

Short communication. Comparing flammability traits among fire-stricken (low elevation) and non fire-stricken (high elevation) conifer forest species of Europe: a test of the Mutch hypothesis

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Abstract

Aim of study: The flammability of the main coniferous forest species of Europe, divided into two groups according to their fire regime and altitudinal distribution, was tested in an effort to detect species-specific differences that may have an influence on community-wide fire regimes.

Area of study: Conifer species comprising low- and high-elevation forests in Europe.

Materials and methods: The following conifer species were tested: low elevation; *Pinus halepensis* (Aleppo pine), *Pinus brutia* (Turkish pine), *Pinus pinaster* (maritime pine), *Pinus pinea* (stone pine) and *Cupressus sempervirens* (cypress), high elevation (*i.e.*, above 600 m a.s.l.); *Pinus sylvestris* (Scots pine), *Abies alba* (white fir), *Picea excelsa* (Norway spruce), *Abies borissii regis* (Macedonian fir) and *Pinus nigra* (black pine).

Flammability assessment (time-to-ignition and ignition temperature) was conducted by an innovative ignition apparatus, heat content was measured with an IKA Adiabatic Bomb Calorimeter and ash content by heating 5 g of plant material in a muffle furnace at 650°C for 1 h. Differences among species was statistically analysed by Duncan's multiple comparison test.

Main results: The results did not distinguish separate groups among the tested flammability traits between fire- and non-fire-stricken communities at the individual species level.

Research highlights: Differences in fire regimes among low and high elevation conifer forests could be attributed either to differences in flammability of the plant communities as a whole (*i.e.*, fuelbed or canopy properties vs. individual fuel properties) or to other factors (climatic or anthropogenic).

Key words: ash content; conifer species; flammability; heat content; ignitability; Mutch hypothesis.

Introduction

Increased fire hazard is present in all areas of Mediterranean climate. In the countries of the Mediterranean Basin as much as 10% of total areas covered by forests and shrubs are burned annually by wildland fires (Pausas and Vallejo, 1999). Coniferous forests are the most affected by fire (Dimitrakopoulos and Mitsopoulos, 2006). In Europe, the coniferous forests can be distinguished in two groups according to their altitudinal distribution (Quezel, 2000):

1. At lowland areas, where Mediterranean climate prevails, the main coniferous forests are comprised of *Pinus halepensis* (Aleppo pine), *Pinus brutia* (Turkish

pine), *Pinus pinaster* (maritime pine), *Pinus pinea* (stone pine) and *Cupressus sempervirens* (Cypress).

2. At higher elevations (*i.e.*, above 600 m a.s.l.), where continental climate prevails (characterized by cooler and wetter conditions), coniferous forests are primarily formed by *Pinus sylvestris* (Scots pine), *Abies alba* (white fir), *Picea excelsa* (Norway spruce), *Abies borissii regis* (Macedonian fir) and *Pinus nigra* (black pine).

The fire regime to which the biota of each forest group is subjected to differs considerably. In the lowland coniferous forests the natural fire return interval is between 30 to 50 years, characterised by high intensity crown fire incidents in terms of fire behavior. However, during the last century, due to increased

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human activities and climatic change, the fire return interval has been significantly shortened to less than 10-15 years in some cases (Ne'eman and Trabaud, 2000). On the other hand, fire incidents at high elevation coniferous forests are in most cases lightning-caused understory fires of moderate severity, occurring approximately once every 80-100 years. In such environments, forest ecosystems are not resilient to high intensity fires, as they have not been evolutionary exposed to their frequent action (Agee, 1998).

Plant flammability (ignitability) is defined as the easiness of ignition of a plant when exposed to a heat source and it is measured by the time-to-ignition period and the ignition temperature (Anderson, 1970; Martin *et al.*, 1994).

Plant flammability is also related to two chemical fuel properties (Rundel, 1981):

1. Heat content (calorific value) defined as the potential thermal energy that can be released during the burning of a fuel. High heat content increases fuel combustibility and fire intensity (Shafizadeh *et al.*, 1977).

2. Ash content reduces the amount of combustible fuel mass, since only the organic part of the fuel supports combustion. High ash content reduces fuel flammability (Philpot, 1970).

Mutch (1970) first formulated the hypothesis that plant traits that enhance flammability are adaptive, after he observed that fuel of different plant species vary greatly in their degree of flammability and that highly flammable species are prevalent in fire-prone communities. Mutch hypothesis has been criticized on the basis that enhanced flammability may result from selection for other beneficial traits such as drought tolerance (Snyder, 1984).

Traits enhancing flammability could evolve if the result of individual flammability is elevated neighborhood mortality, even if the flammable individual also incurs mortality, through the freeing up of space for recruitment opportunities (Bond and Midgley, 1995). This model and others suggest that flammability enhancing traits may actually have an adaptive function in the structuring of species within communities. Species possessing pre-existing traits that conform to a prevailing fire regime will tend over time to exclude species without such traits (Kerr *et al.*, 1999).

The main objective of this study was to investigate if there are species-specific differences in flammability traits among coniferous forests of low and high fire frequency. In order to achieve this, we compared the flammability characteristics among five fire-stricken

and five non fire-stricken conifer species in terms of their time to ignition, ignition temperature, heat content and total ash content.

Materials and methods

The studied species are representative of the main conifer vegetation types of Europe. Specifically:

Low elevation conifer species (fire stricken): *Pinus halepensis* (Aleppo pine), *Pinus brutia* (Turkish pine), *Pinus pinaster* (Maritime pine), *Pinus pinea* (Stone pine) and *Cupressus sempervirens* (Cypress).

High elevation conifer species (non fire stricken): *Pinus nigra* (Black pine), *Pinus sylvestris* (Scots pine), *Abies borissii regis* (Macedonian fir), *Picea excelsa* (Norway spruce), *Abies alba* (white fir).

For each species, a bulk sample was comprised of needles detached from 3-8 individual trees growing at three different locations at least 50 km apart from each other, in order to minimize interspecies and intralocation differences. Only needles were used in order to achieve a uniform and smooth surface of plant samples, according to the requirements of the flammability test. Also, due to their high surface area-to volume ratio and essential oil content, needles are considered as the most flammable plant parts of the conifer species during fire initiation and propagation. The collection of the plant samples took place during the summer and at the hottest hours of the day (12:00-15:00). After field sampling, the needles were immediately placed in sealed plastic bags and brought to the laboratory. The same day, part of the needles was oven-dried for 3 days at 105°C to determine moisture content.

After every field collection, part of the fresh needles was immediately subjected to the flammability tests to investigate the ignitability of fresh (live) needles. The ignition apparatus with a cone radiator used in the flammability tests was manufactured according to the specifications of the International Standards Organisation (ISO No. 5657-1986E). This ensured both stability and continuity in the heat source parameters (heat flow, temperature) and accuracy and precision in the flammability measurements (Dimitrakopoulos and Papaioannou, 2001).

Heat content was measured with an IKA Adiabatic Bomb Calorimeter. Gross calorific value, the total amount of heat produced by the complete burning of the substance, was measured in kJ g⁻¹.

Total ash content was determined by heating 5 g of plant material in a muffle furnace at a temperature of

650°C for 1 h. It is expressed as a percentage of the oven-dry weight of the sample before heating.

Four individual measurements were conducted for every fuel property and plant species. Statistical analysis was performed with the SPSS statistical package (Norusis, 1997). The one-way analysis of variance (ANOVA) was followed by Duncan's multiple comparison test, at the 95% confidence level.

Results and discussion

The results were dubious in the sense that there was no clear distinction into two separate groups between the low and the high elevation conifer species in terms of their flammability traits.

ANOVA and Duncan's multiple comparison test (95% confidence level) showed statistical differences which formed five levels of significance among the time-to-ignition values, four levels of significance among the ignition temperature and ash content values and six levels of significance for the heat content values (Table 1). Aleppo pine and Turkish pine were the most flammable (lowest ignition time). This can be attributed to the fact that these two species are extremely rich in flammable volatile essential oils. Norway spruce was the least flammable (highest ignition time) among the species tested. Aleppo pine and Turkish pine had significantly lower ignition temperature values from the other species. Stone pine and Scots pine presented the lowest and highest heat content values, respectively. The measured heat content values all fall within the range of values reported for

the rest of the world, supporting the idea that calorific value is a relatively constant fuel parameter among plant species. Finally, Macedonian fir, Aleppo pine and White fir had the highest ash content values while Black pine and Scots pine presented the lowest values.

Natural selection of flammability characteristics or traits in fire prone environments has been a topic of scientific debate. On a more individualistic approach, Bond and Midgley (1995) concluded that a flammability trait might evolve in a species only in certain circumstances, dependent on the fire survival mechanisms of the species and the density of the surrounding plant community. The evolution of a flammability trait is more likely to occur when the trait also provides additional benefits to the plant. Schwilk and Caprio (2011), working on pine litter fuel beds, state that single flammability traits of species (such as pine needle length) can lead to prediction of the fire behaviour in the whole plant communities. From this study it can be inferred that differences in fire regimes among low and high elevation conifer species in Europe cannot be attributed to differences in single flammability traits of species, but rather to the whole plant community fuel properties or to other factors (climatic or anthropogenic). More explicitly, flammability seems to be influenced more by the fuelbed properties (*i.e.* the whole forest) rather than the individual forest fuel characteristics.

Fire regimes of low elevation fire prone conifer forests in the Mediterranean Basin are often attributed to socioeconomic factors and land-use changes (Velez, 1993; Pausas and Vallejo, 1999; Pausas *et al.*, 2008). It is assumed that human pressure for land use

Table 1. Flammability traits of the conifer species examined. Test of significance was performed by Duncan's multiple range test, at $p = 0.05$. Values with the same letter are not significantly different

Species	Time to ignition (s)	Ignition temperature (°C)	Heat content (kJ g ⁻¹)	Ash content (%)
<i>Abies borissii regis</i>	31.815 BC	243.75 ABC	18.028 D	6.065 A
<i>Pinus halepensis</i>	20.233 F	206.25 D	19.228 BC	5.985 A
<i>Abies alba</i>	26.305 DE	242.5 ABC	18.943 BC	5.770 A
<i>Picea excelsa</i>	39.573 A	231.75 ABC	19.118 BC	4.530 B
<i>Cupressus semprevirens</i>	33.835 B	234.75 ABC	18.365 CD	4.125 B
<i>Pinus brutia</i>	21.785 EF	213.5 D	19.519 B	3.945 BC
<i>Pinus pinaster</i>	27.450 CD	213 C	18.734 BCD	3.330 BCD
<i>Pinus pinea</i>	33.968 B	247.25 AB	16.825 E	2.900 CD
<i>Pinus silvestris</i>	28.063 CD	248.25 AB	20.484 A	2.530 D
<i>Pinus nigra</i>	30.233 BCD	215.5 A	19.661 AB	2.155 D

change has been a very significant factor in the increased wildfire frequency and area burned in recent decades, although the influence of climatic changes (frequent drought episodes and higher summer temperatures) cannot be overlooked (Pausas, 2004; Dimitrakopoulos *et al.*, 2011).

Conclusions

Comparison of the main coniferous forest species of Europe, divided into two groups according to their fire regime and altitudinal distribution, showed that the fire-stricken low elevation conifer species do not demonstrate higher flammability traits than the high elevation, non fire-stricken species. Thus, species-specific differences in flammability characteristics cannot be linked to the community-wide fire regime. On the contrary, from this study it can be inferred that flammability does not appear to be species dependent and that the flammability traits of conifer species are not the only factor affecting fire frequency at European conifer forests. Therefore, differences in fire regimes among low and high elevation conifer species in Europe could be attributed to differences in the flammability among the plant communities as a whole (*i.e.*, fuelbed or canopy properties vs. individual fuel properties) and/or to external factors (climatic or anthropogenic).

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