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Design of forest biomass energetic maps as a tool to fight forest wildfires

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Abstract

In this paper we are setting the bases for the elaboration of energy maps of forest biomass. It shows the results obtained from the calculation of the calorific values and of the flammabilities of each of the forest species studied in Galicia (NW, Spain) along the year. With these data, it is possible to classify the species in terms of their energy content and of their resistance to forest fire. This classification is useful to draw realistic energy maps. With them, it will be possible to prevent and fight forest fires more effectively. These studies are complemented with chemical analyses of each forest species and bioclimatic diagrams of the areas to be studied. The main equipments used to carry out this research were an isoperibol calorimeter with agitated liquid in a static bomb, an epiradiator, an atomic absorption spectrophotometer and tools for elementary analyses. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Forest fire; Calorific value; Flammability; Energy map; Bioclimatic diagram; Environment

1. Introduction

In the last 20 years forest fires have become one of the major causes of environmental degradation. The loss of forest surface and the progress of desertization have made society and governments alike aware, all over the world, of the need to close ranks and fight this plague.

Galicia has not been free from this problem either, and in the last 20 years it lost about 1 000 000 ha, which amounts to half of its forest surface [1,2].

The problems concerning forest fires are rather economical than scientific, as in 90% of the cases the fire is intentionally started.

Our aim is to set up energy maps that can, at a first stage, help preventing forest fires, and fight them efficiently when they have started. To achieve this, we must have a full knowledge of two key parameters:

1. the calorific value, i.e., the energy contained in each forest species. This knowledge gives us information about the magnitude and virulence that the fire is going to have. It depends on two factors: the nature of the fuel, in this case the forest species in the area, and the moisture content, which varies in function of the bioclimatic conditions of the area, especially the amount of rainfall and the temperature. Depending on the energy value, more suitable reforestations can be carried out to prevent forest fires or their spreading. The basic idea is to create strips with trees of low calorific value and flammability as natural fire-breaks.

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2. the flammability, i.e., the resistance of these species to forest fire spreading. Just like calorific power, it depends on the nature of the fuel and the moisture level, both of the material and of the ambience. It is a key factor when it comes to planning fire extinction strategies.

For each species, these data must be complemented with a full chemical analysis both in elements (C, H, O, N and S) and in Cl and heavy metals (Cu, Cd, Mn, Pb and Zn), moisture level in the sample, density measurement of the different forest species and ash percentage after combustion.

Forest fires start in a natural environment, not under a laboratory control. The climatic variables (temperature, moisture, pluviosity, water availability, evapotranspiration, etc.) of each area have a determinative influence on the start and spreading of fires. All these variables are put together at the moment of drawing bioclimatic diagrams. These diagrams describe the area to be studied and have a direct influence on all the aforementioned physico-chemical parameters.

Once the energy maps have been drawn, it will be possible to make realistic forest plans to preserve the forest resources, work out strategies for a rational forest exploitation and to design mechanisms that are less aggressive to the environment than those currently used fire-breaks, very aggressive preventive silviculture that makes soil barren, improper reforestations that prevent the natural recovery of the ecosystem, etc. in our fight against forest fires.

2. Experimental

Bulk samples consisting of bark, branches having a diameter less than 8 cm [3] from pruning of trees, fruits, leaves, and in general, all the living parts of trees were collected from a previously chosen 1 ha of forest in each of the zones. The plots were divided into 1 m^2 size sites, five of which were randomly chosen. These bulk samples from the five sites were reduced by a coning and quartering procedure to a representative sample of about 1 kg. Branches having diameters less than 8 cm are mainly responsible for forest fires, because they are easy to ignite and also to spread fire. Once collected, the samples were stored in hermetically closed polyethylene bags in order to avoid loss of moisture which is a key parameter in this kind of study. Part of the sample was used in the flammability experiments which were performed according to the procedure given by Valette [4], using a standard epiradiator of 500 W constant nominal power. The remaining sample was used for analyses and for measuring calorific values. The material 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 determined as the weight loss of the sample after treatment in the stove. The dry sample was ground using two mills, a Retsch SM-1 and a Taunus MS-50, in order to homogenize the sample as much as possible before pressing the pellets to be used in the calori-

Table 1
Devesa da Rogueira (Lugo, Spain)

Continental high mountainous zone (altitude: 700–1300 m)	
Annual rainfall index	2042 mm
Summer rainfall index	69.3 mm
Mean annual temperature	8.0°C
Mean daily maximum temperature of the warmest month (July)	29.2°C
Hydric deficiency	No available data
Mediterraneanity index	1.29

Representative species of the zone: *Sorbus aucuparia* L., *Sarothamnus scoparius* (L.) *Link*, *Acer pseudoplatanus* L., *Taxus baccata* L., *Quercus robur* L., *Quercus pyrenaica Willd.*, *Pinus sylvestris* L., *Pinus radiata* D., Heath and *Castanea sativa Miller.*

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

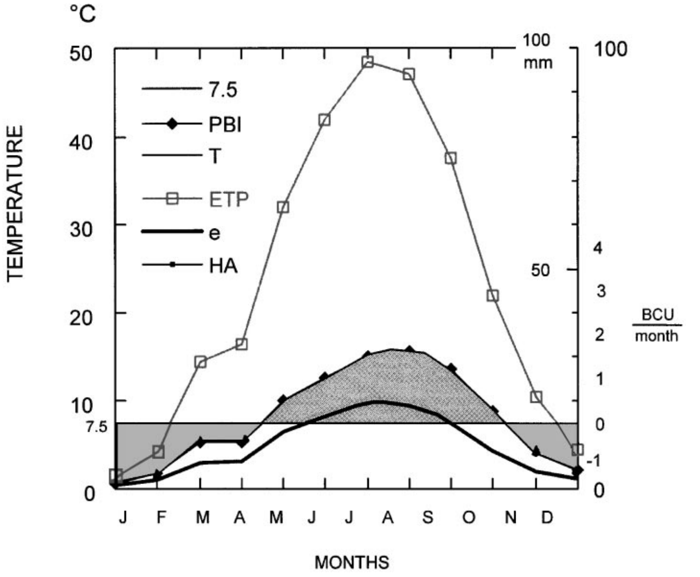
	Spring	Summer	Autumn	Winter
A. pseudoplatanus L.[a]	3	5	4	3
C. sativa Miller[a]	4	5	5	4
Q. robur L.[a]	5	5	4	4
S. aucuparia L.[a]	5	5	4	3
T. baccata L.[a]	3	4	3	2
Q. pyrenaica Willd.	1	5	4	2
P. radiata D.	2	4	3	3
P. sylvestris L.	4	4	3	3
S. scoparius (L.) *Link*[b]	1	1	2	2
Heath	2	5	5	3

0: Very low flammability; 1: low flammability; 2: flammable; 3: moderately flammable; 4: very flammable; 5: extremely flammable.

[a] Taken from L. Núñez et al. (1996) (13).

[b] Taken from L. Núñez et al. (1995) (12).

metric experiments. A part of this ground sample, named as fraction A, was used to measure density and average chemical composition of each of the species being studied. The samples were analyzed using a Carlo Erba analysis equipment for determination of elementary composition (C, H, N, O and S) and a Perkin-Elmer atomic absorption spectrophotometer to determine heavy metal contents (Cu, Cd, Zn, Pb, Mn and Cl). A second fraction named B was used to determine calorific values and ash percentages after combustion of the different species. Calorimetric experiments were performed following the procedure described by Hubbard et al. [5]. Sample pellets of about 1 g [6] size were burnt in a static bomb calorimeter. The static bomb was a sealed Parr-1108 made of a special columbium-stabilized stainless steel. The sample was put into a stainless steel crucible inside the bomb. A cotton thread fuse of empirical formula $CH_{1.686}O_{0.843}$ was attached to the platinum ignition wire and placed in contact with the pellet. In all the



Months	T (°C)	P(mm)	ETP (mm)	e (mm)	HA (mm)	BCU		CDI
						PBI	FBI	
J	0.7	226	3	0.7	326			-1.36
F	1.8	164	9	1.9	264			-1.14
M	5.4	239	29	5.9	339			-0.42
A	5.4	166	33	6.5	266			-0.42
M	10.1	147	64	12.9	247	0.52	0.52	
J	12.7	97	84	16.7	197	1.04	1.04	
J	15.1	48	97	19.4	148	1.52	1.52	
A	15.7	62	94	18.8	113	1.64	1.64	
S	13.7	98	75	14.9	117	1.24	1.24	
O	8.9	189	44	8.9	231	0.28	0.28	
N	4.5	254	21	4.1	354			-0.60
D	2.1	353	9	1.9	453			-1.08

Mean values during the year of: (T) temperature, (P) rainfall,. (ETP) evapotranspiration, (e) residual evapotranspiration, (HA) hydric availability. (BCU) bioclimatic units: (PBI) potential bioclimatic intensity, (FBI) free bioclimatic intensity, and (CDI) cold bioclimatic intensity.

Fig. 1. Bioclimatic diagram of the studied continental high mountainous zone showing the most important bioclimatic indexes. Values taken from Carballeira et al. [7].

Table 3
Results of analysis of the total samples (Devesa da Rogueira (continental high mountainous zone))

	Moisture (%)	Density (kg m^{-3})	Bomb ashes (%)
S. aucuparia L.[a]			
Spring	63.90	850	1.00
Summer	58.40	840	2.39
Autumn	48.93	860	1.29
Winter	47.00	830	0.67
A. pseudoplatanus L.[a]			
Spring	49.31	890	4.62
Summer	60.50	820	2.67
Autumn	56.25	810	2.13
Winter	41.00	820	1.15
T. baccata L.[a]			
Spring	57.10	660	2.46
Summer	62.50	670	1.82
Autumn	58.22	660	1.72
Winter	60.00	650	2.40
Q. robur L.[a]			
Spring	61.36	640	0.66
Summer	47.80	620	2.28
Autumn	51.00	630	1.42
Winter	58.16	640	2.53
S. scoparius (L.) *Link*[b]			
Spring	66.68	860	0.77
Summer	62.66	900	0.74
Autumn	47.55	870	0.15
Winter	59.00	640	0.32
C. sativa Miller[a]			
Spring	58.08	610	1.58
Summer	57.49	590	2.18
Autumn	40.00	590	1.71
Winter	50.00	600	0.30
Q. pyrenaica Willd.[a]			
Spring	47.64	1020	1.14
Summer	36.36	930	1.20
Autumn	33.33	800	1.70
Winter	38.05	900	1.52
P. sylvestris L.[a]			
Spring	54.03	890	0.53
Summer	58.41	840	0.29
Autumn	61.29	890	0.58
Winter	52.81	870	0.51
P. radiata D.[a]			
Spring	53.33	850	0.69
Summer	60.27	790	1.06
Autumn	55.32	870	0.78
Winter	54.09	910	0.61
Heath[a]			
Spring	42.61	1030	0.36
Summer	29.52	990	0.21
Autumn	40.00	990	0.79
Winter	36.54	990	0.49

Moisture (%)=100 (initial weight of collected sample−weight of sample after drying)/initial weight of collected sample.
Bomb ashes (%)=100 (weight of crucible and contents after combustion−weight of empty crucible)/weight of pellet.
[a] Values taken from L. Núñez et al. (1996) (13).
[b] Values taken from L. Núñez et al. (1995) (12).

experiments the bomb was filled with C-45 oxygen 99.99995% pure from Carburos Metálicos (Spain) at 3.04 MPa. Ignition was at 298.15 K with 1.0 cm^3 of water added to the bomb. The calorimeter was placed in an isothermal jacket with an air-gap separation of 10 mm between all surfaces. The electrical energy for ignition was determined from the change in potential across a 1256 or 2900 μF capacitor when discharge from about 40 V through a platinum wire.

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 to 4631 g. The calorimeter jacket was maintained at constant tem-

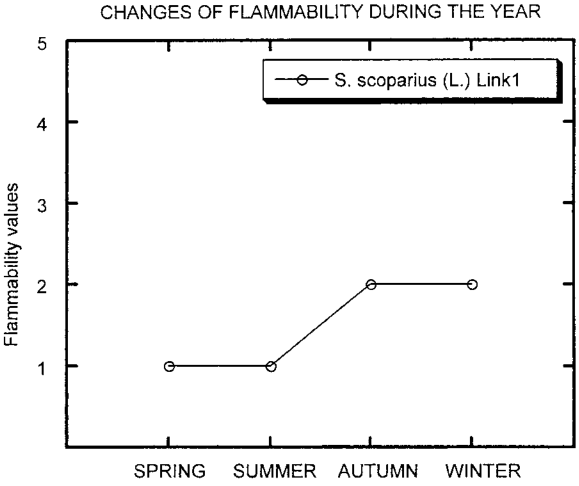


Fig. 2. *S. scoparius* (L.) *Link* changes of flammability during of the seasons of the year.

Table 4
Results of chemical analysis and volatile metals for dry sample

	Chemical analysis (% of total composition)						Volatile metals (ppm)				
	N	C	H	O	S	Cl	Cu	Cd	Zn	Pb	Mn
S. aucuparia L.[a]											
Spring	1.67	46.59	6.34	45.16	0.17	0.07	4.40	2.93	27.85	1.46	55.80
Summer	1.86	47.31	6.51	44.05	0.12	0.15	16.57	1.00	29.80	2.70	106.80
Autumn	1.89	48.36	7.78	41.82	0.13	0.02	8.25	6.60	37.95	1.20	280.52
Winter	1.54	47.72	6.02	44.60	0.12	–	7.13	2.35	30.32	1.21	195.32
A. pseudoplatanus L.[a]											
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	2044.5
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	90.00
T. baccata L.[a]											
Spring	2.86	45.31	7.54	44.21	0.08	0.08	5.14	40.13	40.32	1.13	59.32
Summer	1.66	45.99	12.91	39.31	0.13	0.11	9.22	3.07	46.11	1.53	3074.00
Autumn	1.81	50.10	7.47	40.45	0.13	0.04	4.43	4.40	39.90	0.90	465.50
Winter	1.94	49.17	6.83	41.77	0.10	0.19	6.12	4.20	40.30	0.73	245.32
Q. robur L.[a]											
Spring	3.05	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	21.30	1.63	3100.00
Autumn	1.97	45.87	6.12	45.96	–	0.08	6.30	1.00	18.31	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*[b]											
Spring	2.01	50.55	7.04	40.03	0.21	0.16	38.39	1.60	22.30	0.80	199.90
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
C. sativa Miller[a]											
Spring	0.86	45.60	5.84	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
Q. pyrenaica Willd.[a]											
Spring	1.83	45.43	5.42	47.20	0.12	>0.01	43.00	<1.00	133.00	25.00	114.00
Summer	1.55	46.86	6.29	45.16	0.14	>0.01	18.00	<1.00	93.00	4.00	311.00
Autumn	0.76	47.14	5.65	46.33	0.08	0.04	31.00	<1.00	66.00	18.00	75.00
Winter	1.42	47.73	5.83	44.86	0.06	0.10	16.00	<1.00	36.00	4.00	89.00
P. sylvestris L.[a]											
Spring	1.44	51.55	6.96	39.94	0.11	>0.01	20.00	<1.00	109.00	4.00	86.00
Summer	0.60	50.30	6.40	42.60	0.10	>0.01	14.00	<1.00	104.00	4.00	120.00
Autumn	1.04	50.61	6.34	41.91	0.10	>0.01	27.00	<1.00	75.00	10.00	42.00
Winter	1.65	53.09	6.88	38.30	0.08	>0.01	18.00	<1.00	52.00	8.00	87.00
P. radiata D.[a]											
Spring	1.35	49.50	6.19	42.84	0.12	>0.01	20.00	<1.00	59.00	1.00	167.00
Summer	1.47	48.72	6.41	43.33	0.07	>0.01	19.00	<1.00	44.00	9.00	86.00
Autumn	1.26	51.59	6.76	40.30	0.09	>0.01	31.00	<1.00	57.00	11.00	83.00
Winter	1.76	51.45	6.23	40.46	0.10	>0.01	22.00	<1.00	57.00	10.00	129.00
Summer	1.41	53.23	6.52	38.74	0.07	0.03	23.00	<1.00	17.00	13.00	172.00
Autumn	1.00	53.74	6.38	38.75	0.10	0.03	51.00	<1.00	117.00	20.00	59.00
Winter	1.68	55.51	7.06	35.64	0.08	0.03	14.00	<1.00	28.00	4.00	138.00

[a] Values taken from L. Núñez et al. (1996) (13).
[b] Values taken from L. Núñez et al. (1995) (12).

Table 5
Mean high heating values (HHV) and mean low heating values (LHV) of the different species along the seasons of the year in the zone

	HHV ($\mathrm{kJ\,kg^{-1}}$)	LHV ($\mathrm{kJ\,kg^{-1}}$)
S. scoparius Link.[b]		
Spring	20533.91±46.04 (0.22%)	3664.90±15.34 (0.42%)
Summer	19019.07±93.92 (0.49%)	4125.41±35.07 (0.85%)
Autumn	20520.97±51.89 (0.25%)	8186.70±27.21 (0.33%)
Winter	20677.99±94.81 (0.46%)	4504.76±39.75 (0.88%)
S. aucuparia L.[a]		
Spring	18236.14±85.01 (0.47%)	3629.40±30.69 (0.85%)
Summer	20331.44±68.40 (0.34%)	5600.99±28.46 (0.51%)
Autumn	19166.93±50.22 (0.26%)	6883.79±25.65 (0.37%)
Winter	18210.32±14.00 (0.08%)	7180.65±7.47 (0.10%)
A. pseudoplatanus L.[a]		
Spring	17795.00±71.15 (0.40%)	4950.20±36.07 (0.73%)
Summer	17848.87±74.59 (0.42%)	4256.41±29.46 (0.69%)
Autumn	18436.86±27.10 (0.15%)	3962.83±11.86 (0.30%)
Winter	17834.93±12.05 (0.07%)	8209.30±7.11 (0.09%)
T. baccata L.[a]		
Spring	18301.07±9.05 (0.05%)	4799.63±3.88 (0.08%)
Summer	20259.38±58.98 (0.29%)	3233.66±22.12 (0.68%)
Autumn	20561.95±75.10 (0.37%)	5527.29±31.38 (0.57%)
Winter	20249.00±117.09 (0.58%)	5133.30±46.84 (0.91%)
Q. robur L.[a]		
Spring	17627.15±45.35 (0.26%)	2684.15±17.53 (0.66%)
Summer	18541.89±78.72 (0.42%)	7137.97±41.09 (0.58%)
Autumn	17468.03±10.70 (0.06%)	5968.86±5.24 (0.09%)
Winter	18112.93±54.09 (0.30%)	4468.08±22.63 (0.51%)
B. sativa Miller[a]		
Spring	17460.78±58.86 (0.34%)	4617.73±24.68 (0.53%)
Summer	17436.70±86.35 (0.50%)	4713.93±36.71 (0.78%)
Autumn	17130.09±85.03 (0.50%)	7991.37±51.02 (0.64%)
Winter	18653.17±50.59 (0.27%)	6556.67±25.31 (0.39%)
Q. pyrenaica Willd.[a]		
Spring	19166.71±35.56 (0.19%)	7681.11±18.62 (0.24%)
Summer	19394.49±80.31 (0.41%)	10072.33±51.11 (0.51%)
Autumn	19254.37±59.52 (0.31%)	10781.21±39.68 (0.37%)
Winter	18893.57±33.65 (0.18%)	9494.07±20.85 (0.22%)
P. sylvestris L.[a]		
Spring	21956.26±50.21 (0.23%)	7248.60±23.08 (0.32%)
Summer	21653.85±48.38 (0.22%)	6172.88±20.12 (0.33%)
Autumn	21619.80±61.44 (0.28%)	5478.92±23.78 (0.43%)
Winter	22155.57±41.72 (0.19%)	7653.51±19.69 (0.26%)
P. radiata D.[a]		
Spring	21047.31±48.04 (0.23%)	7160.02±22.42 (0.31%)
Summer	20203.93±52.38 (0.26%)	5146.44±20.81 (0.40%)
Autumn	21833.44±119.89 (0.55%)	6918.55±53.57 (0.77%)
Winter	21402.49±96.59 (0.45%)	7135.78±44.34 (0.62%)
Heath[a]		
Spring	22728.69±200.97 (0.88%)	10634.23±115.33 (1.08%)
Summer	21653.13±129.04 (0.60%)	13107.28±90.95 (0.69%)
Autumn	21981.18±144.32 (0.66%)	10809.71±86.59 (0.80%)
Winter	21636.56±68.73 (0.32%)	11286.60±43.62 (0.39%)

18653.17±50.59 (0.27%) (mean heat value±standard deviation of the mean).

[a] Taken from L. Núñez et al. (1996) (13).

[b] Taken from L. Núñez et al. (1995) (12).

Table 6
Fire risk rank of the species present in the zone as a function of HHV, flammability values and climatic characteristics

	Spring	Summer	Autumn	Winter
S. scoparius (L.) *Link.*				
HHV	3	3	3	3
Flammability	1	1	2	2
Risk index	2	3	3	2
S. aucuparia L.				
HHV	2	3	3	2
Flammability	5	5	4	3
Risk index	3	4	3	2
A. pseudoplatanus L.				
HHV	2	2	2	2
Flammability	3	5	4	3
Risk index	2	3	2	2
T. baccata L.				
HHV	2	3	3	3
Flammability	3	4	3	2
Risk index	2	3	2	2
Q. robur L.				
HHV	2	2	2	2
Flammability	5	5	4	4
Risk index	3	3	2	2
B. sativa Miller				
HHV	2	2	2	2
Flammability	4	5	5	4
Risk index	3	3	2	2
Q. pyrenaica Willd.				
HHV	3	3	3	3
Flammability	1	5	4	2
Risk index	2	4	3	2
P. sylvestris L.				
HHV	4	4	4	4
Flammability	4	4	3	3
Risk index	4	5	5	3

Table 6 (*Continued*)

	Spring	Summer	Autumn	Winter
P. radiata D.				
HHV	4	3	4	4
Flammability	2	4	3	3
Risk index	3	5	4	3
Heath				
HHV	4	4	4	4
Flammability	2	5	5	3
Risk index	4	5	5	3

Risk rank. 1: Without apparent danger; 2: little dangerous; 3: dangerous; 4: very dangerous; 5: extremely dangerous.

perature 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 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 capacitor. This ignition started the

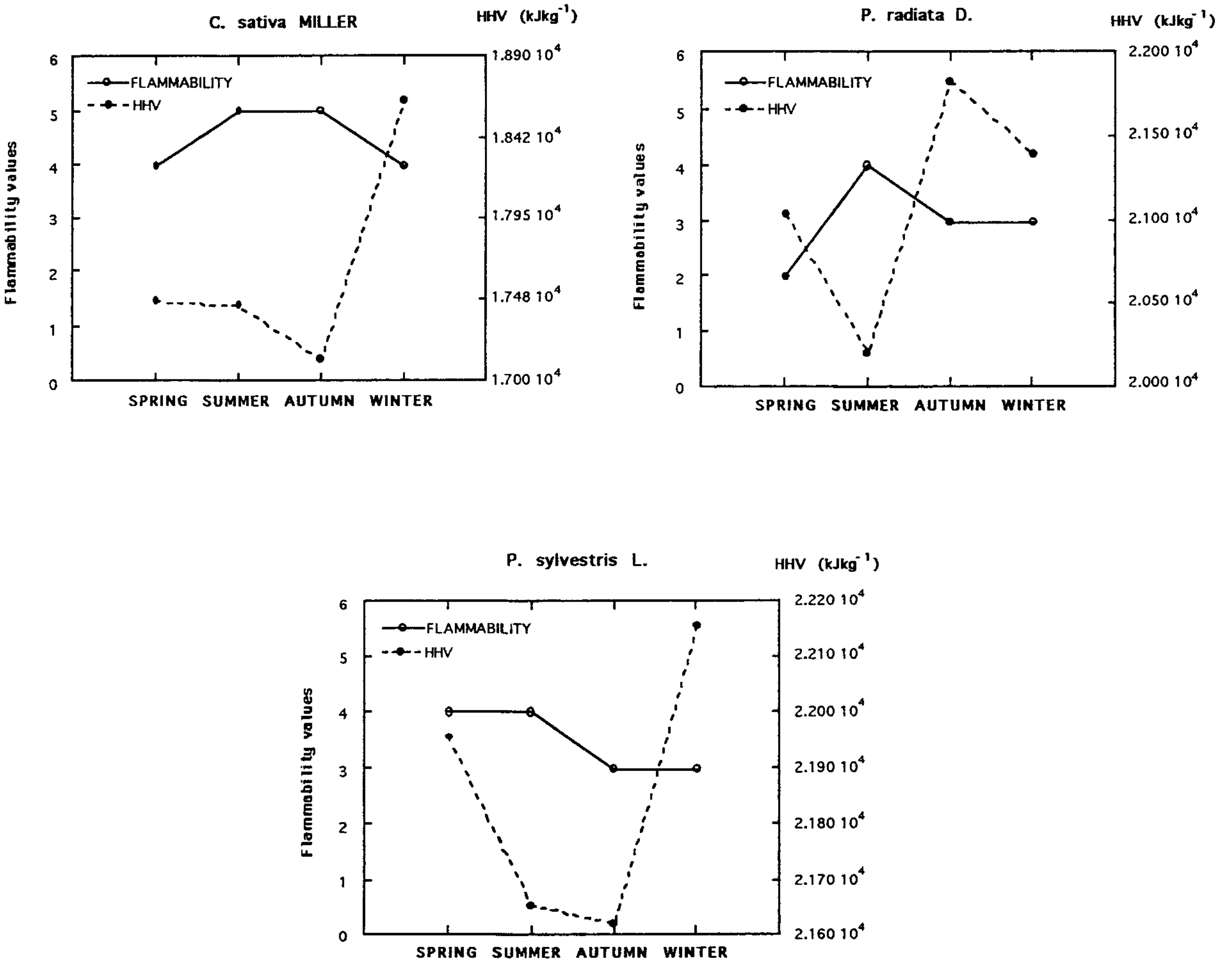


Fig. 3. Flammability and HHV values and their evolution during the year for three of the species studied.

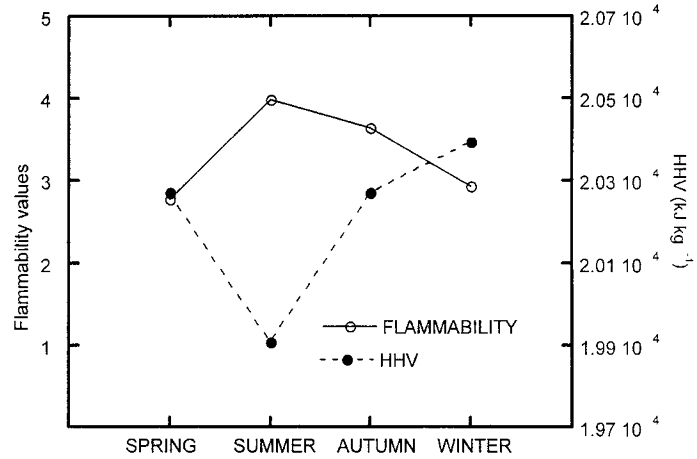


Fig. 4. Mean HHV and flammability values during the year for the studied zone.

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.

The equivalent energy of the calorimeter was determined using the combustion of benzoic acid, BCS CRN-ISOP standard reference sample from Bureau of Analyzed Samples, having an energy of combustion under standard bomb conditions of 26431.8± 3.7 kJ kg^{-1}. From five calibration experiments E(calor)=22402.5±1.9 (J K^{-1}) (0.0085%), where the uncertainty quoted is the standard deviation of the mean.

3. Results and dicussion

The results reported in different tables and figures correspond to the evolution of physical–chemical parameters along the year as a function of climatic variables and the state of the different species.

The main characteristics of the zone studied are shown in Table 1. These data are used to construct bioclimatic diagrams [7,8]. The zone is a continental high mountainous area and its representative species are listed in the same Table 1. Fig. 1 corresponds to the bioclimatic diagram in which the most important bioclimatic indices are shown.

Flammability values, and their evolution during the seasons of the year, corresponding to all the species present in the zone are shown in Table 2. The data correspond to the model proposed by Valette. It can be seen that except for one, the species show the highest values in summer, which make this season as a risk period for forest fires to initiate and spread. Moisture content, density and percentage of ash resulting from the experiments carried out in the bomb calorimeter are listed in Table 3. This table shows the high percentage of moisture of the species, as a consequence of the intermittent rains and mild temperatures characteristics of the zone.

Table 4 shows mean elementary compositions, necessary to calculate calorific values and heavy metal contents which are very important to study forest pollution. Contents of Mn are very high compared to the other elements studied. This fact can be explained by the need for this ion in the transportation from water, electron donor, to the photosystem II [9,10].

Mean calorific values of the species representative of the zone are listed in Table 5. According to Hough (Doat and Valette, 1981) the different forest species can be arranged in five energetic classes:

- Class 1: HHV<16747.2 kJ kg^{-1}.
- Class 2: 16747.2<HHV<18840.6 kJ kg^{-1}.
- Class 3: 18840.6<HHV<20934 kJ kg^{-1}.
- Class 4: 20934<HHV<23027.4 kJ kg^{-1}.
- Class 5: 23027.4 kJ kg^{-1}<HHV.

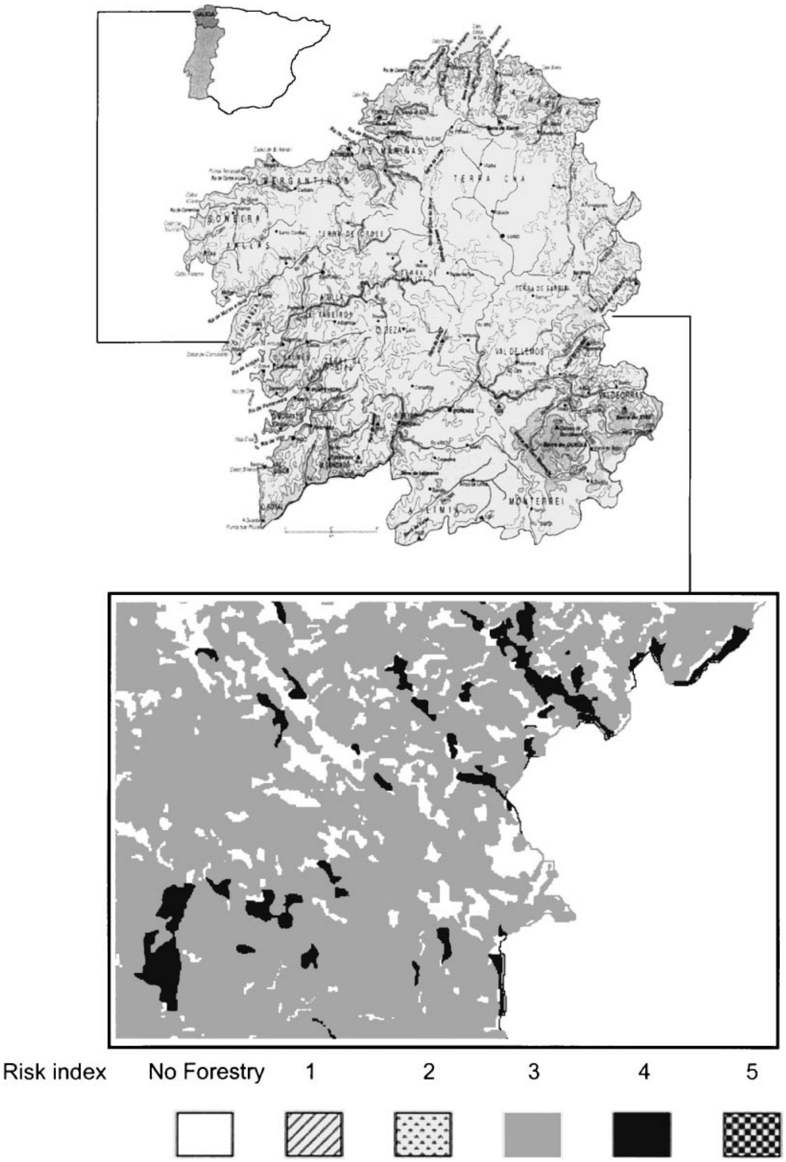


Fig. 5. Risk index map along the year.

Taking into account these figures, the data recorded in Tables 2 and 5, and the bioclimatic diagram and data in Fig. 4, the species of the zone can be classified in the way shown in Table 6. This table gives information about the behavior of the different species in case of forest fire and can be used to prevent and/or to fight wildfires in a rational way.

Combined analysis of this table together with Table 2 shows that, some species with both high calorific values and high flammability values, and so with a high potential fire risk, show their highest values in winter time. Because in this season rains are frequent and temperatures are low, the fire risk is practically negligeable. This is the case of *S. scoparius*

Link and may be understood as a nature self-defence mechanism to fight forest fires [11,12].

Flammability values during the seasons of the year of *S. scoparius Link* are presented in Fig. 2.

Other species such us *P. radiata* D., *P. sylvestris* L., and *C. sativa Miller* show their highest calorific values at the time their flammabilities are lowest, so presenting a great resistance to ignition and considerably diminishing the risk of forest fires. Calorific values and flammabilities of these species are shown in Fig. 3. An exception to this rule is shown by *P. pinaster Aiton*, which has an extremely high calorific power and also high flammability during the whole year. The great amount of resins and essential oils, and its readiness to start and spread forest fires places this species in the group of high-risk trees.

Fig. 4 shows changes of mean calorific values and flammabilities during the year in the zone studied. As it was previously pointed out, high flammability values coincide with lowest calorific values.

4. Conclusions

From the calorific values and flammabilities measured for the different species present in the zone, a forest map, shown in Fig. 5, was constructed.

The studied zone, Devesa da Rogueira (Galicia, Spain), can be considered as a high risk zone because of its easiness to initiate wildfires fire owing to the presence of species such as bushes and coniferous which have high flammabilities during the whole year. The existence of harwood with high calorific and flammability values also make easy for fire to spread. These species are represented by *Q. robur* L. and *C. sativa Miller*. Data recorded in Table 5 show that forest waste in this zone may achieve a mean value above 20 000 $\mathrm{kJ\,kg^{-1}}$, which make these kind of residue valuable to be used as an alternative energy source material [13].

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