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CALORIFIC VALUES AND FLAMMABILITY OF FOREST SPECIES IN GALICIA. COASTAL AND HILLSIDE ZONES

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Abstract

Changes in heat values and in flammability with the seasons of the year for the different species which make up the woodland map of two zones, Sada (coastal area) and Santiago (hillside and plateau area), situated in La Coruña (Galicia, Spain), are reported. These data were evaluated as a help for fighting forest fires, which have been very frequent in this region during the last decade. The species studied are the most abundant in the areas: Eucalyptus globulus *Labill.,* Pinus pinaster *Aiton,* Ulex europaeus *L.,* Rubus fructicosus *L.,* Pteridium aquilinum *L.,* Sarothamnus scoparius *(L.) Link,* Quercus robur *L.,* Castanea sativa *Miller and* Acer pseudoplatanus *L. The calorific values were measured by static bomb calorimetry. These data were complemented with flammability determinations and completed with chemical analyses of the different species. Copyright © 1996 Elsevier Science Ltd.*

Key words: calorific values, flammability, forest fires, Spain.

INTRODUCTION

In the eighties, large forest areas were devastated by a great number of wildfires. Galicia (Spain) was not free from this problem: in less than 10 years it lost 50% of its woodlands: about 900 000 ha. This ecological disaster was restrained in the 1990s through fire-fighting plans set up by Galicia Autonomous Government and the favourable weather conditions with frequent rains in the months of higher risk. These achievements lead us to think of preparing suitable woodland maps to prevent fires, reforest areas damaged by fire and to preserve the region's autochthonous forest biomass as an inheritance for future generations (Rodríguez Añón, 1994). In order to set up clear scientific bases for the preparation of woodland maps, it was necessary to creat an up-to-date inventory of the most frequent species in Galicia and of the hectares occupied by them. Afterwards, and following the method recommended by Hubbard *et al.* (1956) the calorific values of the different woodland species were measured by means of a static bomb calorimeter in an oxygen atmosphere at the temperature of 25°C. The heating values, that is, the energy released per unit of combustible mass, are basic parameters to be studied, since they become a clear reference to the virulence that a forest fire can reach, depending on the kind of trees existing in the area where it rages. The stronger the tree calorific value, the greater the virulence that the fire can attain, and the greater, too, the difficulty of extinguishing it.

There are two calorific values to be considered. The higher heating value (HHV) is defined as the quantity of heat generated by complete combustion, in a bomb calorimeter, of a unit mass of a sample in an oxygen atmosphere assuming that both the water contained in the sample and that generated from the combined hydrogen remains in liquid form. The lower heating value (LHV) can be calculated if it is assumed that the water in the products remains in the form of steam.

One other basic point in this study was to calculate the inflammability or, in other words, the resistance that a combustible material, trees and shrubs in the present case, can oppose to fire. The higher the inflammability values, the smaller its resistance to the flames, and the quicker the spreading of the fire. In these tests, we simulated the resistance of the trees to the attack of the forest fire front.

Data of calorific values and flammability were complemented by a full chemical analysis, in which the contents, in C, H, O, N, S, Mn, Pb, Zn, Cu, Cd and Cl, were studied, as well as the density, humidity and ash resulting from the combustion.

To carry out this study, two of the representative areas of most ecosystems in Galicia were chosen. In these areas, Sada (coastal area) and Santiago (hillside and plateau area), all the most frequent species

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that make up the forest map of Galicia can be found.

METHODS

For collection and preparation of the samples, 1 ha of woodland in each of the areas was chosen. The plots were divided into 1 m^2 size sites, five of which were randomly chosen. From every site, bulk samples consisting of bark, branches having a diameter not greater than 8 cm (Martin and Lara, 1989) from pruning of trees, fruits, leaves and, in general, all of the living parts of trees were collected. This bulk sample was reduced by a coning and quartering procedure to a representative sample of about 1 kg.

Part of this sample was used in the flammability experiments which were performed, following the standard UNE-23-721, using a standard epiradiator of 500 W constant nominal power. Flammability values were obtained according to the tables proposed by Valette (1988).

The remaining sample was weighed to 0.1 or 1.0 g using a double-scaled Salter EP-22KA balance and then left for 12 h in a Selecta 200210 natural desiccating stove. Humidity of the sample was

Table 1. Main characteristics of the zones where the study was done

Zone 1. Sada (La Coruña). Coastal zone.

Altitude: 0–100 m
Annual rainfall index: 1012 mm
Summer rainfall index: 140 mm
Mean annual temperature: 13.9°C
Mean daily maximum temperature of the warmest month (June): 28°C
Hydric deficiency: 171
Mediterraneanity index: 2.11
Representative species of the zone: *Pinus pinaster* Aiton, *Eucalyptus globulus* Labill., *Sarothamnusscoparius* (L.) Link, *Ulex europaeus* L., *Rubus fructicosus* L. and *Pteridium aquilinum* L.
Other species: *Quercus robur* L., *Castanea sativa* Miller.

Zone. 2. Santiago (La Coruña). Plateau and start of foothill zone.

Altitude: 100–320 m
Annual rainfall index: 1865 mm
Summer rainfall index: 217 mm
Mean annual temperature: 12.1°C
Mean daily maximum temperature of the warmest month (June): 31.5°C
Hydric deficiency: 26
Mediterraneanity index: 1.27
Representative species of the zone: *Eucalyptus globulus* Labill., *Sarothamnus scoparius* (L.) Link, *Ulex europaeus* L., *Rubus fructicosus* L., *Pteridium aquilinum* L., *Castanea sativa* Miller, *Quercus robur* L. and *Acer pseudoplatanus* L.
Other species: *Pinus pinaster* Aiton.

Table 2. Flammability values according to the model proposed by Valette (1988)

	Spring	Summer	Autumn	Winter
Eucalyptus globulus Labill.	4	4	4	3
Pinus pinaster Aiton	4	5	4	3
Pteridium aquilinum L.	1	5	5	3
Quercus robur L.	5	5	4	4
Sarothamnus scoparius (L.) Link	1	1	2	2
Rubus fruticosus L.	4	5	4	2
Ulex europaeus L.	1	2	2	1
Castanea sativa Miller	4	5	5	4
Acer pseudoplatanus L.	3	5	4	3

0: Very low flammability.
1: Low flammability.
2: Flammable.
3: Moderately flammable.
4: Very flammable.
5: Extremely flammable.

determined as the weight loss of the sample after treatment in the stove.

Once the humidity was determined, the sample was ground using two mills of different power, a Retsch SM-1 blade mill and a Taunus MS-50 grinder, in order to homogenize the sample as much as possible, so making the preparation of the sample pellets to be used in the calorimetric experiments easier.

The final sample was divided into two parts. Part 1 was used in the analyses to determine humidity, density and average composition of each of the species being studied. The samples were analyzed by a Perkin–Elmer atomic absorption spectrophotometer to determine their C, H, O, N, S, Cu, Cd, Zn, Pb, Cl and Mn contents. The calorimetric experiments were performed using Part 2. Sample pellets of about 1 g (Wagman, 1982) size were placed in a stainless-steel crucible introduced into a Parr-1108 sealed static bomb calorimeter made of Carpenter-20-Cb-3 special stainless steel. The samples were ignited at 298.15 ± 0.01 K in oxygen at 3.04 MPa with 1 cm^3 of water added to the bomb. The electrical energy for ignition was determined from the change in potential across a 1256 or 2900 μF capacitor when discharged from about 40 V through a platinum wire. The pellet was connected to the ignition system by means of a cotton thread fuse, empirical formula $CH_{1.686}O_{0.843}$ with $-\Delta_c U_o = 16250$ kJ kg^{-1}. The samples, crucible, cotton thread and platinum wire were weighed using a Sartorius R 200 D balance.

The bomb calorimeter was submerged in a calorimeter can filled with 4631 g of distilled water weighed by a Mettler P-11 balance (sensitivity ±0.1 g). A correction to the energy equivalent was made for the deviation of the mass of water from 4631 g. The calorimeter jacket was maintained at constant temperature by circulating water kept at 25°C by a Tronac PTC-41 temperature controller, with a precision of 0.003°C per week, including a probe, a heater and cooling coil. The temperature

Table 3. Results of analyses of the total samples

	Moisture, %	Density, kg m^{-3}	Bomb, %	Ash
E. globulus Labill.	Spring	52.80	0.64	1.37
	Summer	57.80	0.62	1.56
	Autumn	47.60	0.65	0.28
	Winter	56.72	0.66	2.58
P. pinaster Aiton	Spring	56.30	0.65	1.04
	Summer	53.50	0.64	0.84
	Autumn	61.50	0.64	0.91
	Winter	60.46	0.63	0.71
P. aquilinum L.	Spring	68.53	0.76	2.26
	Summer	52.80	0.75	2.16
	Autumn	47.62	0.78	1.18
	Winter	72.53	0.70	2.74
Q. robur L.	Spring	61.36	0.64	0.66
	Summer	47.80	0.62	2.28
	Autumn	51.00	0.63	1.42
	Winter	58.16	0.64	2.53
S. scoparius (L.) Link	Spring	66.68	0.86	0.77
	Summer	62.66	0.90	0.74
	Autumn	47.55	0.87	0.15
	Winter	59.00	0.64	0.32
R. fruticosus L.	Spring	57.97	0.94	1.96
	Summer	65.66	0.93	0.84
	Autumn	62.20	0.95	1.23
	Winter	55.00	0.88	1.44
U. europaeus L.	Spring	61.32	0.83	0.68
	Summer	59.49	0.86	0.73
	Autumn	57.50	0.90	0.78
	Winter	62.00	0.84	1.14
C. sativa Miller	Spring	58.08	0.61	1.58
	Summer	57.49	0.59	2.18
	Autumn	40.00	0.59	1.71
	Winter	50.00	0.60	0.20
A. pseudoplatanus L.	Spring	49.31	0.89	4.62
	Summer	60.50	0.82	2.67
	Autumn	56.25	0.81	2.13
	Winter	41.00	0.82	1.15

Moisture (%) = 100 (weight of initial sample − weight of dry sample)/weight of initial sample.

Bomb ashes (%) = 100 (weight of crucible and content after the combustion − weight of empty crucible before the experiment)/weight of sample.

was kept homogeneous in the whole calorimeter by means of two motors which continuously shook both the calorimetric tank and the calorimeter. Temperature changes taking place in the calorimeter can during the experiments were followed by a Isotech 935-14-13 platinum resistance thermometer connected to an ASL F-26 resistance bridge. Temperature data were taken every 15 s and recorded by a 2086 Amstrad computer. The ignition of the sample was achieved on step 80, through the discharge of the condenser. This ignition started the main period of the calorimetric run. The experiment ended at step 240, after which ash and water resulting from the combustion were evaluated following routine procedures. The corrected temperature rise was obtained using a computer program and the analytical data. Once this temperature was known the calorific values could be evaluated.

RESULTS AND DISCUSSION

The main characteristics of the two zones studied, Sada (La Coruña, Spain) and Santiago (La Coruña, Spain), are listed in Table 1.

Flammability values, and their evolution during the seasons of the year, corresponding to all the different species present in the two areas are shown in Table 2. These data correspond to the model proposed by Valette. In general, all the species showed their highest flammability in summertime and the lowest in spring and winter. These last values were related to the high degree of humidity of the species in these seasons.

Table 4. Chemical analyses and volatile metals

		Chemical analyses (% of total composition)						Volatile metals (ppm)				
		N	C	H	O	S	Cl	Cu	Cd	Zn	Pb	Mn
E. globulus Labill.	Spring	2.11	46.65	12.42	38.68	0.13	0.084	46.31	2.38	12.35	1.12	795.12
	Summer	2.25	50.13	6.54	40.46	0.10	0.52	52.34	1.94	19.40	6.78	6390.00
	Autumn	1.90	44.64	5.71	47.46	0.22	0.067	6.13	2.30	17.48	1.86	83.12
	Winter	1.65	48.10	7.31	42.83	0.06	0.05	4.32	2.88	11.53	0.90	92.24
P. pinaster Aiton	Spring	3.02	46.96	6.39	43.41	0.22	—	0.29	1.60	25.60	2.10	1206.30
	Summer	1.88	49.74	6.40	41.57	0.15	0.26	36.55	1.00	38.90	1.80	1754.40
	Autumn	2.01	50.26	6.01	41.58	0.14	—	13.10	3.21	28.30	1.61	11730.10
	Winter	1.86	52.89	6.45	38.69	0.08	0.03	5.71	4.28	18.57	0.90	54.28
P. aquilinum L.	Spring	1.41	45.38	5.82	46.81	0.19	0.39	2.57	—	32.85	2.85	41.42
	Summer	1.71	45.50	5.97	45.60	0.31	0.91	8.40	1.50	16.90	1.30	1963.10
	Autumn	2.58	46.57	572	44.77	0.22	0.14	21.70	2.41	41.00	4.83	410.00
	Winter	4.84	46.20	11.53	37.34	0.09	0.11	4.30	—	44.00	1.43	3714.00
Q. robur L.	Spring	105	44.70	11.96	40.14	0.15	8.71	6.50	1.85	18.51	0.60	293.50
	Summer	1.82	45.88	6.25	45.66	0.25	0.14	75.05	3.26	21.20	1.63	3100.00
	Autumn	1.97	45.87	6.12	45.96	—	0.080	620	1.00	1821	0.40	295.80
	Winter	1.16	46.87	7.69	44.10	0.15	0.03	8.42	3.37	16.84	0.80	397.40
S. scoparius (L.) Link	Spring	2.01	50.55	7.04	40.03	0.21	0.16	38.39	1.60	22.30	0.80	99.90
	Summer	1.99	48.23	6.58	42.81	0.17	0.22	7.74	1.00	36.90	1.80	2756.70
	Autumn	1.01	51.06	6.44	41.30	0.08	0.11	8.57	—	27.14	4.29	1600.00
	Winter	4.84	46.20	11.53	37.34	0.09	0.11	4.30	—	44.00	1.43	3714.00
R. fruticosus L.	Spring	1.73	47.22	6.13	44.58	0.16	0.18	16.71	1.67	16.71	0.8	10.00
	Summer	1.71	45.64	6.05	46.23	0.14	0.23	44.30	1.00	26.30	1.10	1377.90
	Autumn	2.97	46.21	5.98	44.53	0.13	0.18	18.00	—	24.00	54.00	1800.00
	Winter	2.92	46.82	6.13	4186	0.12	0.15	12.00	—	36.00	24.00	1840.00
U. europaeus L.	Spring	1.00	49.70	6.88	42.07	0.23	0.12	15.00	3.33	89.28	1.80	60.00
	Summer	2.67	48.70	6.71	41.49	0.07	0.36	19.24	1.60	25.60	4.81	1218.00
	Autumn	3.06	47.03	6.41	43.35	0.08	0.080	8.08	—	36.40	12.10	1778.50
	Winter	2.80	48.96	6.53	41.41	0.12	0.18	32.00	—	42.00	6.00	1920.00
C. sativa Miller	Spring	0.86	45.60	5.89	47.49	0.16	0.05	8.03	3.20	35.33	2.10	63.70
	Summer	1.98	45.71	5.89	45.97	0.26	0.19	160.72	1.96	25.50	3.92	4704.00
	Autumn	2.53	47.16	5.96	44.24	0.11	—	9.31	1.35	30.21	3.21	1931.10
	Winter	2.26	48.28	7.08	42.29	0.10	—	4.70	—	18.32	1.40	2212.31
A. pseudoplatanus L.	Spring	2.66	45.45	13.04	38.70	0.15	—	13.12	1.13	28.15	1.01	891.32
	Summer	1.77	45.00	5.99	46.93	0.23	0.08	18.13	1.65	39.00	1.65	2044.50
	Autumn	1.95	47.92	12.42	37.61	0.10	—	17.12	1.10	41.80	4.10	160.30
	Winter	2.01	46.96	5.97	44.88	0.18	—	7.82	1.06	24.37	7.20	9000

Moisture content, density and percentage of ash resulting from the bomb experiments, corresponding to the species studied, are given in Table 3. Table 4 shows the mean chemical compositions and volatile metals data. High contents in Mn, compared to the other elements studied, are observed. This fact can be explained by the need for this ion in the transportation from water to photosystem II (Lehninger, 1979). As was pointed out previously (Rodríguez Añón *et al.*, 1995), trees are very important models of forest pollution evolution. This fact makes the detection of all the heavy metals a basic matter to be considered.

Table 5 shows the calorific values, HHV and LHV, of the species studied and changes during the seasons of the year. Knowledge of these values is very important when considering the prevention of potential damage caused by wildfires. Values of HHV and LHV listed in Table 5 are averages of four experiments on each species.

A correct interpretation of the different values shown here can be helpful in foreseeing the behaviour of the different zones as a response to wildfire. In this way, the different woodland zones can be classified as high-, medium-, and low-risk areas.

Figure 1 shows the changes in HHV during the seasons of the year. The results plotted are mean values of measurements performed using representative samples of each zone. These samples were prepared in the laboratory using the percentages corresponding to the different species present in the two zones. As expected, these calorific values are highest in summer and lowest in spring. As was mentioned, this fact is related to the blooming periods of most of the species that, in Galicia (Spain), coincide with a season of frequent rain, so increasing their moisture content and diminishing their HHV. It can be noticed that these values are higher in Santiago, the plateau and hillside zone, than in Sada, the coastal zone. This can be understood in terms of species, trees and bushes, with high calorific power, existing in the first zone. Figure 2 shows values of flammability that, again, are higher in the hillside zone. Obviously, the risk of wildfire is higher in the area of Santiago. These studies may help when planning afforestations in the different zones, trying to intermingle species of low

Table 5. High heating values (HHV) and low heating values (LHV) of the different species along the seasons of the year

		HHV (kJ kg^{-1})	LHV (kJ kg^{-1})
E. globulus Labill.	Spring	18576.90 ± 54.55 (0.29%)	6197.22 ± 30.89 (0.50%)
	Summer	20760.83 ± 80.64 (0.39%)	6743.34 ± 34.04 (0.50%)
	Autumn	19142.75 ± 81.64 (0.43%)	8211.11 ± 42.65 (0.52%)
	Winter	17539.08 ± 64.72 (0.37%)	5510.80 ± 28.01 (0.51%)
P. pinaster Aiton	Spring	19480.91 ± 35.41 (0.18%)	6524.90 ± 15.48 (0.24%)
	Summer	20658.80 ± 61.11 (0.30%)	7646.12 ± 28.42 (0.37%)
	Autumn	20463.05 ± 10376 (0.51%)	5868.74 ± 39.43 (0.67%)
	Winter	20398.48 ± 79.11 (0.39%)	6028.93 ± 31.28 (0.52%)
P. aquilinum L.	Spring	17613.89 ± 50.45 (0.29%)	3477.21 ± 15.88 (0.46%)
	Summer	18967.45 ± 2640 (0.14%)	3290.09 ± 7.54 (0.23%)
	Autumn	18420.05 ± 65.90 (0.36%)	7827.35 ± 34.52 (0.44%)
	Winter	18624.83 ± 56.50 (0.30%)	2987.38 ± 15.51 (0.52%)
Q. robur L.	Spring	17627.15 ± 45.35 (0.26%)	4297.44 ± 17.53 (0.41%)
	Summer	18541.89 ± 78.72 (0.42%)	7794.85 ± 41.09 (0.53%)
	Autumn	17468.03 ± 10.70 (0.061%)	6655.14 ± 523 (0.079%)
	Winter	18112.93 ± 54.09 (0.30%)	5451.37 ± 22.63 (0.42%)
S. scoparius (L.) Link	Spring	20533.91 ± 46.04 (0.22%)	4698.36 ± 15.34 (0.33%)
	Summer	19019.07 ± 93.92 (0.49%)	5031.90 ± 35.07 (0.70%)
	Autumn	20520.97 ± 51.89 (0.25%)	8860.00 ± 27.22 (0.31%)
	Winter	20677.99 ± 94.81 (0.46%)	6822.06 ± 42.66 (0.63%)
R. fruticosus L.	Spring	17777.51 ± 11.11 (0.062%)	5490.33 ± 4.68 (0.085%)
	Summer	18059.86 ± 30.88 (0.17%)	4142.05 ± 10.61 (0.26%)
	Autumn	18478.27 ± 95.61 (0.52%)	4969.40 ± 36.15 (0.73%)
	Winter	19451.13 ± 57.71 (0.30%)	6803.95 ± 25.97 (0.38%)
U. europaeus L.	Spring	20182.38 ± 64.15 (0.32%)	5724.55 ± 24.81 (0.43%)
	Summer	20680.74 ± 73.71 (0.36%)	6327.94 ± 29.86 (0.47%)
	Autumn	20950.41 ± 87.82 (0.42%)	6901.35 ± 37.33 (0.42%)
	Winter	20472.57 ± 81.33 (0.40%)	5720.51 ± 30.90 (0.54%)
C. sativa Miller	Spring	17460.78 ± 58.86 (0.34%)	5363.50 ± 24.68 (0.46%)
	Summer	17436.70 ± 86.35 (0.50%)	5458.45 ± 36.70 (0.67%)
	Autumn	17130.09 ± 85.03 (0.50%)	8515.60 ± 51.01 (0.50%)
	Winter	18653.17 ± 50.59 (0.27%)	7327.87 ± 25.29 (0.35%)
A. pseudoplatanus L.	Spring	17795.00 ± 71.15 (0.40%)	6363.80 ± 36.07 (0.57%)
	Winter	17848.87 ± 74.59 (0.42%)	5053.20 ± 29.46 (0.58%)
	Autumn	18436.86 ± 27.10 (0.15%)	5498.67 ± 11.86 (0.22%)
	Winter	17834.93 ± 12.05 (0.068%)	8747.55 ± 7.11 (0.080%)

Mean heat value ± standard deviation of the mean: 17834.93 ± 12.05 (0.068%).

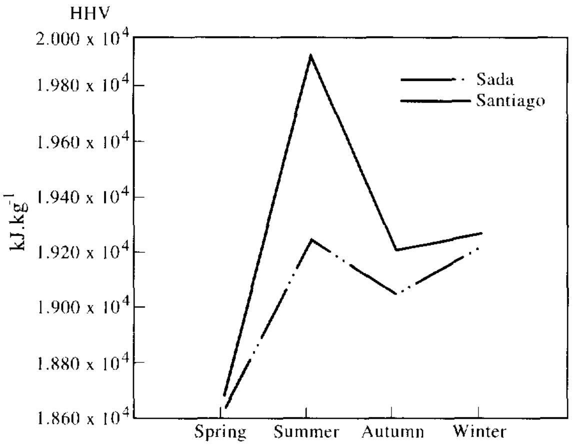

Fig. 1. High heating values and their evolution during the year for the two areas studied.

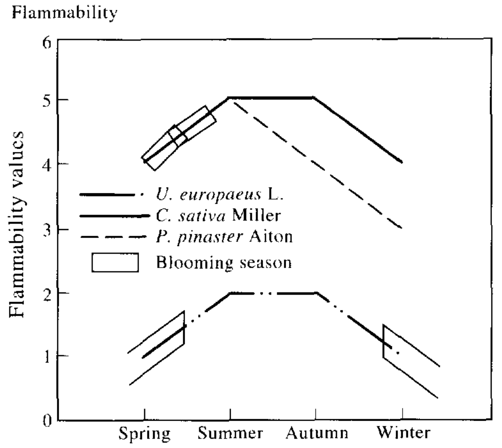

Fig. 3. High heating values and their evolution during the year for three representative species.

calorific value and low flammability in the areas where there are other species which can be considered as high-risk ones. In this way, forest maps can help in firefighting.

HHV and flammability values during the seasons of the year of *C. sativa* Miller, *U. europeaus* L. and *P. pinaster* Aiton are presented in Figs 3 and 4. Comparison of both figures shows that *U. europeaus* L., with the highest HHV, presents the lowest flammability. In contrast, *C. sativa* Miller, with the highest flammability, shows the lowest HHV. This can be understood as a self-defence mechanism of nature, where species with high calorific values present a great resistance to ignition. An exception to this rule is shown by *Pinus pinaster* Aiton, which has an extremely high calorific power and also high flammability during the whole year. The great amount of essential oils and resins, combined with a HHV above 25.000 kJ kg^{-1} and the high inflammability of this species, places it in the group of high-risk trees, because of its readiness to start and spread forest fires.

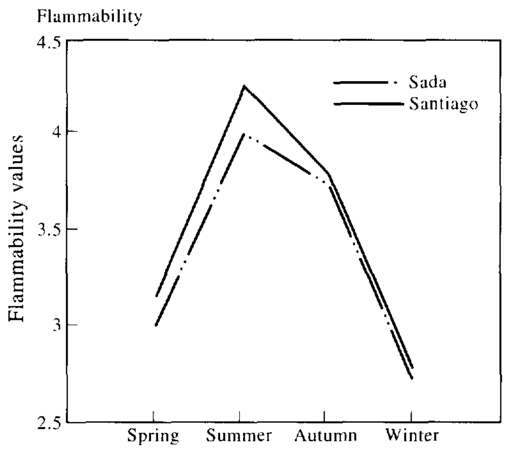

Fig. 2. Flammability values and their evolution during the year for the two areas studied.

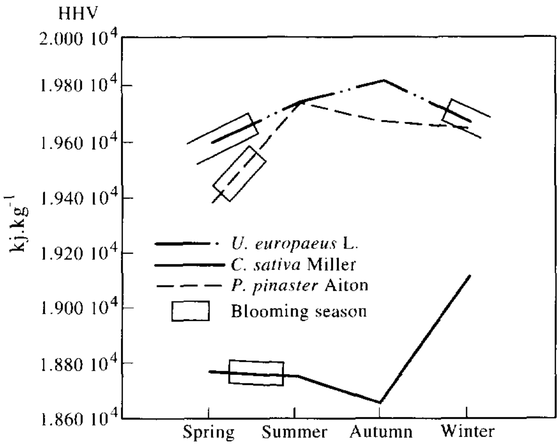

Fig. 4. Flammability values and their evolution during the year for three representative species.

Table 6. Species present in the two zones arranged according to descending values

	Calorific power	Flammability
High	*Ulex europaeus* L.	*Castanea sativa* Miller
	Pinus pinaster Aiton	*Quercus robur* L.
	Sarothamnus scoparius (L.)	*Pinus pinaster* Aiton
	Eucalyptus globulus Labill.	*Acer pseudoplatanus* L.
	Rubus fruticosus L.	*Robus fruticosus* L.
	Pteridium aquilinum L.	*Eucalyptus globulus* Labill.
	Acer pseudoplatanus L.	*Pteridium aquilinum* L.
	Quercus robur L.	*Sarothamnus scoparius* (L.) Link
Low	*Castanea sativa* Miller	*Ulex europaeus* L.

Table 6 shows an arrangement of the different species according to descending values of calorific power (left) and flammability (right).

The results presented here give information about forest wildfire risk and the areas to be focused on to prevent these fires.

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