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Some particularities and findings in the characterization of forest fuels in Tenerife Island (Spain)

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ABSTRACT: This poster present the main findings in the characterization of surface forest fuels in Tenerife Island (Canary Islands, Spain) which TECNOMA has finished in year 2001. Although detailed methodologies have been widely described and applied to measure variables which most affect forest fire propagation (Brown, Anderson), Tenerife Island has some particularities that has forced us to modify classical sampling methods and design new ones. This region has shown to be a good test field for new approaches, such as the continuous fuel modeling (Xanthopoulos), in which spatial changes in vegetation coverage happen within hundreds or even dozens of meters in form of complex mosaics. Particular attention has been paid to the dynamics of species adapted to forest fires, such as *Pinus canariensis*, and the presence of arborescent shrubs, deep duff and litter beds and noticeable presence of dead needles hanging in branches of species other than pine after high wind episodes. Local meteorology conditions vegetation distribution and forest fire danger in a particular way which current fire danger indexes barely can explain. In the positive side, a mention is done about species that under certain conditions are fireproof, such as *Laurus sp.*, as historical records show.

1 INTRODUCTION

In the last years the request for a characterization of forest fuel complexes for the different regions in Spain has increased noticeably. The practical application of this information go beyond its mere use for simulation, in fact many forest fire defense planners base their activities on the knowledge about the distribution and type of biomass that participate in the initiation and propagation of fire, commonly addressed as fuel load. Forest fuel management comprises modification in the distribution and type of burning material in the wildland. A good number of best practices on the vegetation can modify noticeably the potential hazard of forest fire initiation, propagation and consolidation, thus reducing the risk of loses and impacts on citizens, properties and natural resources.

2 JUSTIFICATION AND OBJECTIVE

The current work of characterization of forest fuels of Tenerife Island has been designed to accomplish the objectives and scope of the Canary Islands Forestry Plan, which has a Forest Management and Exploitation Program that envisages the elaboration of a forest biomass map and a forest fuel map.

The objective is to obtain a catalog of the most frequent or important fuel complexes in Tenerife Island in which main parameters driving forest fire propagation are described. Besides, and given the results, to use this characterization for the simulation of surface fires aiming at the description of best practices in forest fuel management and their predicted effect in the initiation and spread of fires.

3 METHODOLOGICAL APPROACH

3.1 *The concept of Elementary Forest Fuel Units (EFFU)*

As pointed above, the work presented is aiming at the identification and characterization of vegetation complexes which presumably have different fire behavior. In this sense it is required a sampling on the vegetation layers (i.e. duff, litter, slash, grass, shrubs and small trees) which initiate and propagate the fire. This sampling is always time-consuming as it is required a detailed separation of fuel components, i.e fine, average and large dead fuel particles and live components, and the measurement of their properties.

In the aim to reduce cost and time of forest fuel complexes sampling, it has been applied the concept of **E**lementary **F**orest **F**uel **U**nit (EFFU). This method relies in the fact that, frequently, forest fuel complexes are compound of vegetation individuals (EFFUs) of a given species, shape and size (age) which mix and repeat themselves in a region forming patterns that can be associated to different layers in the fuel complexes.

Following this concept the effort focus, first, on the identification and characterization of such patterns in the sampling plots, just by counting one by one all EFFUs existing in each layer and including some basic data, such as species, height and foliage crown diameter. In a second step a number of EFFU individuals, for every class found in a region, are measured, cut and dismantled into particles which are classified and measured in the laboratory. Out of this process, and after statistical process, different EFFUs can be parameterized and catalogued and used afterwards for the modelisation of patterns and characterization of fuel complexes. Other material contributing to forest fire propagation, basically ground and downed material such as litter, slash and duff, is sampled apart in the same plots. For continuous, small EFFUs, such as grass plants, the material is referred to a unit area (i.e. a square meter of cured grass) instead to individuals.

This two-step sampling process is highly effective when a definite, not large number of EFFUs are found in a region forming different mixes and patterns which compound the forest fuel complexes. In fact, in some regions such as Madrid province (Spain), a good characterization of a limited number EFFUs provides enough information background to characterize a large number of forest fuel complexes. Our challenge has been to test this method in an environment, such as Tenerife Island, in which vegetation patterns are changing almost continuously along the territory.

3.2 *General scheme of the methodology*

The methodology for the characterization of forest fuels in Tenerife Island is resumed in the following points:

1. Previous documentation
2. Identification of forest fuel complexes
3. Characterization of forest fuel complexes

- Sampling of forest fuel complexes

- Sampling of Elementary Forest Fuel Units (EFFU)

4. Estimation of forest fire behavior
   - Parameterization of forest fuel complexes
   - Forest fire simulation
   - Analysis of results and conclusions
5. Characterization of aerial fuels
6. Radiometric response of forest fuel complexes

A brief description and some particularities found in the application of this method is presented below.

3.3 *Previous documentation*

Prior to the field work, it has been required to gather information about Tenerife Island in order to understand the basics of vegetal ecosystem dynamics and to establish classification criteria for vegetation complexes. This information has included:

- Geographical description of Tenerife Island
- Vegetation map and communities description
- Historical fires
- Meteorological characterization and particularities

3.4 *Description of Tenerife Island environment*

In Tenerife the vegetation distribution is tightly related to the topography and the local meteorology. An initial division can be done looking at the aspect and the altitude which segmentates the island into different zones.

Climate in Canary Islands is marked by their geographical position. Due to their latitude, the Canary Islands is affected by High Pressures located in Azores, giving east winds (Trade Winds), which moves in north-south axis according seasons. Besides, the islands are affected by cold ocean currents from west Africa which entails, in general, poor rainfall and attenuation of air temperatures.

In Tenerife the relief, which spans from 0 to more than 3,000 meters, is influencing locally temperature and rainfall regime, giving dramatic differences in temperature for points located in the south and in the north. Besides the presence of a permanent cloud layer, which altitude varies seasonally, which provides an extra source of air humidity that condenses according the presence of topography.

Besides there exist a particularity in the precipitation regime for the areas exposed to Trade Winds and those protected in the other side. The air elevates along the wind side, discharging humidity, and descends very dry along the opposite side. In this sense drizzle and clouds are present in the wind side, while in the opposite side sun is hitting ground without any other obstacle. Besides in August, there are some episodes of Saharian winds blowing from west, giving extremely high temperatures. The north part of the island is most affected by some precipitation due Trade Winds and some oceanic perturbations, where in the south the expected effect is the opposite. Nevertheless, real, measurable rainfall registered in the island is most frequently associated to the irruption of polar air masses in winter.

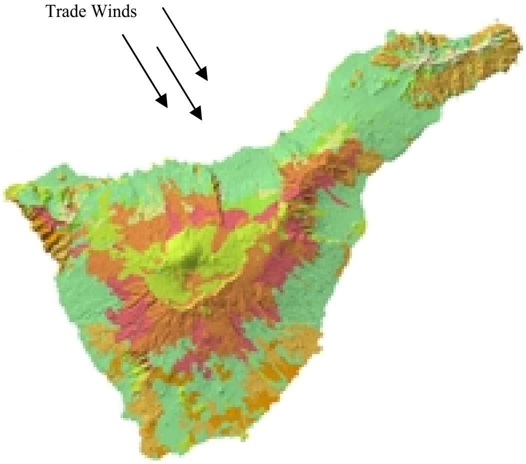

Fig. 1. Vegetation classes distribution in Tenerife

As seen, climatic factors (temperature and rainfall) are tightly related to topography thus explaining the distribution of vegetation in the islands. Slopes with aspect looking north and northeast are receiving wet winds which generate fog, although fogs are limited by altitude between 500 and 1500 meters, so it is in this altitudinal strap in which it is found higher humidity and consequently more mesophile vegetation species. In the other hand, in the slopes facing south and southwest and in the zones above and below the mentioned altitudes, a much more xerophitic vegetation is found.

Following this separation, a number of vegetation levels can be described (see also Fig. 1):

- Low level and xerophitic formations, under 400 meters of altitude, with low temperatures and low relative humidity. This is the domain of tabaiba and cardon (euphorbiaceae) very adapted to these arid conditions.
- Intermediate level, mesophile formations in the north and pine stands in the south. This level is mostly affected by fog with aspects facing north and north-west, in which a typical formation, the fayal-brezal and monteverde is found, distributing the species according altitudinal constraints (lauraceae more termophile in the base, fayal in the interim and *Erica* in the upper part). The *Laurus sp.* stands (laurisilva) is one of the most interesting formations of evergreen species, adapted to high humidity and shadow conditions, presenting stands with little understory. Due to the xerophitic conditions in the south, these formations are only present in the north part of the island and the altitudinal niche is occupied by pine stands instead.
- Higher level domain, the pine stands and high-elevation shrubs. Upper levels in the north, above 1500 m in which fog is not present, present pine stands of *Pinus canariensis*, a xerophitic formation adapted to extreme temperatures (high and low), extending its presence from 1800 to 2400 meters of elevation. Up to 2000 meters is the domain of horizontal formations of very well-adapted vegetation with low heights and sparse coverage. Above this 2000 m. point, in which high winds, high light, cold weather and low precipitation are common conditions, it is the endemisms domain; beyond no vegetation is found at all.

3.5 *Reconnaissance*

Based on the initial distribution of vegetation, as presented above, and the preliminary documentation, a number of reconnaissance routes have been designed to cover all the vegetation complexes in the territory which are suspect to give different fire behavior. Along the routes a number of control points have been marked in which the criteria of identification of forest fuels are applied.

As a result of the initial reconnaissance a broad list of vegetation complexes has been obtained as well as a list of the Elementary Forest Fuel Units (EFFU) identified in such complexes.

3.6 *Sampling campaign, measurement and data processing*

The sampling campaign has been performed in two phases:

Phase I. Sampling plots for the characterization of fuel complexes. For this job more than 200 plots of 10x10 meters were set-up and sampled in the different vegetation complexes. Besides to general information about the plot itself, such as co-ordinates, slope, aspect, a detailed description of the different layers of vegetation was performed, including the systematic counting of all EFFUs in every layer. Afterwards two to four 1x1 m sub-plots were set-up and downed material was sampled.

Phase II. Sampling of Elementary Forest Fuel Units (EFFU). A number of vegetation individuals of every EFFU have been cut and dismantled into pieces to characterise the distribution of fuel load for every one and correlate it with physical and geometrical variables, such as species, size, diameter etc.

All the resulting data, from downed material and from EFFU, has been summed up and statistically processed, first, by layer and, second, by plot. Plots where describing fuel complexes through significant variables such as total fuel load, load of fine dead components, load of live components, height, fuel depth, surface to volume ratio, heat content and extinction moisture content. These variables described which complexes were clustering around average models thus identifying the initial list of groups and subgroups. Afterwards, expert eye adjusted the resulting list into more realistic classification according experience regarding forest fire behavior in real cases.

4 PARTICULARITIES OF MAIN GROUPS OF FUEL COMPLEXES IN TENERIFE ISLAND

The main identified groups are described below:

Group 1

Continuous layer of cured grasses, either natural or cultivation, less than 1 meter height. Although some shrubs are present, coverage is always less than 25%. Total fuel load is aroun 3 ton/ha. Fire is propagating very quickly, with average speeds of 40 m/min and more up to more than 100 m/min under extreme wind conditions.

Group 2

Continuous layer of cured, fine grass with presence of sparse shrubs covering more than 30% but always less than 75% of the surface. Fire propagation speed is lower than in the previous group, averaging 30 m/min and up to 60m/min and more under extreme conditions. Fires in this group tend to consolidate quickly and give high flame front intensities (up to 6.000 kW/m).

Group 3

Dense complexes of fine and tall material (more than 2 meters), both herbaceous and woody with predominant presence of dead particles, frequently associated to marshes or damps. This complex shows very high fuel loads (up to 60 ton/ha). Fire in this fuel is very intense (up to 15.000 kW/m) and relatively quick. The presence of such high load of fine elements make almost impossible a direct attack in the front.

Group 4

Very tall (2 meters and more) and dense shrubs which are almost impossible to penetrate and covering more than 75% of the surface. Vegetation is structured in layers which interlace both horizontal and vertically, giving high fuel loads. Three subgroups have been identified. The fire behaviour is variable but always very intense (from 3.000 kw/m to more than 20.000 kW/m in the most dangerous subgroups). Some of the subgroups present a dramatic change in fire behavior under moderate and high wind speeds

Group 5

Low shrublands, less than 1.2 meters tall, with variable density, covering from more than 30% up to more than 75% and giving total fuel loads around 15 ton/ha. Four subgroups have been identified.

Group 6

Medium to tall shrubs (1.2 to 2 meters) with high densities, always more than 50%, frequently associated to the abandonment of agriculture grounds disposed in variable patterns, from continuous layers to clusters and linear distributions. This complex is always composed by several species with noticeable load of live and woody particles. Three subgroups have been identified.

Group 7

A large group which includes all cases of shrubs under forest canopy. Up to 12 subgroups have been identified, but three main structures have been clearly separated. In one of the structures the shrubs and the trees are inter-connected vertically in a continuous web of fine dead and live material, propiciated by the presence of different layers of vegetation, including young trees of several age. In some cases pine needles hang in branches of trees in the understory after strong wind episodes, distributing along the vertical axis this flammable material in very sparse (low density) patterns. These two factors made this complex very dangerous even explosive under some extreme conditions.

In the second structure two clear layers are identified, namely a shrub layer of flammable vegetation (up to 1.6 meters) and the mature tree layer. Shrubs cover more than 50% of the surface. In some cases the shrubs are compound of species which react briskly to changes in moisture content, particularly live twigs and leaves, when it is in the vicinity of a inflection point (i.e., *Erica*). In these cases, the knowledge of extinction moisture and moisture content is critical to predict realistic fire behaviour.

In the third structure shrubs are smaller (up to 1.5 meters) and cover less than 50% of understory surface in mature forest stands. This has been observed that, in some cases, this sparse distribution of shrubs act as heat sink due to their relatively high moisture content of living parts, thus partially protecting trees against intense fires.

Group 9

This group includes litter under mature tree stands, including pine needles and broadleaf species. In all cases, coverage of fuel layer is above 50%. In most cases this group is associated to pine stands.

Group 10

This is the group of slash and downed material, either due to sylvicultural treatments or due to natural factors, such as wind and snow. This group is almost completely associated to pine stands. Given the size of particles, only a fraction of the material is participating actively in the fire.

Group 11

In this group it has been included vegetation complexes which are typical in the extremely arid parts of the island, which corresponds mostly to cactus and crassae plants. The interest of this group in terms of fire propagation is very little.

5 AERIAL FUELS

A crown fire is defined as a forest fire that burns the tops of trees. Also, some fire scientists classify fires in shrub fields as crown fires because, technically, such fires spread mainly through the crowns of the shrubs (Albini 1984).

It has been done an effort to evaluate the various fuel situations on the island in regard to their crown fire potential and include both basic principles of assessing this potential locally and specific recommendations for actions that can reduce crown fire hazard. Weather conditions and crown fuel characteristics in Tenerife are quite different than those found in typical Mediterranean ecosystems and of course in the American and Canadian ecosystems where much of the existing literature on crown fire initiation and spread has been developed (Van Wagner 1977, Forestry Canada Fire Danger Group. 1992, Rothermel 1991). Consequently, although most of the principles are the same, there are clearly many differences, so certain rules and models have to be used with caution.

Tenerife Island was visited for an assessment of forest fuels from the ground and from the air in order to obtain a good understanding about them. Also, extensive discussions where carried out with forest managers which provided an insight on the fire behavior observed during specific, large, historic fires that exhibited crowning.

The conclusion drawn from the discussions and the visit in Tenerife is that crown fires are not a problem at all times, but they may occur in certain fuel types and under specific high danger conditions. There was no testimony for independently moving crown fires but passive and even active crown fires (at least locally) are not uncommon. Following this information the significant variety of forest fuel situations present on Tenerife Island were recognized and classified according to their crown fire potential.

The method chosen to depict the fuels on Tenerife Island is to present pictures of selected common fuel situations associating them with expected crown fire behavior. This behavior is described for "average" (or relatively easy) conditions and high fire danger conditions. Average conditions can be roughly quantified as follows:

Moisture content of fine dead fuels	>12 %
Moisture content of live shrub foliage	>70 %
Moisture content of overstory foliage	>100 %
Wind present but not extreme	< 25 km/hr
Slope	< 25 %

When conditions are significantly worse (in regard to their influence on fire behavior) than these values for one of the parameters above, or two or more parameters are a little worse than these values then the conditions can be considered as "high" fire danger for the purposes of this description. A reference to extreme conditions would mean very low moisture content of fine dead fuels (e.g. <6%) and wind >40 km/hr. Under such conditions long-range spotting from crown fires is very likely.

The variety of forest fuels on Tenerife island led to the identification of a multitude of fuel situations, many of them with significant differences form each other. In general, most Tenerife forests would develop significant crown fire problems only under high danger conditions, in contrast to classic Mediterranean ecosystems were this happens often under less-than-extreme conditions.

Pine plantations, *Pinus canariensis* stands and the few eucalypt plantations appear as the most endangered forest types in regard to crown fire potential. Sylvicultural treatments in the first two are effective in reducing crown fire probability. In many fuel situations the probability of fire, let alone a crown fire is only increased by the probability of fire imported from lower lying areas, often agricultural where many human activities take place. The elevation profiles are clearly conducive to that.

The characterization of fuels presented here has been based mainly on their morphology with emphasis on the crown characteristics (Fahnestock 1970). The evolution of fuel condition through the year, especially in regard to live fuel moisture, is not known accurately by the author. Some information was obtained through discussions with foresters working on the fuel identification work, and some observations were made on the spot (presence of fern, mosses, etc.). However, a critical advancement in the characterization of fuels in general and on aerial fuels in particular, would be a project for a two-year monitoring of the most extensive fuel types, mainly in regard to live fuel moisture, in association with the evolution of weather conditions. Such data would allow actual fire behavior modeling, and as part of a complete fire management plan, when associated with a detailed study of weather records and past fires, would allow an in depth identification of alarm-conditions and the development of appropriate prevention/suppression scenarios.

6 IMMEDIATE APPLICATION OF RESULTS

Out of this characterization a number of immediate applications are envisaged, namely:

- The elaboration of a forest fuel map
- The edition of specific vegetation treatments protocols
- The elaboration of forest fire suppression protocols
- To identify links with forest management and sylviculture operations
- To estimation of forest fire defense demand throughout intrinsic values of forest fires

7 FUTURE DEVELOPMENTS

Out of the activity carried out in this work, a number of future developments are envisaged, namely:

- Calculation of intrinsic values and fire danger indexes
- In depth study of some fuel complexes
- Application of continuous forest fuel modeling approach
- Implementation in fire management information systems

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