]
[1]Shinshu University, Japan; [2]Nagano Prefecture Forestry Research Center, Japan

Valuable physical and mechanical data were obtained by the wood quality survey for Japanese larch (Larix kaempferi) selected plus trees. Then, we attempted to apply factor analysis for these data to reveal the hidden relationship of various characteristic values among trees, logs, and lumbers. The results suggested that three factors were proposed: tree diameter at breast height (DBH) as factor 1, mechanical properties as factor 2, tree height as factor 3. To harvest mechanically superior lumber, it might be necessary to measure mechanical properties of each tree for selecting plus trees in addition of measurements of tree height and DBH.

Practical techniques for the vibration method with additional mass part 1: effect of crossers' positions in longitudinal vibration

Y. Kubojima[1], S. Sonoda[2], H. Kato[1]
[1]Forestry and Forest Products Research Institute, Japan; [2]Toyama Prefectural Agricultural, Forestry & Fisheries Research Center, Japan

The effect of the crosser's position used for piled lumber on longitudinal vibration was investigated. As a model case, specimens with and without a concentrated mass were compressed in their thickness direction at nodal and antinodal positions of longitudinal vibration. Longitudinal vibration tests were then conducted. Young's modulus was unaffected by compressing the specimen at the nodal position, but it was affected by compression at the antinodal position. When crossers are placed at the nodal positions, accurate density and Young's modulus values will be determined without the influence of weight of the upper lumber using the vibration method with additional mass.

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PHYSICO-MECHANICAL PROPERTIES, DURABILITY AND IMPREGNABILITY OF *PINUS UNCINATA* FROM THE PYRENEES

Eduard Correal-Mòdol[1], Marcel Vilches Casals[2], Patrick Langbour[3], Marie-France Thevenon[4], Jean Gérard[5], Daniel Guibal[6]

ABSTRACT: *Pinus uncinata* is a native pine from the mountain zones of Spain and of the centre and west of the Alps. From yesteryear, it has been known that this species presents an excellent structural competence and his heartwood has a big durability. Nevertheless, his properties have not been studied in detail. The timber characterized comes from the French and Spanish Pyrenees and the study analyses the mechanical and the physical properties of the clear wood plus the durability and the impregnability. All the tests were done according the Spanish and the European standards. *Pinus uncinata* is soft, lightweight and not as stiff in comparison with the native pines of southern Europe. The natural durability was evaluated and pine mountain was classified as non-durable. The sapwood wood is impregnable while the heartwood wood is not it.

KEYWORDS: *Pinus uncinata*, basic properties, durability, impregnability

1 INTRODUCTION

Pinus uncinata is a conifer of the family pinaceae, commonly known as mountain pine. Inhabits the Pyrenean subalpine zone and has an important forest crop in the French Pyrenees. The mountain pine was used traditionally in carpentry and construction in mountain houses, but nowadays might lose this use due to current legislation of the structural timber. This situation is happening because the basic properties of the timber, the durability and the behaviour against the protective treatments are still not characterized yet. The results obtained will allow improve the use of this species and sell the timber with the best warranties.

The goal of this study is to characterize the physical and mechanical properties of the *Pinus uncinata* from Catalan and French Pyrenees according to the Spanish standards. Furthermore, will be evaluated the durability and impregnability of the wood.

2 MATERIALS AND METHODS

2.1 BASIC PROPERTIES

The timber was extracted from two locations of the Catalan Pyrenees and of nine different zones of the French Pyrenees. The clear wood was conditioned at 20ºC and 65% of relative air humidity until they reached 12% of moisture content and afterwards characterized with test samples made according to UNE 56528:1978 (AENOR, 1978). The properties analysed are described in Table 1.

Table 1: *Clear wood properties studied*

Clear wood properties	UNE norms	Test samples mm	n France	n Catalonia
Density	56531:1977	20×20×30	90	60
Shrinkage	56533:1977	20×20×40	90	60
Hygroscopicity	56532:1977	20×20×40	90	60
Hardness	56534:1977	20×20×40	90	60
Compression strength	56535:1977	20×20×60	90	60
Bending strength	56537:1979	20×20×300	90	60

2.2 DURABILITY

The durability was determined according to the technical standard XP Cen/TS 15083-1 (2006). Samples were selected from 5 Spanish and 3 French trees. Heartwood samples of dimensions 50x25x15 mm (L,R,T) were weighed, measured, and half of them were leached according to the guidelines of EN84 (1997) prior to

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[3] Patrick Langbour, CIRAD, France, patrick.langbour@cirad.fr
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[6] Daniel Guibal, CIRAD, France, daniel.guibal@cirad.fr

biological testing against *Coniophora puteana* and *Poria placenta*, both cubic rots. The unleached and leached samples (30 samples/fungal strain) were sterilized and put in culture flasks with each fungal strain for 16 weeks. After the fungal exposure, the mass loss of each sample was calculated.

2.3 IMPREGNABILITY

The impregnability tests were performed on an autoclave with samples of 40×40×800 mm and copper salts. Once made the treatment for obtaining de penetration of cooper salts, the samples were painted with an indicator solution in the transversal and longitudinal section. The impregnability was evaluated with de measures of penetration performed in the samples and the result was classified according to the established classes in the standard UNE-CEN/TR 14734 IN:2008. With the treatment performed, the absorption and retention of the protector product also has been evaluated.

3 RESULTS

The Table 2 and the Table 3 show the results of the tests of clear wood. The wood batches analysed from Catalan and French Pyrenees are relatively more soft, lightweight and flexible compared to other pines present in Southern Europe.

Table 2: *Physical and mechanical clear wood properties of Pinus uncinata of France*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	499,358	36,125	443,826
Shrinkage (%)	12,77	1,55	9,88
Shrinkage coefficient (%)	0,48	0,04	0,42
Higroscopicity (kg/m^3)	0,0026	0,00017	0,00237
Hardness (mm^{-1})	1,88	0,49	1,29
Axial compressive strength (kg/cm^2)	449,36	54,54	360,22
Bending strength (kg/cm^2)	855,03	104,72	676,18

Table 3: *Physical and mechanical clear wood properties of Pinus uncinata of Catalonia*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	504,739	35,431	447,580
Shrinkage (%)	12,39	1,99	9,23
Shrinkage coefficient (%)	0,46	0,05	0,38
Higroscopicity (kg/m^3)	0,0027	0,00019	0,00242
Hardness (mm^{-1})	1,85	0,39	1,18
Axial compressive strength (kg/cm^2)	338,16	77,90	216,06
Bending strength (kg/cm^2)	761,81	135,53	558,59

The results of the durability towards the two Basidiomycetes are given in table 4. Based on the median mass loss of the most discriminant fungal strain, *Coniophora puteana*), the natural durability results indicates tha *Pinus uncinata* is non durable (median mass loss > 30%)

Table 4: *Evaluation of the durability of Pinus uncinata of Spain and France*

Mass loss %	$\bar{x}$	median
Unleached samples		
Coniophora puteana	34.7	35.9
Poria placenta	29.7	29.6
Leached samples		
Coniophora puteana	35.8	37.0
Poria placenta	29.7	30.3

The sapwood wood can be impregnated and the heartwood wood cannot be impregnated. These results are similar to the others species of pines referenced in the standard UNE-EN 350-2:1994. The absorption and retention of the wood has been greater in the sapwood (≈10 kg/m^3) than in the heartwood (≈6–8 kg/m^3) coinciding with the impregnability.

4 CONCLUSIONS

The results obtained for the Catalan and French mountain pine are in keeping with the results obtained in other publications, with the exception of the shrinking, the axial compressive strength and the bending strength

The natural durability assessment in laboratory, towards 2 pure cultures of cubic rots, showed that mountain Pine was not durable. No difference was noticeable between the French and the Spanish sampling.

The comportment of the wood with the protective treatments in autoclave shows that the heartwood is not impregnable or is very little impregnable and the sapwood is totally impregnable.

ACKNOWLEDGEMENT

This study was carried out thanks to the support of INCAFUST and CIRAD on the frame of the Unci'Plus project of the GEIE Forespir.

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PHYSCO-MECHANICAL PROPERTIES, DURABILITY AND TREATABILITY OF *PINUS UNCINATA* FROM THE PYRENEES

Eduard Correal-Mòdol[1], Marcel Vilches Casals[2], Patrick Langbour[3], Marie-France Thevenon[4], Jean Gérard[5], Daniel Guibal[6]

ABSTRACT: *Pinus uncinata* is a native pine from the mountain zones of Spain and of the centre and west of the Alps. Since centuries, it has been known that this species presents an excellent structural competence and his heartwood is perceived as highly durable. Nevertheless, its properties have not been studied in depth. The timber characterized comes from the French and the Spanish Pyrenees. The study analyses the mechanical and the physical properties of the clear wood, as well as the durability and the treatability. All the tests were done according the European standards. *Pinus uncinata* is soft, lightweight and not as stiff as the native pines of southern Europe. The natural durability was evaluated and the mountain pine was classified as non-durable. The sapwood wood is treatable while the heartwood is little or non-treatable.

KEYWORDS: Clear wood, basic properties, impregnability, absorption, retention, mountain pine, sapwood, heartwood

1 INTRODUCTION

Pinus uncinata is a conifer of the *Pinaceae* family, commonly known as mountain pine or less frequently Pyrenean pine. Currently there is no consensus on its taxonomy because is a morphologically highly variable species. Nevertheless, the most accepted classification defines *Pinus uncinata* as one of the two subspecies of *Pinus mugo*: *Pinus mugo* subsp. *mugo* and *Pinus mugo* subsp. *uncinata*. *Pinus mugo* subsp. *mugo* is a shrub up to 1.5 meter tall with prostrate growth; meanwhile *Pinus mugo* subsp. *uncinata* is a tree. In fact, compared to the rest of populations of *Pinus mugo*, the Pyrenean mountain Pine presents a high level of differentiation [14] [20].

According to the data of the IFN2 [24] and the IFN3 [25] the trees of 25 cm of diameter have an average height of 10 metres and a maximum of 20 metres. The tallest trees are of 27 metres high and, at most, 80 cm of diameter. Exceptionally, individual trees of 120 cm of diameter exist. The shrub form is more common in the Eastern Europe meanwhile the tree is typical in the Western Europe and on the Iberian Peninsula forests.

There are presumptions that *Pinus uncinata* may have shared genome with *Pinus sylvestris* in its evolutionary history as is possible to find hybrid trees of both species [21] [26]. This usually happens on the upper altitudinal limit of *P. sylvestris*, height at which the *P. uncinata* starts to appear in the Pyrenees. In fact, the hybrid is so common that a nothospecies called *P. x rhaetica* was defined to refer to these trees [16]. *Pinus* x *rhaetica* populations exist in Spain [22].

Pinus uncinata inhabits the Pyrenean subalpine zone and has an important forest crop in the French Pyrenees. About 86% of the woods of the species stand between 1,600 and 2,200 metres above sea level and the total altitudinal range of the species goes from 1,000 metres up to 2,400 metres just below the alpine zone [19].

Nowadays *Pinus uncinata* is more abundant than in the past because the ancient pasturelands that existed at the top of the Pyrenean Mountains have turned into forest. This transformation of the landscape is the consequence of the change of use of the mountains along the XXth century. In parallel, many natural areas have been protected in the Pyrenees to preserve the ecosystems with high ecological values. The habitat of *Pinus uncinata* is usually included in these areas. Consequently, the exploitation of the forests in which *Pinus uncinata* are abundant are under regulation.

The situation of the *Pinus uncinata* forests in France and in Spain is different. The two main reasons are the main orientation of the mountains and the age of the forests. France is in the north face while Spain is in the south face; therefore, the insolation degree is different. Moreover, the French side has Atlantic influence meanwhile the Spanish is more Mediterranean. Thus, the Spanish side is sunnier and the trees tend to have more branches and a slightly lower growth rate because of the lack of rain. In addition to that, many Spanish forests are

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of first generation unlike the French ones. Thus, the form of the trees in France is straighter than in Spain. This affects the growth rate of the trees and therefore the properties of wood.

The mountain pine was used traditionally in carpentry and construction in the mountain houses. There are several reasons for that. It is a local and available softwood, the stems are straight, it is easy to saw and work with and the heartwood is considered durable. Nevertheless, nowadays the use of this timber is in danger due to current legislation of the structural timber. Since the approval of the Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2,011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, the construction products permanently installed on a construction must have the CE marking [17].

The first step to take to overcome this situation is to characterize the basic properties of the timber, the durability and the behaviour towards the protective treatments. The results obtained will allow improve the use of this species and have better quality warranties.

The goal of this study is to characterize the physical and mechanical properties of the *Pinus uncinata* from Catalan and French Pyrenees according to the Spanish standards. Furthermore, the durability and impregnability of the wood will be evaluated.

2 MATERIALS AND METHODS

2.1 PROVENANCE OF WOOD

The timber was extracted from two locations of the Catalan Pyrenees and of nine different zones of the French Pyrenees. All the forests belong to the historical shire of la Cerdanya (la Cerdagne), a territory of 1,086 km^2 divided by the border of Spain and France and located at the east of Andorra. The altitudinal range of the shire goes from 950 metres up to 2,921 metres above the mean sea level.

The trees from the Spanish forests were from the municipalities of Alp and Aransa. The forest from Alp was a south face and the forest from Aransa was a north face. The altitude over the sea level of the two forests was slightly below 2,000 m and far from the timberline (Table 1).

Table 1: *Origin of trees. Municipalities from the Spanish Cerdanya*

Municipality	Amount	
	Trees	Samples
Alp	12	10
	12	10
	12	10
Lles de Cerdanya (Aransa)	12	10
	12	10
	12	10

The selection of the French sites was done with the aim to have a representative sample of the different kind of Forests of mountain pine of the Pyrenees (Table 2). Nine plots from eight municipalities were selected. The average growth of the French trees was lower than the Spanish ones.

Table 2: *Origin of trees. Municipalities from the French Cerdanya*

Municipality		Amount	
		Trees	Samples
FD Camporells		8	10
Formiguères		8	10
Les Angles		6	10
Matemale		6	10
FD Clavéra		8	10
Eyne		8	10
Oceja	Jaça de les corones	6	10
	Col de Pradelles	6	10
Porté de Puymorens		6	10

2.2 BASIC PROPERTIES

The basic properties were analysed on wood without defects and straight fibres. The clear wood was conditioned at 20ºC and 65% of relative air humidity until they reached 12% of moisture content and afterwards characterized with test samples made according to UNE 56528:1978 [1]. The test samples were parallelepipeds of 20×20 mm of section with the growth rings parallel to two sides of the sample and with small curvature.

The most common physical and mechanical properties of wood were analysed: density, shrinkage, hygroscopicity, hardness, compression strength and bending strength. (Table 3).

Table 3: *Clear wood properties studied*

Clear wood properties	UNE norms	Test samples		
		mm	Amount	
			Fr	Cat
Density	56531:1977 [2]	20×20×30	90	60
Shrinkage	56533:1977 [4]	20×20×40	90	60
Hygroscopicity	56532:1977 [3]	20×20×40	90	60
Hardness	56534:1977 [5]	20×20×40	90	60
Compression strength	56535:1977 [6]	20×20×60	90	60
Bending strength	56537:1979 [7]	20×20×300	90	60

2.3 DURABILITY

The durability was determined according to the standard XP CEN/TS 15083-1 [13]. Samples were selected from five Spanish and three French trees. Heartwood samples of dimensions 50×25×15 mm (L,R,T) were weighed, measured, and half of them were leached according to the guidelines of EN 84 [12]. Afterwards, they were biologically tested against *Coniophora puteana* and *Poria placenta*, both cubic rots (Basidiomycetes). The unleached and leached samples were sterilized and put into culture flasks in contact with each fungal strain for sixteen weeks. Thirty samples per fungal strain were tested. After the fungal exposure, the mass loss of each sample, as well as average and median mass losses were calculated.

2.4 TREATABILITY

The transport of preservatives into wood when treated with an autoclave mainly depends on structural characteristics of wood, the moisture of wood, the physical and chemical properties of the transported liquid substance and the pressure applied during the treatment. Therefore, to characterize the treatability of wood all the other factors must be standard.

The protection treatment was performed on an autoclave with samples of 40×40×800 mm and copper salts. Ten samples of sapwood and heartwood were used for each provenance. An autoclave is used to impregnate the test samples. After forty-five minutes of vacuum, the copper sulphate solution is introduced into the tank. Then, the pressure raises up to the atmospheric pressure and afterwards up to 9.0×10^2 kPa for 120 minutes. Finally, the pressure is removed until the tank reaches the atmospheric pressure and the copper sulphate preservative is evacuated.

The transversal and longitudinal penetration of the protective treatment was evaluated with Chrome Azurol S dye. The penetration on the test samples was classified according to the standard UNE-CEN/TR 14734 IN:2008 [10]. Additionally, the absorption (1) and retention (2) of the protector product also has been evaluated. See equations below:

$$\text{Absorption} = \frac{W_T - W_0}{V} \quad (1)$$

$$\text{Retention} = \frac{W_{T0} - W_0}{V} \quad (2)$$

Where W_T = Weight of the sample after the treatment, W_0 = Anhydrous weight of the untreated sample, W_{T0} = Anhydrous weight of the treated sample, V = Volume of the sample at 12% of moisture.

3 RESULTS

The Table 4 and the Table 5 show the results of the tests of clear wood. The results of the durability towards the two Basidiomycetes are given in Table 6. Based on the median mass loss of the most discriminant fungal strain (*Coniophora puteana*), the natural durability results indicate that *Pinus uncinata* is non-durable (median mass loss > 30%).

Table 4: *Physical and mechanical clear wood properties of Pinus uncinata of France*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	499.368	36.125	443.826
Shrinkage (%)	12.77	1.55	9.88
Shrinkage coefficient (%)	0.48	0.04	0.42
Hygroscopicity (kg/m^3)	0.0026	0.00017	0.00237
Hardness (mm^{-1})	1.88	0.49	1.29
Axial compressive strength (N/mm^2)	44.04	5.34	35.30
Bending strength (N/mm^2)	83.79	10.26	66.27

Table 5: *Physical and mechanical clear wood properties of Pinus uncinata of Catalonia*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	504.739	35.431	447.580
Shrinkage (%)	12.39	1.99	9.23
Shrinkage coefficient (%)	0.46	0.05	0.38
Hygroscopicity (kg/m^3)	0.0027	0.00019	0.00242
Hardness (mm^{-1})	1.85	0.39	1.18
Axial compressive strength (N/mm^2)	33.14	7.63	21.17
Bending strength (N/mm^2)	74.66	13.28	54.74

Table 6: *Evaluation of the durability of Pinus uncinata from Spain and France*

Samples	Cubic rot fungi (Basidiomycota)	Mass loss %	
		$\bar{x}$	Median
Unleached	*Coniophora puteana*	34.7	35.9
	Poria placenta	29.7	29.6
Leached	*Coniophora puteana*	35.8	37.0
	Poria placenta	29.7	30.3

The treatability tests show that the heartwood of the mountain pine is impermeable. Sapwood reached at least an average radial penetration higher than 6 mm and a minimum radial penetration of 3 mm. Most samples of sapwood were fully treated (Table 7).

Table 7: Treatability class of *Pinus uncinata*

Country	Wood type	Percentage of samples classified according to the treatability as defined on UNE-CEN/TR 14734:2008 IN [10] (%)					
		1	2	2+	3	3+	4
France	Sapwood	60	20	20	0	0	0
	Heartwood	0	0	0	0	0	100
Spain	Sapwood	50	10	40	0	0	0
	Heartwood	0	0	0	0	0	100

The average absorption on the sapwood of both provenances is nearly the same but the Spanish heartwood absorbs a 27.6% more than the French (Table 8). The sapwood from France and Spain is a 60.4% more impregnable than the French heartwood.

Table 8: Treatment absorption on *Pinus uncinata*

Wood type	Country	Absorption (kg/m^3)	
		Average	Standard deviation
Sapwood	France	678.33	17.54
	Spain	678.47	26.65
Heartwood	France	422.89	50.81
	Spain	539.58	88.15

The retention follows a similar pattern. The retention on the sapwood is nearly the same on both provenances but the Spanish heartwood retains a 37.2% more of product than the French heartwood (See Table 9).

Table 9: Treatment retention on *Pinus uncinata*

Wood type	Country	Retention (kg/m³) Average	Standard deviation
Sapwood	France	10.14	0.45
	Spain	10.38	0.87
Heartwood	France	6.02	0.97
	Spain	8.26	1.55

4 DISCUSSION

4.1 BASIC PROPERTIES

The properties of the wood of Spain and France have some differences, especially in the mechanical properties. The analysis of the results was done with statistical hypothesis testing. ANOVA was used in the cases that the sample meet all the criteria of normality. T-test and Z-test was used on the rest.

The results show that there were no significant differences in the density and in the shrinkage (Figure 1 and Figure 2). Conversely, there are significant differences in the coefficient of volumetric shrinkage. To analyse properly this result it should be taken into account that the shrinkage coefficient is a property derived from density and volumetric shrinkage. Therefore, the result indicates that the non-significant differences between batches on the density and volumetric shrinkage present the same trend (Figure 3).

The hygroscopicity of the wood from France is significantly lower than the one from Spain. However, the difference is very small. The analysis of variance is able to discriminate between provenances because this property varies little among specimens from the same batch (Figure 4).

Contrary to hygroscopicity, hardness is a property with a high variability (Figure 5). The coefficient of variation of the French wood is 25% and 21% of the Spanish. For this reason and because the hardness of the two provenances is similar there are no significant differences between batches. Therefore, considering all the results no significant differences exist on the analysed physical properties.

However, the mechanical properties of wood are significantly different depending on the provenance. The axial compressive strength of the French wood is a 33% higher than the Spanish and the bending strength is 12% higher. Moreover, the French wood is less variable (Figure 6 and Figure 7).

These trends have been also observed on the structural timber on a complementary study done using the same logs. The results are the basis of the visual grading standards for structural timber of France [11] and Spain (*Pinus uncinata* is currently under approval) [8]. The strength classes assigned to the French timber resulted higher than the assigned to the Spanish timber.

These results are correlated with the growth conditions of the trees. The French plots have a lower quality than the Spanish ones making the trees to grow slower and have a higher proportion of heartwood.

Table 10: *Statistical comparison of wood depending on the provenance*

Property	Test	p-value
Density	ANOVA	0,369
Shrinkage	T-Test & Z-Test	0,218
Shrinkage coefficient	ANOVA	0,003
Hygroscopicity	ANOVA	0,0001
Hardness	T-Test & Z-Test	0,692
Axial compressive strength	T-Test & Z-Test	0,0001
Bending strength	T-Test & Z-Test	0,0001

There are no other comprehensive studies about the physical and mechanical properties of *Pinus uncinata*. Thus, the Scots pine will be used as reference to analyse the results because is the most similar and genetically closest species. The data of *Pinus sylvestris* will be taken from other studies done by CIRAD [15] and INCAFUST [18].

On average, *Pinus sylvestris* from France has a density of 550.0 kg/m³ and the wood of the mountain pine from Spain is 527.0 kg/m³. Therefore, the Scots pine is between 5% and 10% denser than the mountain pine.

The mountain pine has a wood with lower mechanical properties than the Scots pine. The axial compressive strength of *Pinus sylvestris* from Catalonia is 53.63 N/mm² and 50.00 N/mm² if the wood is from France. Therefore, Scots Pine from France is 14% stronger and the Catalan up to a 62% more [15] [18].

The bending strength follows the same trend. The mountain pine from France is weaker than the Catalan and in comparison with the *Pinus sylvestris* is far less resistant too. The Catalan Scots pine is 30% stronger than the Catalan mountain pine and the French Scots Pine is 15% stronger [15] [18].

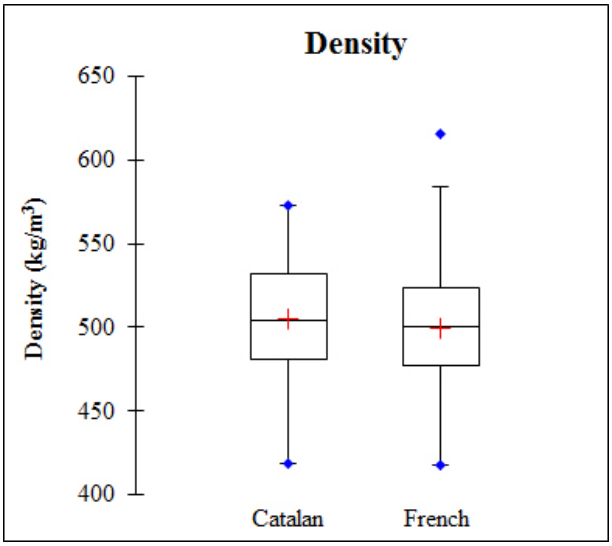

Figure 1*: Density of Spanish and French wood*

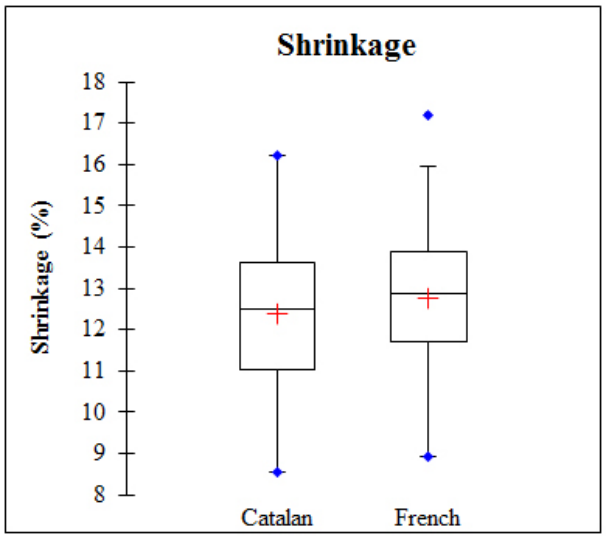

Figure 2: *Shrinkage of Spanish and French wood*

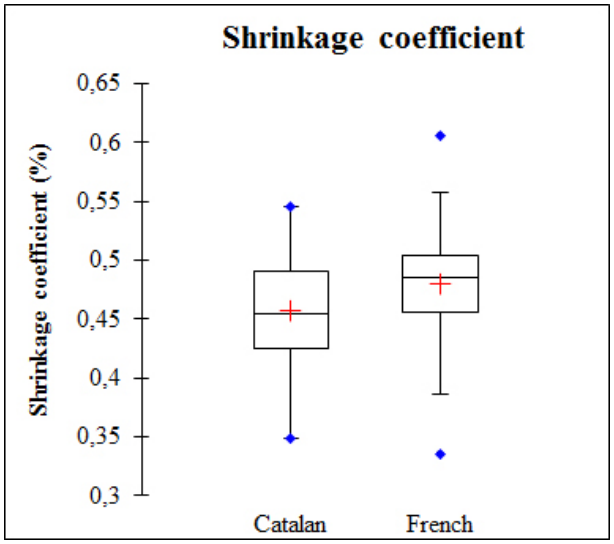

Figure 3: *Shrinkage coefficient of Spanish and French wood*

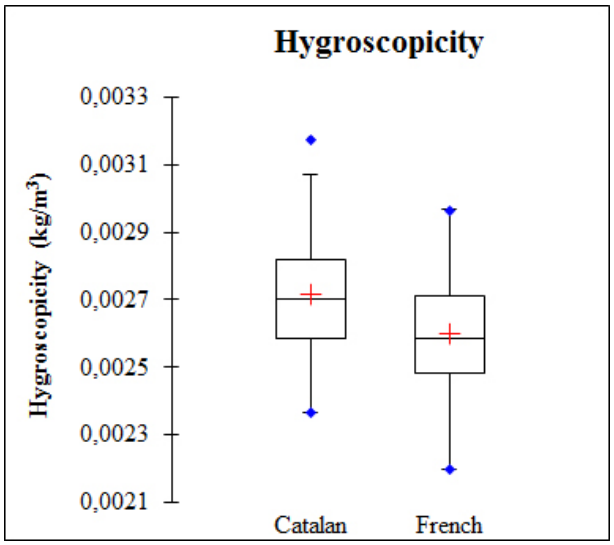

Figure 4: *Hygroscopicity of Spanish and French wood*

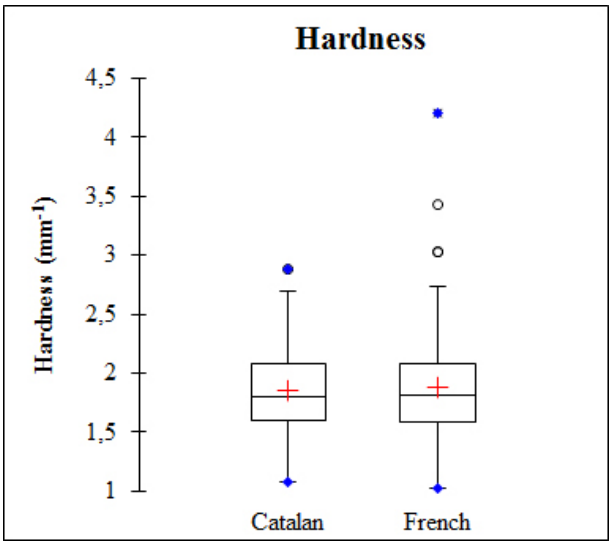

Figure 5: *Hardness of Spanish and French wood*

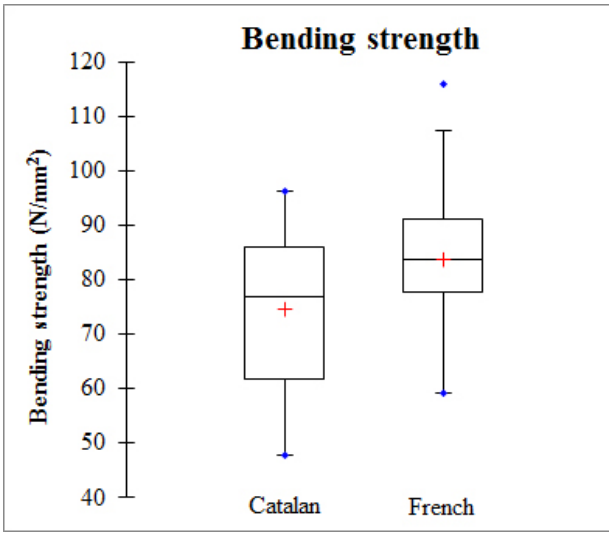

Figure 6: *Bending strength of Spanish and French wood*

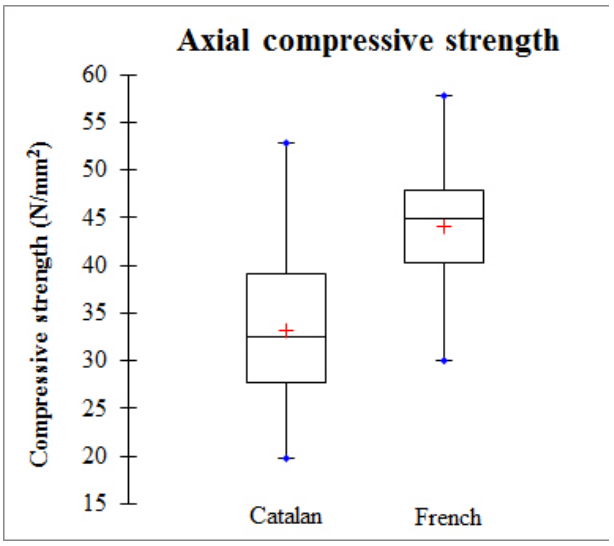

Figure 7: *Axial compressive strength of Spanish and French wood*

As mentioned above, the Scots pine and the mountain pine are two coniferous of the same genus and genetically very similar. The phylogenetic proximity and the habitat that each species occupies in the Pyrenees explain the differences and the similarities of the two woods.

The Pyrenees have a clear stratification of the tree species depending on the altitude, especially with respect to the pines. The Scots pine limits in altitude with the mountain pine and this one reaches the timberline. Therefore, *Pinus uncinata* has to bear harder winters and has a shorter growing season than the Scots pine. Thus, the annual growth is smaller and more irregular and the wood needs to be more flexible to resist the weight of the snowfalls and the heavy winds. The results of this study is in agreement with these assumptions.

4.2 DURABILITY

The results of the decay tests show that *Pinus uncinata* is non durable and is one durability class lower than Scots Pine. However, the inhabitants of the Pyrenees have the perception that *Pinus uncinata* timber is very durable. This believing is based on the traditional use of the timber and the fact that the logs of the tree usually can stand for long years on the ground of the forest before they rot.

The explanation of this apparent contradiction stands on the different conditions of degradation of the test and the real weathering that the timber suffers on the Pyrenean environment. The average temperature, the relative moisture and the exposure at the xylophagous are different. Most of the forests of *Pinus uncinata* grow above 1,600 m above the sea level. In these conditions, the winter is long, the snow is frequent and the vegetative period is very short. As a result, decay fungi and the insects have little time to decompose wood and when they do is in non-optimal climatic conditions.

In addition to that, another important factor reinforces the traditional perception of the high durability of the timber. *Pinus uncinata* has a low growth rate and therefore a high proportion of heartwood in comparison with other pines. Indeed, the heartwood is the most durable part of the trunk. Nevertheless, the mountain pine is equal or less durable than any other common Pyrenean timber species (Table 11).

4.3 TREATABILITY

The treatability of the sapwood is the same in both provenances. Thus, no physiologic differences among batches affects this property. However, the heartwood did behaved differently depending on if it was from Spain or France. The French heartwood appeared far less treatable. No specific references exist on *Pinus uncinata* over this phenomenon but there are several studies related to *Pinus sylvestris.*

Zimmer *et al*. [27] concluded that wider annual rings and higher latewood contents influenced positively on the retention of the protective product. Nevertheless, the tree attributes and the growth conditions explained more of the random variance of its experiment than the anatomical properties alone. In relation to that, wood from warmer sites with large growth increments is therefore easier to impregnate. Trees growing near the timberline of the species and under environmental conditions impairing wood growth develop refractory wood.

The study of Lande *et al*. [23] also investigated the treatability of *Pinus sylvestris*. The factors studied concerning the tree were: site location, latitude of site, height of trees, annual ring width, vertical and horizontal position. The two main conclusions of the research are that the location was the single factor that affected more negatively the treatability and that the treatability of sapwood increase with distance from ground and with distance from heartwood border.

The forests of the study of Lande *et al*. [23] were located in Denmark, south of Norway and north of Norway. In this case, the effect of the increase of the latitude has a similar effect on the growth of the trees like does the increase of the altitude in the Pyrenees.

Therefore, *Pinus uncinata* also develops refractory wood to protective treatments when submitted to adverse growth conditions.

As *Pinus uncinata* was shown non durable, it is thus crucial to associate this timber with an appropriate wood preservative and to treat it in accordance with the specifications of the use class where this timber will be put in service.

Treatability trials demonstrated that *Pinus uncinata* sapwood is impregnable unlike its heartwood. These results are similar to the others species of pines referenced in the standard UNE-EN 350-2:1994 [9] (Table 11).

Table 11: *Durability and impregnability of the timber of the Pyrenean species*

Properties		Common Pyrenean species *UNE-EN 350-2 [9]*						
		Abies alba	*Pinus nigra*	*Pinus sylvestris*	*Alnus glutinosa*	*Betula pendula*	*Fagus sylvatica*	*Pinus uncinata*
Natural durability	Fungi	4	4v	3-4	5	5	5	5
	Hylotrupes	SH	S	S	---	---	---	NA
	Anobiidae	SH	S	S	S	S	S	NA
	Termite	S	S	S	S	S	S	S
Treata-bility	Heartwood	2-3	4v	3-4	3-4	1-2	1-4	3-4
	Sapwood	2v	1v	1	1	1-2	1	1
Sapwood width		x	m-l	t-m	t-m	x	x	t-m

Natural durability: S = Sensitive, SH = Sensitive heartwood, v = variable, NA = Not available, 1 = very durable, 2 = durable, 3 = moderately durable, 4 = little durable, 5 = no durable. Treatability: 1 = treatable, 2 = moderately treatable, 3 = little treatable, 4 = no treatable. Sapwood width: m = medium, l = large, t = thin, x = undistinguishable.

Finally, the correlation between absorption and retention of the protective product has been analysed. The correlation between these properties is very high

considering the entire sample without discriminating provenances and the wood type. The coefficient of correlation is R^2=0.9507. Therefore, the amount of product that is effectively retains the wood once the solvent has evaporated is directly proportional to the amount of product that absorbs the wood during the treatment.

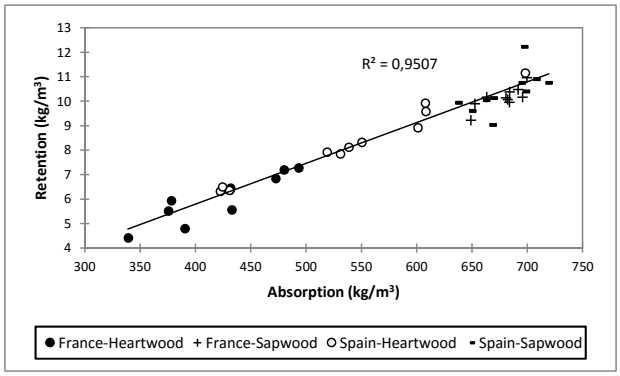

Figure 8: *Correlation between retention and absorption*

5 CONCLUSIONS

The properties of the clear wood of mountain pine of the Pyrenees are those expected for a pine that lives just below the timberline, on an extreme alpine climate, with short growing season, heavy snow and strong winds.

The physical properties of the wood are not significantly different depending if the plots are from France or Spain. Therefore, the growing conditions of the selected forests does not affect these properties. However, the average density and the average volumetric shrinkage is slightly higher in the French wood than in the Spanish one.

Nevertheless, there are significant differences in the mechanical properties. The clear wood from bad quality plots (France) has a higher resistance to axial compression and static bending.

This trend also happens in the treatability. The wood from trees with smaller annual rings is less treatable. Therefore, the duraminization of wood generates variability on the treatability. The heartwood was shown little or no treatable meanwhile the sapwood is fully impregnable.

The natural durability assessment using two pure cultures of cubic rots showed that the mountain pine wood is not durable. No noticeable differences were found between the French and the Spanish samples.

The wood of the mountain pine is little durable despite people having traditionally the opposite perception. This matches with the fact that the mountain pine evolved on a cold climate nearly free of xylophagous.

ACKNOWLEDGEMENT

This study was carried out thanks to the support of INCAFUST (Catalan Institute of Wood) and CIRAD (Centre for International Cooperation in Agronomic Research for Development) in the frame of the project Unci'Plus "La gestion des peuplements et la valorisation du bois de pin à crochets" and has been financed by the Operational Program for Territorial Cooperation Spain-France-Andorra-POCTEFA 2,007-2,013 No. EFA82/08.

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WCTE 2016
World Conference on Timber Engineering
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Physico-mechanical properties, durability and impregnability of *Pinus uncinata* from the Pyrenees

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1. INTRODUCTION

Pinus uncinata is a conifer of the family pinaceae, commonly known as mountain pine. Inhabits the Pyrenean subalpine zone and has an important forest crop in the French Pyrenees. The mountain pine was used traditionally in carpentry and construction in mountain houses, but nowadays might lose this use due to current legislation of the structural timber. This situation is happening because the basic properties of the timber, the durability and the behaviour against the protective treatments are still not characterized yet. The results obtained will allow improve the use of this species and sell the timber with the best warranties.

The goal of this study is to characterize the physical and mechanical properties of the *Pinus uncinata* from Catalan and French Pyrenees according to the Spanish standards. Furthermore, will be evaluated the durability and impregnability of the wood.

2. MATERIALS AND METHODS

2.1. BASIC PROPERTIES

The timber was extracted from two locations of the Catalan Pyrenees and of nine different zones of the French Pyrenees. The clear wood was conditioned at 20ºC and 65% of relative air humidity until they reached 12% of moisture content and afterwards characterized with test samples made according to UNE 56528:1978 (AENOR, 1978). The properties analysed are described in Table 1.

Table 1. *Clear wood properties studied*

Clear wood properties	UNE norms	Test samples mm	n France	n Catalonia
Density	56531:1977	20×20×30	90	60
Shrinkage	56533:1977	20×20×40	90	60
Hygroscopicity	56532:1977	20×20×40	90	60
Hardness	56534:1977	20×20×40	90	60
Compression strength	56535:1977	20×20×60	90	60
Bending strength	56537:1979	20×20×300	90	60

2.2. DURABILITY

The durability was determined according to the technical standard XP Cen/TS 15083-1 (2006). Samples were selected from 5 Spanish and 3 French trees. Heartwood samples of dimensions 50x25x15 mm (L,R,T) were weighed, measured, and half of them were leached according to the guidelines of EN 84 (1997) prior to biological testing against Coniophora puteana and Poria placenta, both cubic rots. The unleached and leached samples (30 samples/fungal strain) were sterilized and put in culture flasks with each fungal strain for 16 weeks. After the fungal exposure, the mass loss of each sample was calculated.

2.3. IMPREGNABILITY

The impregnability tests were performed on an autoclave with samples of 40×40×800 mm and copper salts. Once made the treatment for obtaining de penetration of cooper salts, the samples were painted with an indicator solution in the transversal and longitudinal section. The impregnability was evaluated with de measures of penetration performed in the samples and the result was classified according to the established classes in the standard UNE-CEN/TR 14734 IN:2008. With the treatment performed, the absorption and retention of the protector product also has been evaluated.

3. RESULTS

The Table 2 and the Table 3 show the results of the tests of clear wood. The wood batches analysed from Catalan and French Pyrenees are relatively more soft, lightweight and flexible compared to other pines present in Southern Europe.

Table 2. *Physical and mechanical clear wood properties of Pinus uncinata of France*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	499,358	36,125	443,826
Shrinkage (%)	12,77	1,55	9,88
Shrinkage coefficient (%)	0,48	0,04	0,42
Higroscopicity (kg/m^3)	0,0026	0,00017	0,00237
Hardness (mm^{-1})	1,88	0,49	1,29
Axial compressive strength (kg/cm^2)	449,36	54,54	360,22
Bending strength (kg/cm^2)	855,03	104,72	676,18

Table 3. *Physical and mechanical clear wood properties of Pinus uncinata of Catalonia*

Property	$\bar{x}$	S_{n-1}	P_5
Density (kg/m^3)	504,739	35,431	447,580
Shrinkage (%)	12,39	1,99	9,23
Shrinkage coefficient (%)	0,46	0,05	0,38
Higroscopicity (kg/m^3)	0,0027	0,00019	0,00242
Hardness (mm^{-1})	1,85	0,39	1,18
Axial compressive strength (kg/cm^2)	338,16	77,90	216,06
Bending strength (kg/cm^2)	761,81	135,53	558,59

The results of the durability towards the two Basidiomycetes are given in Table 4. Based on the median mass loss of the most discriminant fungal strain, Coniophora puteana, the natural durability results indicates that *Pinus uncinata* is non durable (median mass loss > 30%).

Table 4: *Evaluation of the durability of Pinus uncinata of Spain and France*

Mass loss %	$\bar{x}$	median
Unleached samples		
Coniophora puteana	34.7	35.9
Poria placenta	29.7	29.6
Leached samples		
Coniophora puteana	35.8	37.0
Poria placenta	29.7	30.3

The sapwood wood can be impregnated and the heartwood wood cannot be impregnated. These results are similar to the others species of pines referenced in the standard UNE-EN 350-2:1994. The absorption and retention of the wood has been greater in the sapwood (≈10 kg/m^3) than in the heartwood (≈6–8 kg/m^3) coinciding with the impregnability.

4. CONCLUSIONS

The results obtained for the Catalan and French mountain pine are in keeping with the results obtained in other publications, with the exception of the shrinking, the axial compressive strength and the bending strength

The natural durability assessment in laboratory, towards 2 pure cultures of cubic rots, showed that mountain Pine was not durable. No difference was noticeable between the French and the Spanish sampling.

The comportment of the wood with the protective treatments in autoclave shows that the heartwood is not impregnable or is very little impregnable and the sapwood is totally impregnable.

ACKNOWLEDGEMENT

This study was carried out thanks to the support of INCAFUST and CIRAD on the frame of the Unci'Plus project of the GEIE Forespir.

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WCTE 2016

Physico-mechanical properties, durability and impregnability of *Pinus uncinata* from the Pyrenees

Wien | 2/9/2016

Dr. Eduard Correal Mòdol | Institut Català de la Fusta

incafust
institut català de la fusta

Espècies fusteres: coníferes i planifolis

The moutain pine (*Pinus uncinata*) is the second most common tree in the Pyrenees only below the Scots pine (*Pinus sylvestris*) and is more abundant than the silver fir (*Abies alba*)

Pinus uncinata

Tree up to 25 m

Pinus mugo

Shrub

Espècies fusteres: coníferes i planifolis

The distribution of the botanical species in the Pyrenees is strongly influenced by the height. The mountain pine inhabits between the Scots pine and the treeline. The Scots pine ascends up to 1600-1800 m and the tree line starts about 2200-2400 m.

The mountain pine was used traditionally in carpentry and construction in mountain houses but the timber hasn't been characterized yet. This was one of the reasons to start with the project UNCI'PLUS "Management of the populations and the recovery of the mountain pine wood".

The part of the UNCI`PLUS project that was focused on wood technology was conducted by:

catalan institute of wood incafust institut català de la fusta

Unci'plus

FOREST SCIENCES CENTRE OF CATALONIA

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Espècies fusteres: coníferes i planifolis

This study characterized the *Pinus uncinata* from the Catalan and the French Pyrenees according to the Spanish standards :

- Physical properties: density, shrinkage, higroscopicity & hardness
- Mechanical properties: axial compressive strength & bending strength
- Durability and impregnability:

General conclusions:

Overall, the mountain pine has lots of similarities with the Scots pine. Indeed, they are genetically close and often they hybridize with each other (*Pinus rhaetica*). One can say that the properties of the species are consequence of:

- Short growing season
- Heavy snow and strong winds
- Absence or little activity of xylophages in its habitat

For further details please ask me at the poster session!!

DANKE SCHÖN!

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