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Evaluation of the flammability of forest species for fire management in wildland urban interface areas of Brazil.

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Abstract

Classification of forest fuels according to their flammability is an essential component of fire risk assessment in the context of forest fire management planning. Surveys on the flammability of forest fuels are useful for fire management because they provide information on the reaction of individual fuels in heating a fire, make it possible to classify different plant species within an ecosystem in terms of fire hazard, and help with selection of suitable species to reduce the danger of fires in reforestation. The flammability characteristics of vegetation have been fundamental in recent methodologies for risk assessment of forest fires in several regions of the world. In addition, knowledge of how species differ in their flammability characteristics is necessary to draw up lists of recommended plants for urban and residential afforestation in wildland urban interface areas. In Brazil, there are no methodologies for classifying tree and shrub species according to the flammability characteristics of the vegetation. The choice of these species is made empirically, considering only the local experiences of vegetation specialists. This research aimed to consolidate in the country a methodology that has been adopted in several countries to characterize plant species according to the degree of flammability, facilitating the use of these species in protection activities against forest fires. The general objective of this research was to evaluate the flammability of native and exotic forest species from forest fragments and wildland urban interfaces (WUI) areas of Curitiba-PR and Gurupi-TO in Brazil, to support fire management planning in these environments. To achieve this objective, fifty-eight species were chosen from the fragment forests and wildland urban interfaces of Curitiba-PR and Gurupi-TO, Brazil, belonging to the southern and northern regions of Brazil, respectively, where forest activities are very important for the regional economy and to which fires cause significant damage. One of the analysis criteria for the selection of species were the morphological characteristics of the species. The selected species were submitted to flammability tests in the Forest Fire laboratories of the Federal University of Paraná and of the Environmental Monitoring and Fire Management Center (CEMAF) of the Federal University of Tocantins (Gurupi-TO)., The results indicated that of the analysed species, 44% had low flammability (IF = 0), and therefore, have potential for use in fire prevention activities at the wildland urban interfaces areas of the cities of Curitiba and Gurupi.

1. Introduction

The behavior of forest fires and the mechanisms involved in this process are highly complex. Studies on the behavior of fire in forest fuels have intensified a lot since the 20th century due to the growing need to develop fire prediction and simulation models to improve systems for preventing and fighting forest fires or, using a broader current concept, to provide more effective instruments for fire management.

Classification of forest fuels according to their flammability is an essential component of fire risk assessment in the context of forest fire management planning. Researchers and administrators have long identified the need to classify the flammability of forest species for use in fire prevention and combat plans and for the improvement of fire behavior prediction models. Surveys on the flammability of forest fuels are useful for fire management because they provide information on the reaction of individual fuels in the combustion process, make it possible to classify different plant species within an ecosystem in terms of fire hazard, and help with selection of suitable species to reduce the danger of fires in reforestation (DIMITRAKOPOULOS AND PAPAIOANNOU, 2001).

From the point of view of natural resource management, the interaction between natural and urban areas is called “wildland urban interface” (WUI). Forest fire prevention and mitigation programs educate and help communities in WUI areas to understand and be prepared for forest fires, including access, buildings and the urban landscape. The techniques and measures to prevent forest fires in the urban landscape around the residences allow access of personnel and firefighting equipment and reduce the risks and damages due to fires. Usually the most effective measures are obtained through the vertical and horizontal separation of vegetation and in these cases the use of less flammable plant species is essential. (BEHM et al, 2004). Therefore, knowledge of how species differ in their flammability characteristics is necessary to draw up lists of recommended plants for urban and residential afforestation in WUI areas (WHITE and ZIPPERER, 2010).

Modeling has become an essential tool in research on forest fires and is currently a crucial tool in studies on risk mapping, fire propagation, as well as forest management (MADRIGAL et al, 2009). Experimental studies are needed both to calibrate and to validate the prediction models. Ignition, fire behavior, risk assessment and fire control require a thorough understanding of the chemical and physical processes involved in wildfires. How forest fuels burn and which parameters have the greatest influence on the combustion process are issues that need to be addressed (BARTOLI et al, 2011).

Forest fires affect vegetation which, in turn, affects fire behavior, as the plant species that provide the fuel for fires have specific flammability (CURT et al, 2011).

Climate change over the last few decades has been cited in numerous reports and surveys as one of the main causes of the increase in the frequency and magnitude of wildfires. Several climatological and ecophysiological models project drier and warmer conditions and, therefore, with greater risk of forest fires (MORENO, 2009, WESTERLING & BRYANT, 2008). But the frequency and magnitude of fires do not depend only on meteorological conditions, they also depend on the characteristics of the vegetation, especially its flammability (ALESSIO et al, 2008).

Flammability can be considered as the ease with which the material ignites and can also be understood as the resistance of the plant species to start and propagate fires (NUÑEZ-REGUEIRA et al, 2004). It can also be defined as the ease with which the material catches fire, both spontaneously and when exposed to certain conditions (ZHANG et al, 2011).

Flammability was initially defined based on three components (ANDERSON, 1970):

a- Ignition potential – time required for the fuel to reach ignition, after being exposed to a source of heat;

b- Sustainability – is the ability to maintain combustion after ignition;

c- Combustibility – is the burning rate after ignition.

Martin et al. (1994) added a fourth component: the amount of fuel burned (consumability).

The concept of flammability can be reduced to different aspects of combustion, according to the type of metric used in its evaluation, as can be seen in Table 1 (WHITE and ZIPPERER, 2010).

Flammability is experimentally evaluated by burning fuels in the laboratory, either in the form of the discrete elements (e.g. a leaf, a branch) for which the concept was coined, or as a bed of fuel or a heterogeneous set of individual units (FERNANDES and CRUZ, 2012).

Scale is an important issue when defining the methodology to be used to measure flammability. Vegetation flammability can be assessed at three levels: plant parts, whole plant and plant groups. In general, small-scale combustion tests are used to assess the flammability of plant parts. Large combustion tests are used to evaluate whole plants and groups of plants (GILL & ZYLSTRA, 2005).

Flammability characteristics are affected by several factors that can be classified into two groups: physical structures and components (twig size, leaf size and shape, dead material retention); and physiological and cellular elements (volatile oils and resins, moisture content, mineral content, lignin and greases), which are described in table 1 (WHITE and ZIPPERER, 2010).

Table 1. Criteria associated with favourable and unfavourable characteristics for determining plant fire resistance.

Favourable characteristics	Unfavourable characteristics
Architecture and Structure	
- Easy maintenance and pruning - Drought tolerant - Free from dead leaves or needles and twigs - Thick, fleshy leaves and branches - Slow growing, with characteristics of - Prostrate or vine growth - Little volume of leaves and small branches - Difficult to ignite - Does not keep flames for a long time - Broad leaves - Produces limited dead and fine material - Low foliage density	- No maintenance and no periodic pruning - Fuel accumulator, including dry twigs, branches and leaves - Producer of large amounts of litter - Dry or dead underground material - Dry and leathery leaves - Needle-like or very thin leaves - Compact and dense shape - Dense, abundant foliage - Rough (shaggy) bark
Physiological and Cellular	
- Low levels of volatile oils and resins - High moisture content, juicy - High ash and mineral content	- High content of oils or resins, including gums and terpenes

Source: WHITE e ZIPPERER, 2010.

2. Objectives

The general objective of this research was to evaluate the flammability of forest species used in forest fragments and (WUI) areas to support fire management planning in these environments. To achieve this objective, the following specific objectives were established: selection of species of frequent occurrence in urban and interface forest fragments of the cities of Curitiba-PR and Gurupi-TO, according to the favourable morphological characteristics of fire resistance and to determine, in laboratory, the flammability characteristics of the selected species.

3. Material and Methods

The flammability tests were carried out in the Forest Fire Laboratories of the Federal University of Paraná and CEMAF (Environmental Monitoring and Fire Management Center) of Federal University of Tocantins, Brazil.

Fifty-seven species were chosen from the fragment forests and wildland urban interfaces of Curitiba-PR and Gurupi-TO, Brazil, belonging to the southern and northern regions of Brazil, respectively, where forest activities are very importante for the regional economy and to which fires cause important damage. The criteria used for the selection of the species followed the recommendations of Biondi and Batista (2010). The selected species were: *Allophylus edulis, Anacardium occidentale, Antonia ovata, Araucaria angustifolia, Aristida sp., Aspilia montevidensis, Bauhinia rufa, Bougainvillea glabra, Byrsonima verbascifolia, Camellia japonica, Casearia sylvestris, Chytraculia concinna, Clethra scabra, Copaifera langsdorffi, Cupania vernalis, Curatella americana, Dalbergia miscolobium, Davilla elliptica, Dimorphandra mollis, Diospyros lasiocalix, Eriotheca gracilipes, Eryngium elegans, Eugenia uniflora, Euonymus japonicus, Guettarda viburnoides, Himatanthus obovatu, Hirtella ciliate, Hyptis meridionalis, Jasminum mesnyi, Lafoensia pacari, Lantana camara, Leandra australis, Leucena leucocephala, Ligustrum lucidum, Luehea divaricate, Macrolobium limbatum, Magnolia grandiflora, Michelia champaca, Mollinedia clavigera, Myrcia splendens, Ocotea puberula, Ouratea hexasperma, Persea americana, Pinus taeda, Pseudobombax grandiflorum, Psidium cattleianum, Qualea multiflora, Rhododendron simsii, Schinus terebentifolius, Tabebuia aurea, Tachigali aurea, Tapirira obtuse, Trachypogon spicatus, Vatairea macrocarpa, Verbena rigida, Viburnum odoratissimum, Ziziphus Cinnamomum.*

Flammability was determined according to the methodology recommended by Valette (1990) and Petriccione (2006). For each evaluated species, 50 firing repetitions were performed in the epirradiator, each one consisting of 1 ± 0.1 g of fresh fine forest fuel (< 0.7 cm in diameter). In the tests, the following combustion characteristics were analysed: ignition time (IT), in seconds, time of complete combustion (TC), in seconds, maximum flame height (FH), in centimetres and ignition frequency (iF), in percentage. iF is the percentage of repetitions in which ignition occurred, considering a maximum IT of 60 seconds. The burnings that exceeded this time were classified as "negative burning" and received standardized values: IT equal to 61 seconds; TC equal zero seconds and FH equal zero centimetres. The flammability index (FI) of the selected species was obtained according to the iF and IT, varying as follow: 0 = very low flammable; 1 = low flammable; 2 = moderately flammable; 3 = flammable; 4 = very flammable; and 5 = extremely flammable (Table 2).

The data obtained were submitted to the flammability rating value (FI) and Cluster analysis, with the objective of validate the classification and identify the variables that present higher influence in the species flammability

Table 2. Classification of flammability according to the ignition time (IT), in seconds, and ignition frequency (iF), in percentage.

IT (s)	iF (%)					
	≤ 50	50 - 79	80 - 84	85 - 89	90 – 94	> 94
> 32.5	0	0	0	1	1	2
27.6 – 32.5	0	0	1	1	2	2
22.6 – 27.5	0	0	1	2	2	3
17.6 – 22.5	0	1	2	2	3	3
12.6 – 17.5	1	1	2	3	3	4
< 12,6	1	2	3	3	4	5

Source: Valette (1990).

4 Results and discussion

The results of the cluster analysis indicated that of the 57 species analysed, 44% were classified as very low flammable (22 native and 3 exotic species), 14 % as low flammable (8 native species), 15,8 % as moderately flammable (7 native and 2 exotic species), 8.8 % as flammable (2 native and 3 exotic species), 5,2 % as very flammable (2 native and 1 exotic species) and 12,2 % as extremely flammable (5 native and 2 exotic species).

The criterion used in this research for the selection of species through morphological characteristics proved to be adequate as a preliminary analysis to the flammability tests, considering that 74% of the analysed species presented low or null flammability. These preliminary results provide a good basis for continuing flammability studies for the potential use of low flammability species in wildland urban interface (WUI) areas and in forming safety green barriers highways and for forest fire prevention. The promising species to continue the flammability studies in the studied WUI areas are presented in table 3.

Regarding the origin of the species, 31% of the species classified as low or null flammability (FI = 0 or 1) belong to the Cerrado biome, a region heavily impacted by forest fires, although many of these species are naturally occurring in fire-adapted environments. This information reinforces the importance of knowing the flammability of the species for fire management in Brazil.

Table 3. Species with low flammability (FI = 0) with potential for use in the cities of Curitiba and Gurupi to prevent forest fires.

Species	Origin
Araucaria angustifolia	Native
Aristida sp.	Native
Aspilia montevidensis	Native
Bougainvillea glabra	Native
Cupania vernalis	Native
Dalbergia miscolobium	Native
Davilla elliptica	Native
Dimorphandra mollis	Native
Eriotheca gracilipes	Native
Eryngium elegans	Native
Eugenia uniflora	Native

Euonymus japonicus	Exotic
Hyptis meridionalis	Native
Lantana camara	Native
Leandra australis	Native
Ligustrum lucidum	Exotic
Luehea divaricata	Native
Macrolobium limbatum	Native
Myrcia splendens	Native
Ocotea puberula	Native
Persea americana	Exotic
Pseudobombax grandiflorum	Native
Psidium cattleianum	Native
Schinus terebentifolius	Native
Verbena rigida	Native

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