Thermochimica Acta 394 (2002) 279–289

thermochimica acta

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Calorimetry as a tool to design campaigns to prevent and fight forest fires originating from shrub species

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Received 10 September 2001; received in revised form 28 January 2002; accepted 2 March 2002

Abstract

In Galicia, different forest species, mainly pine, eucalyptus and bushes occupy around 2.1 million ha. Shrubs take up about 1 million ha and most of this land could be considered unproductive and constitutes one of the main sources for initiating forest fires that devastate more than 40,000 ha per year. One objective of this study was to establish the role of these species in starting and spreading of forest fires through determination of their risk indices. Another study examined the possibility of using the potential biomass originating from these materials as a source of xyloenergy (energy originating from wood). With this aim, different physical, chemical, and biological parameters were determined over the year for different forest species and geographical zones in Galicia. Bomb calorimetry was used to determine caloric values, one of the key parameters in this study. When caloric values are greater than 22,000 kJ kg^{-1} and very homogeneous over the whole year, make the bush biomass very valuable for energy exploitation. An effective control of this biomass could reduce the number of fires and improve forest ecosystems.

The study was carried out using a static bomb calorimeter (caloric values), elemental analysis equipment (C, H, O, N, and S), and an epiradiator (flamabilities), and complemented with the determination of some biological and environmental parameters that are shown together in the form of bioclimatic diagrams.

Keywords: Shrub species; Calorimetry; Caloric values; Flammability; Risk index; Forest fires

1. Introduction

Forest surface taken up in Galicia by bush species is around 80,000 ha [1] and it is increasing as a consequence of the abandonment of agricultural land that is rapidly becoming scrubland, which is similar to the land devastated by forest fires. The increase in land area under bushes is a potential culture for the start and spreading of forest fires. Because of this, reforestation campaigns must be designed to avoid the accumulation of bush species.

The distribution of bushes in Galicia is very well known [1]. In fact, *Ulex europaeus* L. (furze) is very common in the Atlantic coast, *Sarothamnus scoparius* (L.) Link (broom) shares land with furze, increasing its presence with the distance to the coast, and erica species (heath) are predominant in the interior, mountainous zones.

As a consequence of economical and ecological losses originating from forest fires, a search for scientific solutions to prevent and reduce forest fires began in the past few years. Amongst the different measures to be taken, the determination of risk indices

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PII: S0040-6031(02)00260-5

(the potential capacity of a species to originate fires) of different species is a very important one, as it depends on physical, chemical, biological, as well as environmental parameters.

In this study, the following parameters were considered:

1. *Caloric values*: It is the amount of energy released by a mass unit of material after combustion in a bomb calorimeter. Two caloric values must be considered, the higher heating value (HHV) and the lower heating value (LHV). The HHV can be determined experimentally in the laboratory, and the LHV, that can be calculated from HHV. These caloric values are related through the following equation:
   $$\mathrm{LHV} = \mathrm{HHV}(1 - W) - 24.41(W + 9H_{\mathrm{d}}) \qquad (1)$$
   where W is the moisture percentage, and H_{d} is the hydrogen percentage of the dry sample. The heat of vaporization of water is taken as 2441.8 kJ kg^{-1}, and the water formed during combustion is nine times the hydrogen content (%).
2. *Flammability* [2]: It can be defined as the ease with which a material catches fire, both spontaneously or through exposure to certain environmental conditions.
3. *Other parameters*: The elemental chemical composition (C, H, O, N and S), moisture content, density, and ash percentage after combustion in the bomb. All these thermochemical parameters are influenced by the climatic conditions of the area. For this reason, the bioclimatic diagram [3] of the zone where the sample was collected must be taken into account. This bioclimatic diagram, includes many climatic features of the area (temperature, pluviosity, vegetative productivity, different bioclimatic indices, potential evapotranspiration, etc.), will have decisive influence on all the above parameters and is key to an accurate interpretation of the results.

This study was carried out over 1-year period to analyze the possible influence of the parameters studied on the risk indices.

2. Experimental procedure

In this study, shrub species were divided into three groups: furze, broom and heaths, and the main sampling zones were selected according to the presence of different groups of species within them. Because of this sampling design, furze was investigated both in Teixeiro (A Coruña) station 1, and Brión (A Coruña) station 2; heather in Lalín (Pontevedra) station 3 and Brión, and broom in Roupar (Lugo) station 4. The sample collections were carried out in different months and seasons to establish a relationship between caloric values and the sampling zone characteristics (temperature, rainfall, topography, moisture, etc.).

To select the sampling zones, the species to be studied should occupy homogeneously, a surface greater than 1 ha, in these zones. Once chosen, each zone must be characterized by filling in a technical field form in which physical and environmental data, situation and description of the zone, description of the species, etc., were reported. In each zone, four randomly chosen sites with a surface of around 10 m^2 must be cleared. Samples taken from each site were weighed to determine the total biomass of the whole zone (t ha^{-1}), and then mixed. After cutting the samples to small pieces, a final bulk sample of about 5 kg was selected by usual coning and quartering procedure. This sample was introduced in hermetically closed polyethylene bag, to avoid loss of moisture, and sent to the laboratory in less than 10 h.

The rest of the cut material was left on the surface of the zone to be used for future sampling considered as dead matter and thus to analyze the evolution of physical, chemical and biological parameters as a consequence of changes in environmental conditions.

Once in the laboratory, samples were weighed to 0.1 or 1.0 g using a double-scaled Salter EP-22KA balance and then placed in a Selecta 200210 natural desiccating oven at 105 °C to a constant weight, and the moisture content was determined.

After determination of moisture content, the dry sample was ground using two mills of different power, a Retsch SM-1 blade mill and a Taunus MS-50 grinder, to homogenize the sample. The sample pellets were then prepared and used in the calorimetric experiments.

A portion of this ground sample, labeled 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). The second fraction, named B, was used to determine caloric values and ash percentage after combustion of the different species. All the combustion experiments were made in a static bomb calorimeter, a sealed Parr-1108, following the procedure described by Hubbard et al. [4]. Sample pellets of about 1 g size [5] were put in a stainless steel crucible and then 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 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.

Table 1
Main bioclimatic and biological parameters [2,6] corresponding to the main forest zones where sampling was made

Characteristics of standard sampling zone	Value
Altitude (m)	100–400
Annual rainfall index (mm)	1062–1288
Summer rainfall index (mm)	137
Mean annual temperature (°C)	12.9
Mean daily maximum temperature of the warmest month (July) (°C)	22.5–33.3
Hydric deficiency	97–105
Mediterraneanity index	2.39–2.44

The bomb calorimeter was submerged in a calorimeter can filled with 4631 g of distilled water

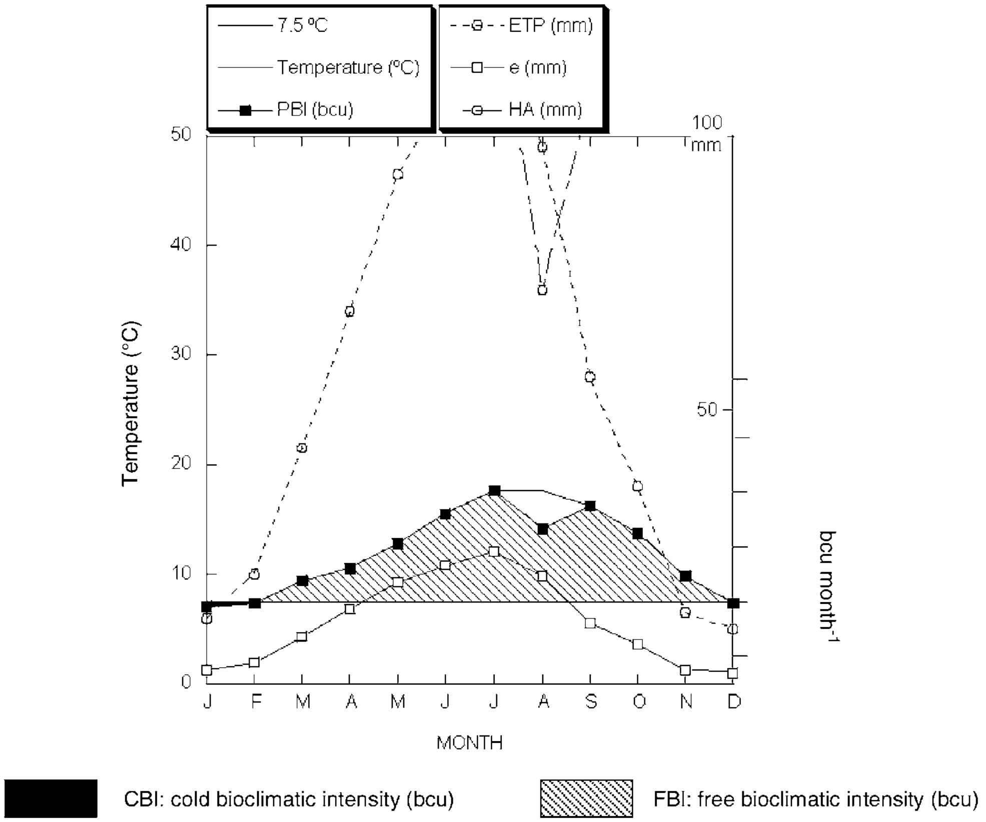

Fig. 1. Representative bioclimatic diagram showing the main environmental characteristics of the sampling zone: temperature (°C); 7.5 °C (minimum temperature for vegetal activity); ETP (evapotranspiration in mm); *e* (residual evapotranspiration in mm); HA (hydric availability in mm); PBI (potential bioclimatic intensity in bcu). The striped zone corresponds to free bioclimatic intensity (FBI).

Table 2
Mean of HHV, LHV, moisture (*M*), density (*D*), and ash percentage (BA) after combustion in the bomb[a]

	HHV (kJ kg^{-1})	LHV (kJ kg^{-1})	*M* (%)	*D* (kg m^{-3})	BA (%)
(a) Corresponding to *U. europaeus* L. (furze) residues collected in station 1 (Teixeiro, A Coruña) and station 2 (Brión, A Coruña)					
Station 1					
November	20459.98 ± 237.24 (1.16)	8421.65 ± 121.71 (1.45)	48.70	1016	0.19
January	19851.84 ± 51.54 (0.26)	7542.67 ± 24.90 (0.33)	51.70	1071	0.26
March	20030.34 ± 302.75 (1.51)	8722.79 ± 161.37 (1.85)	46.70	1046	0.22
May	20153.53 ± 164.35 (0.82)	8217.32 ± 82.63 (1.01)	49.70	806	0.17
July	19654.96 ± 216.36 (1.10)	8084.34 ± 109.91 (1.36)	49.20	1065	0.09
August	20048.54 ± 163.37 (0.82)	8573.41 ± 85.60 (1.00)	47.70	1039	0.36
September	20026.99 ± 124.87 (0.62)	9662.56 ± 71.80 (0.74)	42.50	951	0.18
Station 2					
November	20746.51 ± 135.79 (0.65)	6718.43 ± 57.30 (0.85)	57.80	1008	0.22
January	20184.04 ± 75.21 (0.37)	6619.65 ± 75.21 (0.40)	57.30	989	0.20
March	20564.20 ± 305.24 (1.48)	7932.57 ± 148.34 (1.87)	51.40	996	0.21
May	20144.20 ± 149.11 (0.74)	5616.59 ± 56.62 (1.01)	62.00	800	0.20
July	20771.57 ± 22.04 (0.11)	6612.46 ± 9.15 (0.14)	58.50	971	0.23
August	20191.49 ± 371.23 (1.84)	7387.07 ± 171.88 (2.33)	53.70	1006	0.07
September	19565.25 ± 101.74 (0.52)	7124.02 ± 47.31 (0.66)	53.50	967	0.14
Dead matter					
Station 1					
August	19581.68 ± 272.02 (1.39)	14960.87 ± 229.86 (1.54)	15.50	835	0.20
Station 2					
August	19389.25 ± 145.86 (0.75)	14727.80 ± 122.82 (0.83)	15.80	914	0.10
(b) Corresponding to *S. scoparius* (L.) Link collected in station 4 (Roupar, A Coruña)					
Station 4					
November	20760.42 ± 105.92 (0.51)	7261.73 ± 48.09 (0.66)	54.60	901	0.18
January	20071.95 ± 154.43 (0.77)	6785.76 ± 67.49 (0.99)	56.30	944	0.25
March	20454.02 ± 208.76 (1.02)	7070.06 ± 93.52 (1.32)	55.20	906	0.24
May	19671.64 ± 202.79 (1.03)	5978.45 ± 82.33 (1.38)	59.40	982	0.34
July	19780.99 ± 217.34 (1.10)	7260.49 ± 101.28 (1.39)	53.40	950	0.06
August	19759.44 ± 99.48 (0.50)	7568.40 ± 47.95 (0.63)	51.80	960	0.28
September	19599.35 ± 166.73 (0.85)	9326.37 ± 95.12 (1.02)	43.00	975	0.17
Dead matter					
Station 4					
August	20118.95 ± 146.61 (0.73)	14335.14 ± 116.26 (0.81)	20.70	771	0.22
(c) Corresponding to heath species collected in station 2 (Brión, A Coruña) and station 3 (Lalín, Pontevedra)					
Station 2					
March	18713.36 ± 251.30 (1.34)	8430.78 ± 139.73 (1.66)	44.40	911	0.15
May	18801.39 ± 217.26 (1.16)	5466.86 ± 86.29 (1.58)	60.30	897	0.18
July	18973.69 ± 207.96 (1.10)	6686.14 ± 94.62 (1.42)	54.50	603	0.29
August	18855.03 ± 116.39 (0.62)	7552.84 ± 58.31 (0.77)	49.90	878	0.07
September	19198.50 ± 87.95 (0.46)	7611.13 ± 43.58 (0.57)	50.50	816	0.23
Station 3					
January	19300.04 ± 207.10 (1.07)	8153.87 ± 108.93 (1.34)	47.70	947	0.11
March	18993.87 ± 210.40 (1.11)	8383.14 ± 113.82 (1.36)	45.90	937	0.06
May	19612.45 ± 172.28 (0.88)	5160.45 ± 63.40 (1.23)	63.20	914	0.32
July	18669.97 ± 199.23 (1.07)	7263.55 ± 97.82 (1.35)	50.90	918	0.18
August	18973.34 ± 246.79 (1.30)	8226.99 ± 131.05 (1.59)	46.90	1021	0.13
Dead matter					
Station 3					
August	18895.46 ± 135.97 (0.72)	15390.81 ± 121.15 (0.79)	10.90	771	0.22

[a] Values in parenthesis are in percentage.

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 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 water temperature was kept homogeneous in the whole calorimeter by means of two motors which continuously stirred 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 main period of the calorimetric run. The experiment ended at step 240. The bomb calorimeter was removed from the can and after being carefully opened, ash and water resulting from the combustion were evaluated following routine procedures. The corrected temperature rise was obtained using a computer program and the measured data. Knowledge of this temperature rise allows calculation of caloric values.

The equivalent energy of the calorimeter was determined using the combustion of benzoic acid, BCS CRN-ISOP standard reference sample from Bureau of Analysed Samples Ltd., having an energy of combustion under standard bomb conditions of 26431.8 ± 3.7 kJ kg^{-1}. From five calibration experiments E(calor) = 21182.28 ± 0.22 J K^{-1} (0.000985%), where the uncertainty quoted is the standard deviation of the mean. The temperature rise was corrected for stirring and exchange heating.

3. Results and discussion

Table 1 shows main characteristics [6] of the sampling zones. These data together with biological and

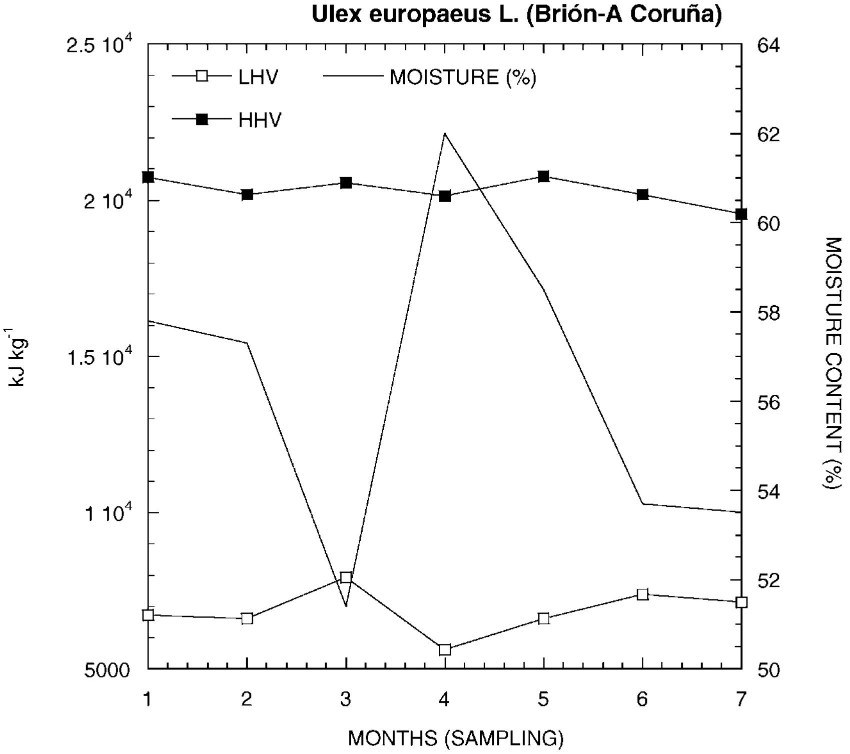

Fig. 2. Mean HHV, LHV, and moisture content evolution over the year for *U. europaeus* L. (furze) collected in Brión (A Coruña).

Table 3
Results of chemical analysis for dry sample

	Chemical analysis (% of total composition)				
	N	C	H	O	S
(a) Corresponding to the seven samplings of *U. europaeus* L. (furze) and the dead matter sampling for stations 1 and 2					
Station 1					
November	1.33	56.87	7.85	33.67	0.28
January	1.69	48.80	6.15	42.99	0.37
March	0.84	55.93	6.94	36.01	0.28
May	1.89	48.84	6.19	42.79	0.29
July	1.25	49.48	6.26	42.65	0.36
August	1.73	50.54	6.50	40.91	0.32
September	1.28	50.08	6.45	41.83	0.36
Station 2					
November	0.91	58.39	6.74	33.79	0.17
January	1.98	49.57	6.39	41.62	0.44
March	1.23	54.53	7.55	36.25	0.44
May	1.42	49.73	6.20	42.32	0.33
July	2.10	49.79	6.35	41.38	0.38
August	2.00	50.43	6.39	40.70	0.48
September	1.60	49.41	6.53	42.05	0.41
Dead matter					
Station 1					
August	1.28	50.08	6.45	41.83	0.36
Station 2					
August	1.60	49.41	6.53	42.05	0.41
(b) Corresponding to the seven samplings of *S. scoparius* (L.) Link and the one of dead matter sampling for station 4					
Station 4					
November	1.61	58.64	8.32	30.98	0.45
January	2.85	49.11	6.36	41.18	0.50
March	1.62	53.13	7.57	35.25	0.43
May	1.65	47.94	6.25	43.72	0.44
July	1.38	49.37	6.38	42.45	0.42
August	2.99	49.94	6.39	40.16	0.52
September	1.39	49.02	6.43	42.74	0.42
Dead matter					
Station 4					
August	1.39	49.02	6.43	42.74	0.42
(c) Corresponding to the five samplings of heath and that of dead matter sampling for stations 2 and 3					
Station 2					
March	0.61	52.64	7.28	39.10	0.37
May	1.48	46.88	6.06	45.23	0.35
July	1.91	47.61	6.16	43.97	0.35
August	1.79	47.43	6.13	44.30	0.35
September	1.80	46.76	6.15	44.94	0.35
Station 3					
January	0.69	50.07	7.27	41.57	0.40
March	0.55	55.12	6.49	37.53	0.31
May	2.17	47.02	6.35	44.05	0.41
July	1.56	47.37	6.12	44.57	0.38
August	1.68	46.71	6.02	45.25	0.34

Table 3 (*Continued*)

	Chemical analysis (% of total composition)				
	N	C	H	O	S
Dead matter					
Station 2					
August	1.80	46.76	6.15	44.94	0.35
Station 3					
August	1.70	55.19	6.95	35.82	0.34

environmental parameters [3] were used for designing of bioclimatic diagrams. These diagrams are very useful to understand the evolution of vegetative productivity (active growing) of plants over the year as a consequence of changes in environmental conditions. Fig. 1 is a diagram corresponding to a representative sampling zone where it can be observed that vegetative productivity, related to PBI, is low in autumn and winter, while in spring and summer this productivity significantly increases.

Table 2(a)–(c) shows mean values corresponding to HHV, LHV, moisture content, density and ashes after combustion in the bomb for the three groups of species studied. From these results the following can be pointed out:

- HHV corresponding to furze keep very steady over different months within an year. However, in some cases, 3–4-year-old furze in station 2 presents slightly higher values than older furze plants

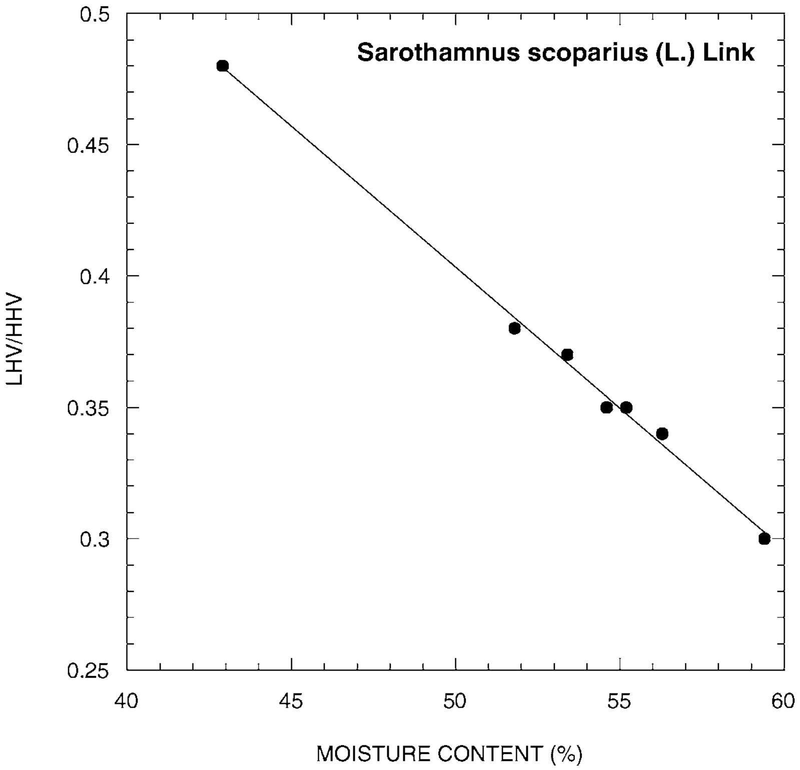

Fig. 3. Plot of LHV/HHV vs. moisture content for broom.

occupying station 1. This can be due to the higher vegetative activity of young furze. LHV shows an opposite behavior as it depends greatly on moisture content that is greater for young furze.

- In general, for the three groups of shrub studied, HHV shows a steady behavior over the year while LHV, depending on moisture contents, shows seasonal changes. However, the trend of variation is not very clear and it can be observed the decrease in LHV with blooming season, furze and broom (May) and heaths (May–July).
- Analysis of Table 2(a)–(c) together with Fig. 1 shows, on the one hand, a decrease of LHV corresponding to high productivity periods (active growing, appearance of new tissues and thus high moisture content, etc.). On the other hand, LHV increases with the activity stop period (loss of moisture by tissues, that become woody matter thus increasing their energy).

Table 4
LHV and flammability classes for the three groups of species and dead matter

	LHV class for station 1[a]	Flammability class for station 2[b]
Furze		
November	5	3, 1
January	5	4, 3
March	5	4, 3
May	4	4, 0
July	5	3, 5
August	5	4, 0
September	4	5, 5
Broom		
November	4	1
January	4	0
March	4	0
May	3	0
July	4	0
August	5	2
September	5	0
Heather		
November	–	–
January	5	0
March	5	1
May	2	0
July	4	0
August	5	0
September	5	–
Dead matter		
August		
Heather	5	5
Broom	5	5
Furze	5	5

[a] LHV classes—class 1: LHV $<$ 4500 kJ kg^{-1}; class 2: LHV $\geq$ 4500 and $<$5500 kJ kg^{-1}; class 3: LHV $\geq$ 5500 and $<$6500 kJ kg^{-1}; class 4: LHV $\geq$ 6500 and $<$7500 kJ kg^{-1}; class 5: LHV $\geq$ 7500 kJ kg^{-1}.

[b] Flammability classes—class 0: very low flammability (>32.5 s); class 1: low flammable (27.5–32.5 s); class 2: flammable (22.5–27.5 s); class 3: moderately flammable (17.5–22.5 s); class 4: very flammable (12.5–17.5 s); class 5: extremely flammable (<12.5 s).

Table 5
Mean risk indices corresponding to the three groups of species studied and dead matter[a]

	Risk index class
Furze	
November	4
January	4
March	5
May	4
July	5
August	5
September	5
Broom	
November	2
January	2
March	2
May	2
July	2
August	3
September	2
Heather	
November	–
January	3
March	3
May	1
July	2
August	3
September	2
Dead matter	
August	
Heather	5
Broom	5
Furze	5

[a] Class 1: 0.5 $<$ risk index final value $\leq$ 1.5 (no apparent risk); class 2: 1.5 $<$ risk index final value $\leq$ 2.5 (little risk); class 3: 2.5 $<$ risk index final value $\leq$ 3.5 (middle risk); class 4: 3.5 $<$ risk index final value $\leq$ 4.5 (high risk); class 5: risk index final value $>$ 4.5 (extremely high risk).

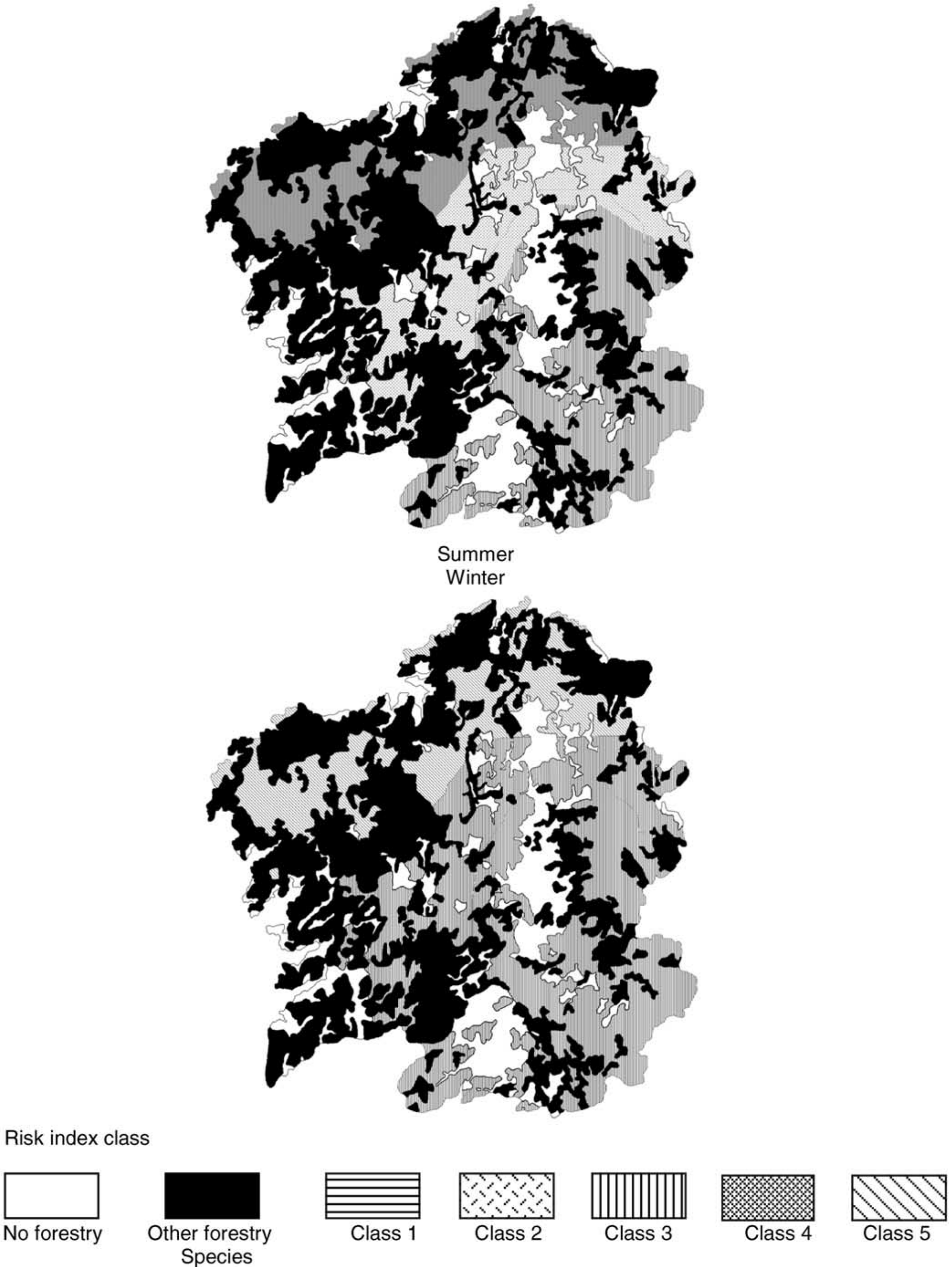

Fig. 4. Risk index maps corresponding to different bush species collected in winter and summer.

Data corresponding to dead matter are also reported in this table. Dead matter was collected 9 months after cutting. Except for furze, that shows a decrease as a consequence of the volatilization of high energy content compounds, all species show similar HHV than those corresponding to live matter (just after cutting).

Fig. 2 shows the behavior of HHV and LHV corresponding to furze over the year for samples collected in Brión (A Coruña) as a function of the sampling period. As it can be seen HHV keeps very steady over the year. However, LHV depending greatly on moisture content in the material (that is related to environmental humidity) shows a behavior more changeable. In this same figure, moisture content (%) evolution is also shown. All the other species show behaviors very similar to this one.

Elementary compositions of the different groups of species are reported in Table 3(a)–(c). Some of these values are important for discussion and calculation of caloric values.

Table 6
Different parameters used for calculation of risk indices for erica species collected in Brión (A Coruña) in September [11]

Erica (age: 10 years)	Experimental values	Calculated values
Thermochemical parameters		
HHV class number (50%)	5	
Flammability class number (50%)	0	2.5
Physicochemical properties		20
Density (kg m^{-3}) (30%)	816	
Own moisture (%) (65%)	50.45	
Bomb ashes after combustion (%) (5%)	0.23	0.0688
Biological characteristics		25
Physiological activity (10%)	0.46	
Essential oils/resins (10%)	Middle/low—4	
Age (10%)	Middle/10 years—5	
Habit (10%)	5	
Forest waste generated (20%)	Low—2	
Forest cover around (20%)	Low—2	
Perennial/deciduous (10%)	5	
Blooming period (10%)	May/July—6	−0.0237
Climate characteristics		40
Rainfall (40%)		
Monthly mean amount (mm) (35%)	241	
Periodicity (65%)	Middle/high—6	
Mean temperature (°C) (20%)	9.8	
Hydric availability (mm per month) (20%)	341	
Environmental humidity (% per month) (20%)	68.4	−0.1162
Parameters depending on physical environmental conditions		15
Zone wind (30%)		
Strength (60%)	Middle/low—4	
Periodicity (40%)	Middle/low—4	
Clouds (10%)		
Amount (50%)	Middle—5	
Regularity (50%)	Middle—5	
Topography (20%)	Little suitable—3	
Sun radiation (10%)		
Sunshine (%) (50%)	Mean—5	
Sunny days (50%)	Mean—5	
Anthropic activity (30%)	High—7	−0.0015
Risk index final value		2.43
Risk index class		2

A plot of the ratio LHV/HHV against moisture content is shown in Fig. 3. The ratio decreases with increase in moisture content of the biomass. It corresponds to *S. scoparius* (L.) Link (broom). The linear behavior shown is in good agreement with Eq. (1). This same behavior was followed by all the different species studied.

In Table 4, species are classified according to their mean LHV and flammability. As it can be seen, furze shows very important differences for flammability values corresponding to the two sampling stations. These differences could originate from the fact that plants in station 2 are much younger than those in station 1 thus becoming more easily influenced by changes in temperature and moisture content. It can be seen also that except for heather (May) and broom (May), as a consequence of the high environmental humidity, LHV show very steady and high class values 4–5. However, for these same species flammabilities are very low. This could be understood on the basis of natural self-defense mechanism [7,8]. Dead matter, due to its low moisture content, shows high LHV and extremely high flammabilities.

Table 5 shows risk indices evolution over the year [9,10] for the different species studied. Through the values reported, it can be seen that broom and heather risk indices show middle/low steady values over the year. However, furze presents high risk indices over the year, presenting dangerous potential for starting and/or spreading forest fires, thus making necessary a careful vigilance on it to prevent forest fires. Fig. 4 is a map showing risk indices evolution over the year.

Table 6 shows key parameters used for calculation of risk index class [9–11] corresponding to heather collected in Brión (A Coruña) after September cutting.

Calculation and elaboration of risk indices maps can become a key tool for the design of campaigns to prevent and fight forest fires. This study can be extended to any other forest species and zones providing a rational study and discussion of the different results obtained.

4. Conclusions

Climatic conditions, mainly temperature and moisture content, have an important influence on flammability values, but not on HHV. As a consequence, HHV stayed constant over the year. This is not the case of LHV that depends greatly on moisture content.

Mean caloric values corresponding to dead matter are very close to those of live matter, collected immediately after cutting. However, flammability values show large increase for dead matter reaching a value of 5, thus making these residues capable of initiating and spreading forest fires. This means that shrub biomass accumulation must be avoided to prevent forest fires.

Acknowledgements

The authors wish to thank Vicerrectorado de Investigación, University of Santiago (Spain), and Maderas Villapol. Part of this research was sponsored by Xunta de Galicia through a fund project XUGA20608B98.

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