Operational tools for improving efficiency in wildfire risk reduction in EU landscapes (FIREfficient)

Crown fire hazard assessment tool for Catalonia region forests (North-East Spain)

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Content

1. INTRODUCTION

1.1. Crown fire hazard assessment

There are different forest fire types depending on the layer involved in its spread: a) ground fires, in which duff, organic soils and roots are consumed (Frandsen, 1987), b) surface fires, where needles, leaves, grass, dead and down branch wood and logs, low brush and short trees are implicated in the combustion, and c) crown fires, in which canopy fuels are involved (Van Wagner, 1977). Furthermore, crown fires are divided into three categories: a) passive crown fires (individual or small groups of trees torch out but flame is not maintained in canopy), b) active crown fires (surface and canopy fuel stratum burn and crown fire spread depends on the heat released by the surface fuel layers), and c) independent crown fire (fire spreads in the canopy independently of the heat released from the surface fire), which occur rarely and under extreme conditions (Van Wagner, 1993).

Undoubtedly, from all these types of fires, **active crown fire is the one that poses the greatest threat to the extinction systems and fire managers** (Albini and Stocks, 1986), often spreading rapidly (Wade and Ward, 1973) and burning with greater intensity and faster spread than surface fires (Rothermel, 1983). Traditional direct attack is impossible to undertake in these type of fires because fire behaviour characteristics are extreme, i.e. high eat intensity, long spotting distances and large flame lengths and rates of spread (Scott and Reinhardt, 2001). So then, prediction of the conditions under which crown fires initiate and propagate are thus of primary concern in fire management.

To avoid such situations a good step forwards is an **active forest management** with the goal **to create forest structures that difficult the development of crown fires and facilitate the fire extinction tasks**, acknowledging the major role of weather in fires behaviour and regime. Role of fuels and forest structure is very important to reduce the risk of transition of surface fires to active crown fires (Fernandes, 2009; Álvarez et al., 2012; Fernandez-Alonso et al., 2013).

However, for integrating the risk of large forest fires (LFF) into the forest planning and management it is necessary to have **tools that help to identify the degree of vulnerability to crown fires of the forests** and to guide stands, through forest management, to a more fire resistant and resilient structures.

There are fire **simulators softwares that evaluate whether within a stand an ignition will develop a crown or a surface fire**, and therefore the effectiveness of silvicultural treatments in crown fire behaviour, they have little practical application because they require variables that are not estimated in conventional forest inventories and are difficult to measure, as canopy fuel load (CFL), canopy bulk density (CBD) or canopy base height (CBH) (Cruz et al. 2003).

Furthermore, there are few **crown fire hazard assessment tools to evaluate easily whether a forest stand with a given silvicultural structure will be capable of generating crown fires** and therefore to estimate the effectiveness of silvicultural treatments with the objective of fire prevention.

Crown fire hazard assessment tools give information on the structural characteristics of the forest stand and its relationship with the vulnerability to generate and maintain high intensity-crown fires. Therefore, **they are useful to assess crown fire potential behaviour and guide forest management for reduce risk of crown fires**.

They are used **to identify how vulnerable is a forest stand**, in relation to the structure and other ecological conditions, to generate and propagate a crown fire. So then, they are handy to **classify priority areas where silvicultural treatments should be implemented in order to reduce risk of LFF**.

Tools for assessing crown fire should be simple and easy to use by forest managers, so then it is important the development of classification criterion of the potential of a stand to sustain different crown fire types, based on forest stand variables that are easily obtained in common inventories.

In this report, we present the methodology followed for the construction of a set of charts for crown fire hazard assessment (CVFoC), as a tool to assess forest stand vulnerability to crown fires, using forest stand variables commonly used in forest inventories.

The CVFoC we present in this report define **structural types for *Pinus* and *Quercus* forests in the region of Catalonia (North-East Spain)**. They are classified in types A, B and C, based on forest variables as: surface covers of different layers of fuel (areal, ladder, and surface) and vertical projection distances between them, being A high vulnerability to active crown fire structures, B medium vulnerability structures and C low vulnerability structures.

2. CROWN FIRE HAZARD ASSESSMENT CHARTS (CVFoC): METHODOLOGY

The crown fire hazard assessment charts (CVFoC), presented in this report, **have been developed following the two stages shown in Figure 1**. Firstly, we selected forest stand variables that influence fire behaviour through the analysis of literature and tools developed in other countries with similar purposes (Fahnestock, 1970; Menninger and Stephens, 2007) and information collected in expert panels. Secondly, we have developed and outlined the CVFoC through field testing.

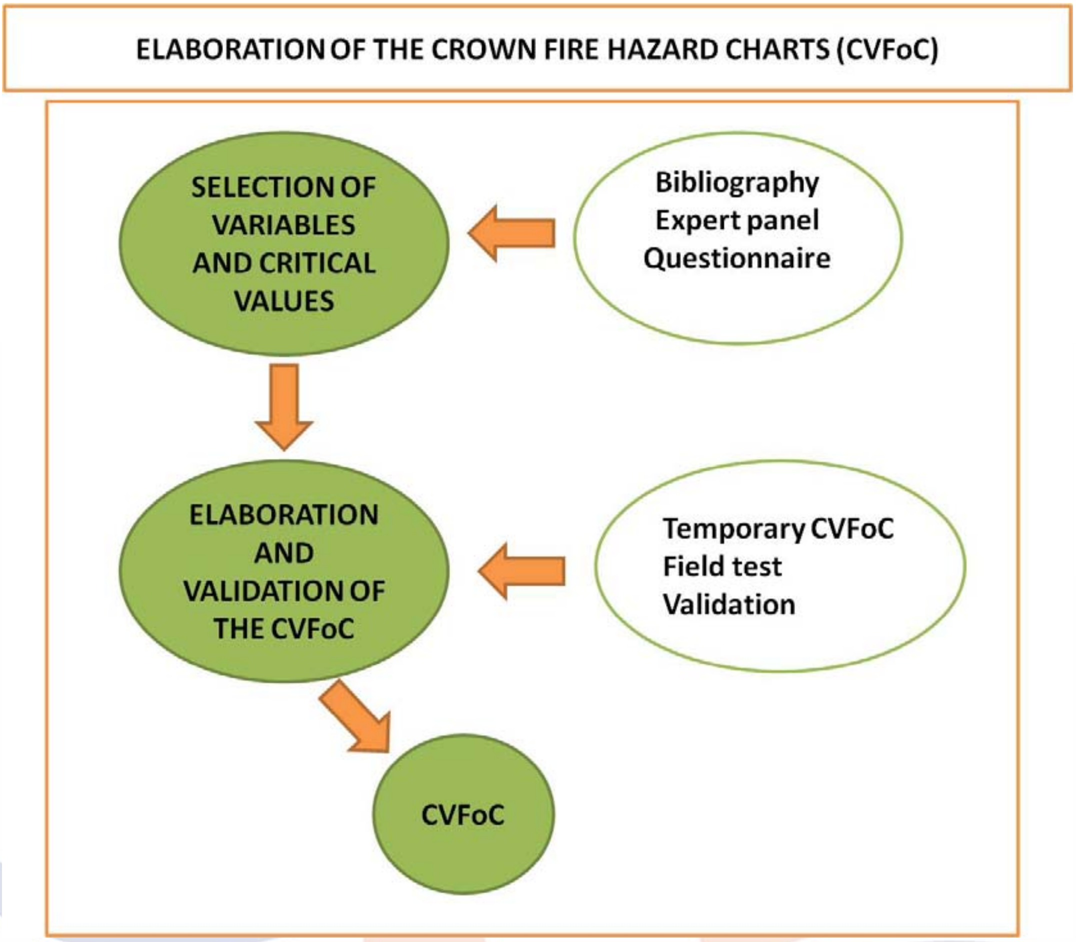


Figure 1. Main tasks developed for the elaboration of the CVFoC.

2.1. Selection of the forest-structural variables that affect fire behaviour

In the first phase we identified forest stand variables and their threshold values that determine fire behaviour. Then, we designed the CVFoC.

The identification of these variables and values was carried out by analyzing bibliographic information and expert knowledge (from questionnaires and expert panels). The Figure 2 shows the process followed.

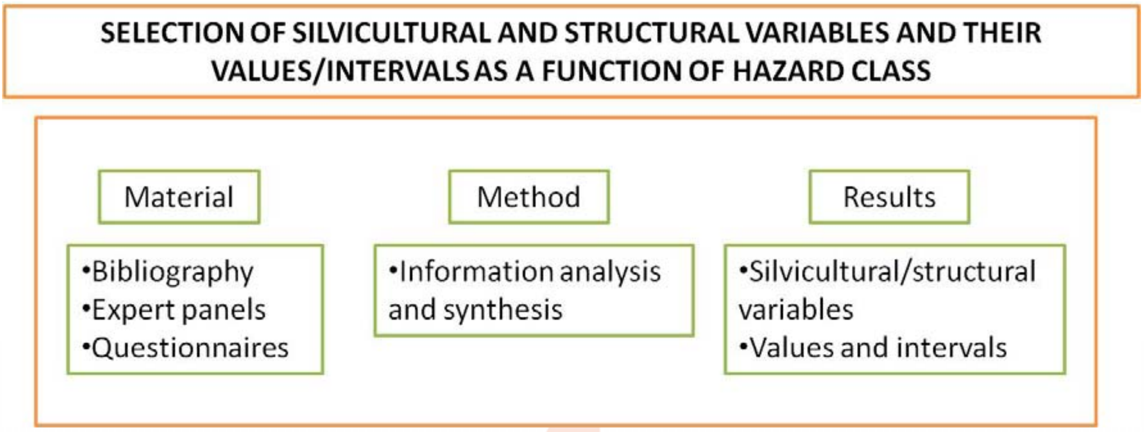


Figure 2. Process followed during the first phase of the methodology

Bibliographic information

Bibliographic information gathered is divided into two sections. The first section includes a description of tools developed around the world, for identifying forest types at stand level and their vulnerability to crown fire. This material has served as a source for building the CVFoC. In the second section, we listed the main scientific articles that present information about the influence of forestry variables in fire behaviour, as well as some thresholds values for specific species. The analysis of this set of information is the basis for the construction of CVFoC (see Annex 1).

Expert panel and questionnaires

The expert panel is defined as a group of specialists with reputation in a particular topic, which try to meet a collective judgment and consensus on the issue of study. In this case, **the choice of experts was carried out using a snowball sampling** (Patton, 1990). We contacted two key informants who identified other participants with expertise. The selected experts are members of the Forest Actions Support Group (GRAF) of the Fire Service of the Generalitat de Catalunya, who are specialists in fire management and forest fire extinction (using technical fire) in Catalonia. The participants have a great knowledge about the behaviour of forest fires and the relationship between type of fire and forest structures. Their background as forests engineers, together with their training and experience in the field of forest fire suppression, make them an excellent group to gather information using a panel of experts.

Seven experts were selected and contacted via email. In the e-mail, it was explained why they were contacted and the **tasks they should undertake during the methodological**

process: i) assistance to expert panels, and ii) testing and validation of crown fire hazard assessment charts.

During the first phase, two expert panels were conducted. Questionnaires were the tool used for collecting information in an orderly and accurate manner.

The first panel of experts was divided into two parts. In the first part, experts were informed about the purpose and premise of application of the CVFoC. Thus, CVFoC have as main objective to offer the manager a tool to identify quickly and easily the degree of vulnerability to crown fires at the stand level or, in other words, typify the forest structures according to their vulnerability to generate crown fires. In this panel, **experts described three classes of vulnerability (high, moderate and low) to crown fires**, in which a forest stand can be classified. The definitions of vulnerability classes, together with the conditions for the application of CVFoC are presented in section 3.

In the second part of the first panel of experts, the experts individually conducted a survey with the aim of **selecting the main forest stand variables** (related to forest structure), **that can influence in the fire propagation** and should be considered for the design of the CVFoC.

In the second panel of experts another questionnaire was completed in order to **set the values of the variables selected (**in the first expert panel) and the design and number of charts that may be necessary depending on the species and the main forest types in Catalonia.

Information analysis: the basis for the construction of the CVFoC

The information obtained through the literature search and expert knowledge was analyzed and synthesized in order to undertake the construction of the crown fire hazard assessment charts. We also incorporated at this stage the information gathered during the field testing.

The information generated from this process is classified into three groups:

a) Fuel types or vegetation stratum.

To characterize forest structure and its relation to crown fires we identified and defined three types of fuels or vegetation layers:

- Surface fuel: stratum up to not more than 1.30 m. Includes shrub, saplings, herbaceous fuel, branches, fallen trees, slash or lower parts of tree canopy.
- Ladder fuel: low aerial fuels of height higher than 1.30 m which are not contained in the upper aerial fuel layer. Includes small trees, tall shrubs, fallen trees or lower parts of the tree canopy.
- Aerial fuel: aerial fuel layer containing crowns of the tallest trees (dominant and co-dominant).

b) Forest-structural variables selected.

The variables selected to characterize the three types of fuels and vertical/horizontal continuity between them as a result of the expert panels and research literature were:

- **Surface fuel cover (%):** surface projection of the surface fuel, without considering the possible multiple covers. This value never exceeds 100%.
- **Surface fuel height (m):** corresponds to the average height of the surface fuel. This value never exceeds 1.30 m.
- **Depth (cm):** corresponds to the thickness of the duff layer. It is evaluated in the case of formations in which the dominant species are *Pinus pinea* or *Pinus pinaster* and which have surface fuel cover <30%.
- **Ladder fuel cover (%):** surface projection of the ladder fuel, without considering the possible multiple covers. This value never exceeds 100%.
- **Aerial forest cover (FCC) (%):** surface projection of the aerial fuel, without considering the possible multiple covers. This value never exceeds 100%.
- **Distance between the three types of fuel (m):** distance measured from the top of the smaller fuels (surface or ladder fuel) to where there is enough living foliage in the higher fuels (ladder or aerial) to allow fire to spread vertically. The average distance should be estimated considering the sampling area. The distance can be between surface and ladder fuels, between ladder and aerial fuels or, between surface and aerial fuels when ladder fuels are scarce or absent.

The distance between the three types of fuels described, together with the characterization of each of the individual variables that are explained above, provides the knowledge necessary to establish the type of vulnerability to crown fire most likely in a given forest structure.

c) Final groups of species with the same charts.

The contributions of experts on whether or not to differentiate charts for species or groups of species, together with the analysis of existing bibliographic information, have resulted in the grouping of the main forest species in four groups (Table 1).

Table 1. Groups of species with the same chart (CVFoC)

Group 1	Group 1.1	Group 2	Group 3
Pinus sylvestris	*Pinus pinaster*	*Pinus halepensis*	*Quercus suber*
Pinus nigra	*Pinus pinea*		*Quercus ilex ilex*
Pinus uncinata			*Quercus ilex ballota*
Pinus pinea			*Quercus faginea*
Pinus pinaster			*Quercus humilis*

2.2. Development and validation of the CVFoC

The results obtained in the previous phase of compilation of bibliographic information and expertise was used to build temporary crown fire charts for each group of species. Simultaneously, through an iterative process of testing and expert panel, these keys were improved. The information obtained from testing was used to improve the selected variables and their critical values (Figure 3).

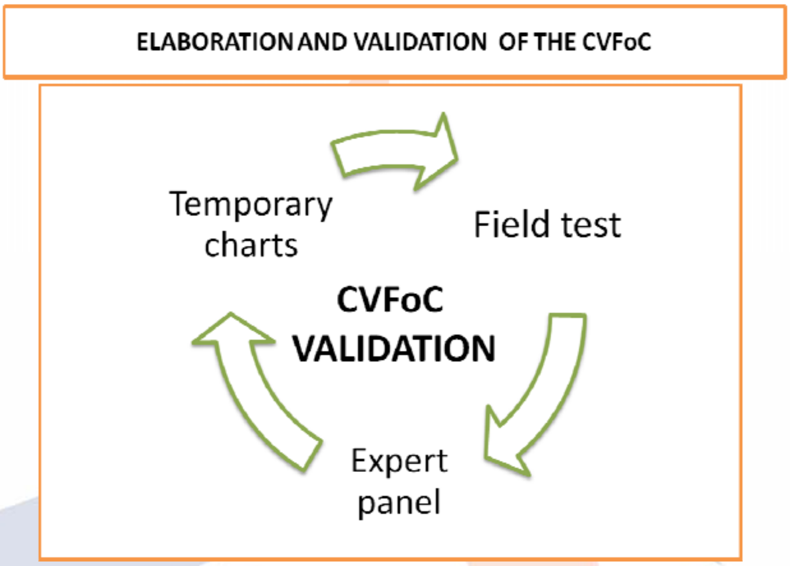


Figure 3. Iterative process for the generation of CVFoC

To build the temporary crown fire hazard chart, forest-structural variables, their values and ranges for each were selected depending on the influence of those in the class of vulnerability. Then, each possible combination of values and intervals of these variables were analyzed. Lastly, a class of crown fire hazard was assigned to each combination.

As explained in the previous section, we prepared four types of charts, one for the case of *Pinus pinea* and *Pinus pinaster* stands with litter and less than 30% of surface fuel (Table 1).

The charts and a field form were distributed among experts and other specialists in the world of forest fires. In this form, the experts write down for each sampling point within a certain stand the crown fire hazard according to their expertise and the hazard obtained by using the chart. They also indicate the estimated values of the variables to assess the possible adjustments of the charts.

During the process, charts were modified and eventually the final version was obtained. The final CVFoC undergo a final validation by a field test on a minimum number of forest structures of different tree species.

3. HOW TO USE THE CROWN FIRE HAZARD ASSESMENT CHARTS (CVFoC)?

Type of fuel

The CVFoC are based on the characterization, by using forest-structural variables, of the three fuel types selected in the methodology. In this regard, one must be familiar with the fuels that can be found at the stand.

The Figure 4 shows the types of fuels used in the CVFoC.

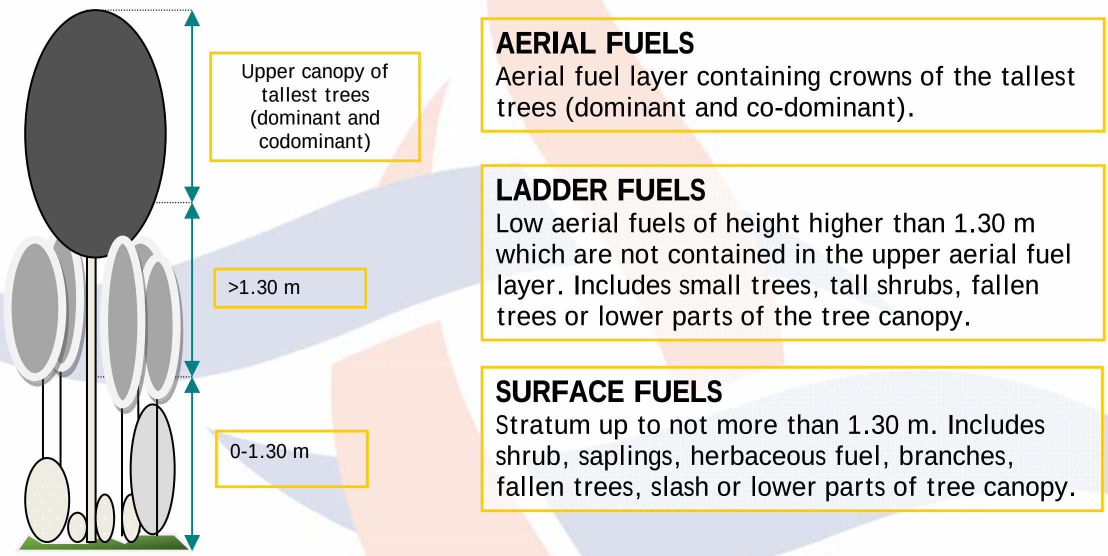


Figure 4. Types of forest fuel depending on their spatial distribution

Classes of crown fire hazard

The classes of crown fire hazard are defined as follows:

High hazard/vulnerability (A): forest structures with silvicultural characteristics (e.g. horizontal and vertical continuity, forest cover) which facilitates that fire climbs to the crowns and remain there. Forest structures in which active crown fires are characteristic, surface fires produces enough heat convection to maintain continuous fire spread between crowns. The structures affected by this type of fire usually have high mortality.

Moderate hazard/vulnerability (B): forest structures with silvicultural characteristics (e.g. horizontal and vertical continuity, forest cover) which restrict more than the forest structures named "A", that fire climbs to the crown and particularly limit the sustainability of the fire at the crowns. These forest-structures generate some crowing and spot fires, burning crowns passively. Small groups of trees burn out but the spread between canopies is not maintained continuously. The structures affected by this type of fire, usually, have lower severity than class A. The existence of a mixture of completely charred trees and others with a high percentage of crown scorched, together with unaffected trees, are characteristic.

Low hazard/vulnerability (C): forest structures with silvicultural characteristics (e.g. horizontal and vertical continuity, forest cover) which restrict fire climbing to the canopies and, also, its sustainability at the crowns. Fire burns below the aerial fuels. The surface and ladder fuels, if any, are consumed, but given the vertical discontinuity with the aerial fuel fire does not climb to the crown and remains on the surface. The forest-structures affected by this type of fire usually have lower mortality. Occasionally, a tree can die. This class includes regenerated stands because the fires that are generated, from the point of view of extinction, are similar to a surface fire, although the mortality of trees is in most cases complete.

Terms of elaboration and application of CVFoC

The conditions for the elaboration and implementation of the charts are:

- The CVFoC works at the stand level.
- The CVFoC evaluates the arrangement and the amount of fuel and, therefore, the variables used are structural and silvicultural. The topography and wind are not taken into account.
- In establishing the critical values of the variables, it is assumed that there is a scenario of drought and consequently, experts have issued their judgments based on this condition.
- The CVFoC typifies the vulnerability of a forest structure to generate a crown fire. It is based on the assumption that the fire starts in the stand, in which the CVFoC is being used, or in the case that fire comes as a surface fire from the stand nearby. For example: if a crown fire gets into a stand classified as (C) the efficiency of the structure is not guarantee, although it will have some probability (depending on the fire characteristics and the surface managed) to resist and reduce the intensity and severity of fire.
- The characterization of the forest structure, at the stand level, with the CVFoC will be made at the sampling points distributed along the stand that may coincide to facilitate the work, with the sampling points of forest inventory. Observations will be estimated, at a radius of 8 m, or the same plot takes it during the forest inventory.
- Given that a forest is characterized by its homogeneity regarding the type and forest structure, the hazard classes should not differ too much at the different sampling points. In the case of observing different types of hazards, one should assign the dominant in the stand.

How to use CVFoC?

Here, it is shown the steps to be followed to choose and use the CVFoC for the main forest species in Catalonia. First, the user through the decision tree of Figure 5 should assess which fuel stratum (tree or ladder), given their forest cover, will be responsible for the spread of a crown fire.

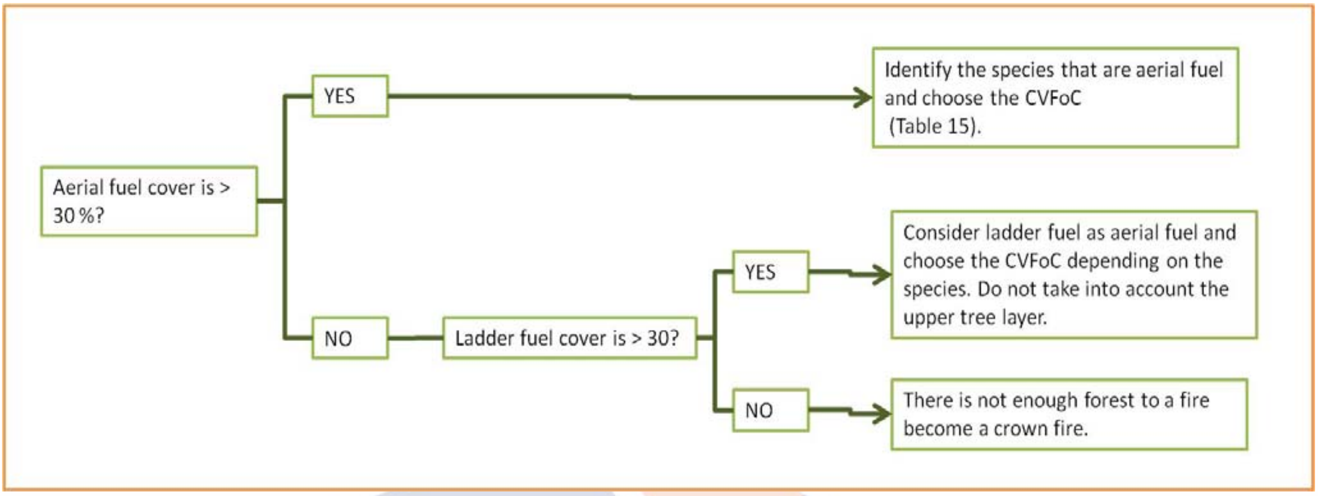


Figure 5. Decision tree to identify the fuel layer capable of maintaining a crown fire. For example, considering an aerial layer of *Pinus halepensis* with FCC <30%, a ladder fuel of *Quercus ilex ilex* with FCC> 50%, the chart chosen will be the one corresponding to *Quercus ilex ilex.*

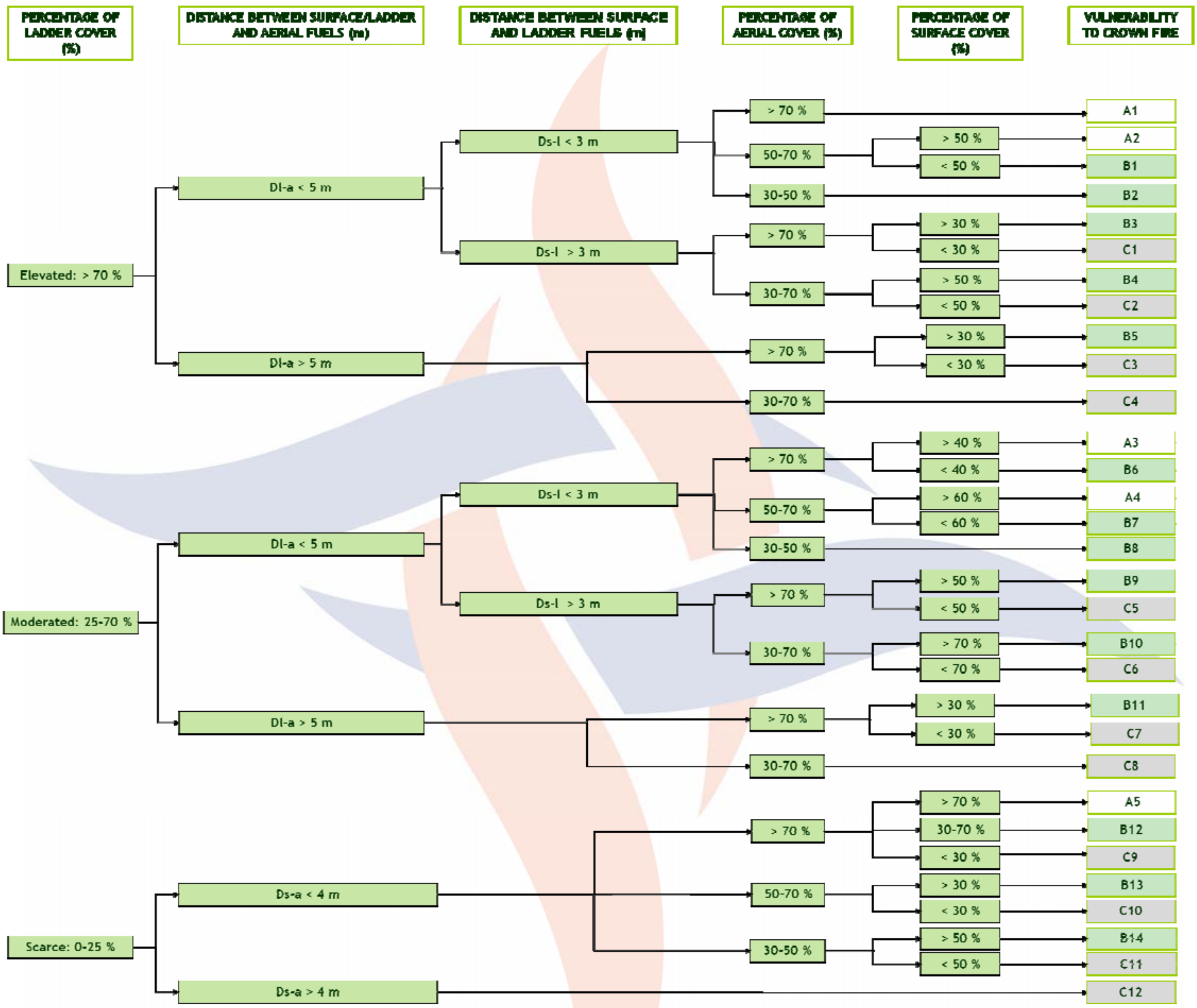
Then, once the dominant specie has been identified and considered as aerial (responsible for the spread of crown fire) the user selects the type of chart (Table 2).

Table 2. Types of CVFoC as a function of the dominant species

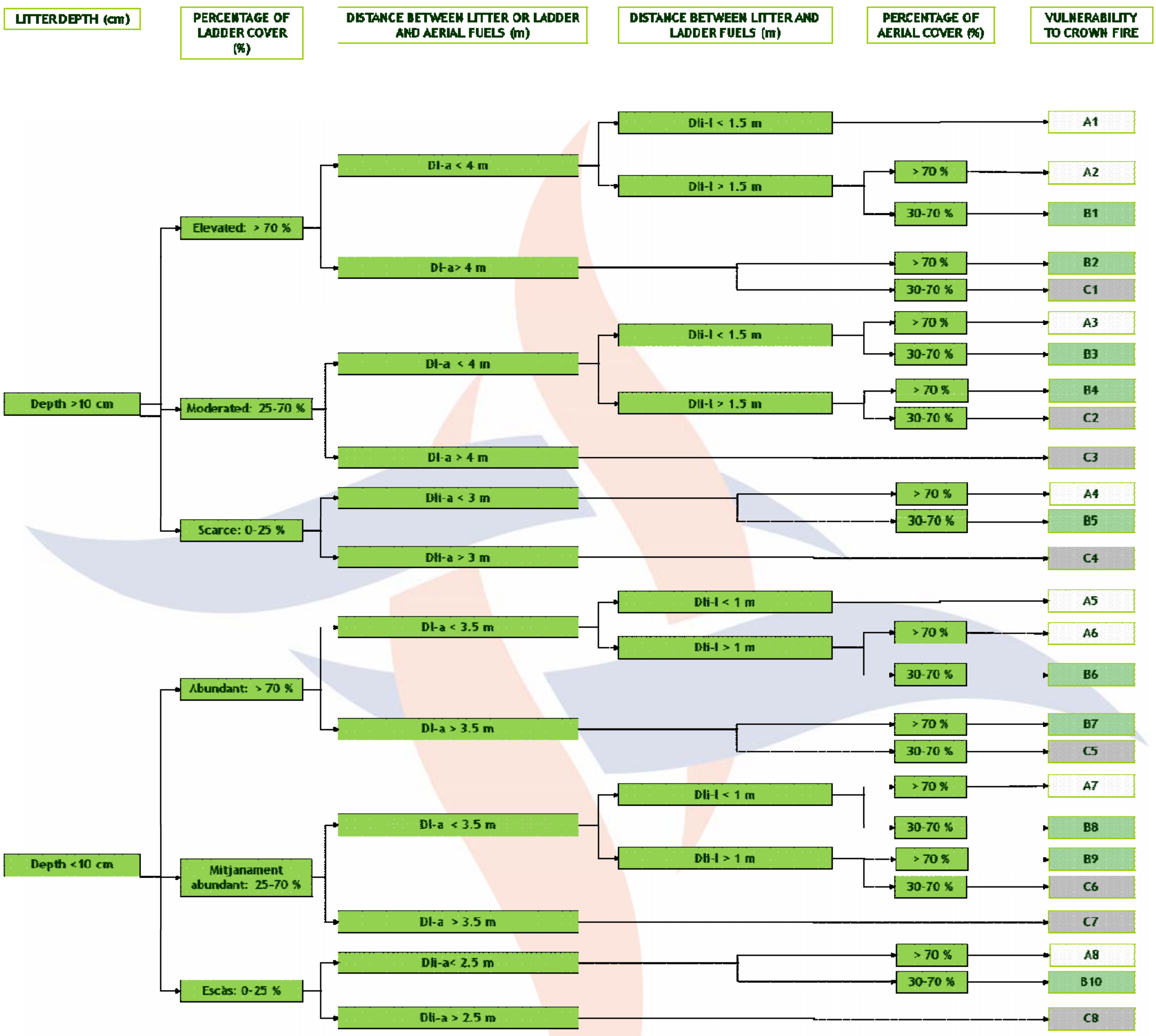
TYPE 1	TYPE 1.1	TYPE 2	TYPE 3
Pinus sylvestris *Pinus nigra* *Pinus uncinata* *Pinus pinea* *Pinus pinaster*	*Pinus pinea* and *Pinus pinaster* with litter (if they have less than 30% of surface fuel)	*Pinus halepensis*	*Quercus suber* *Quercus ilex ilex* *Quercus ilex ballota* *Quercus humilis* *Quercus faginea*

4. CVFoC FOR *Pinus* AND *Quercus* FORESTS IN CATALONIA REGION

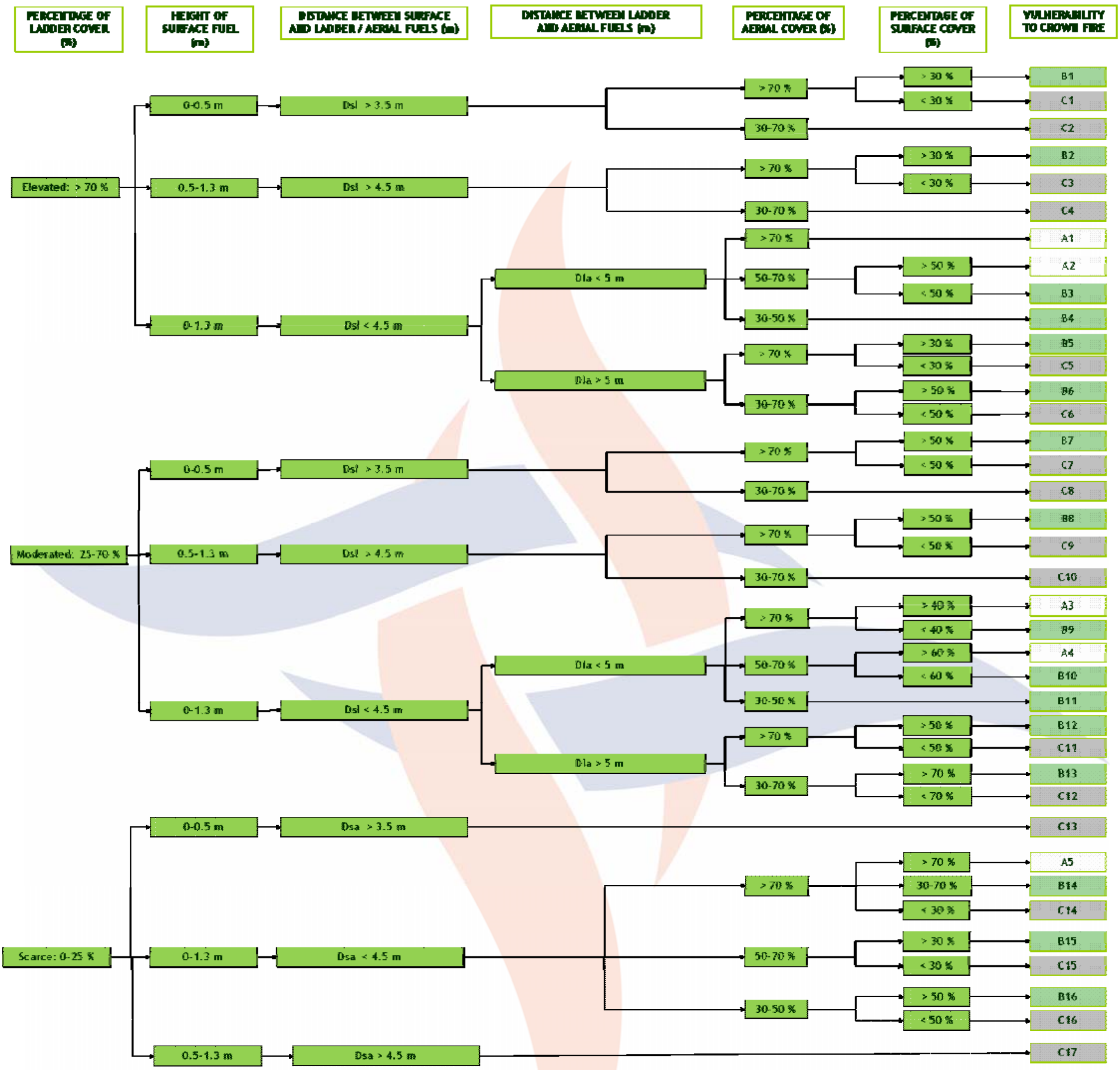
CVFoC Type 1: *Pinus* sylvestris, *Pinus nigra*, *Pinus uncinata*, *Pinus pinea* and *Pinus pinaster*



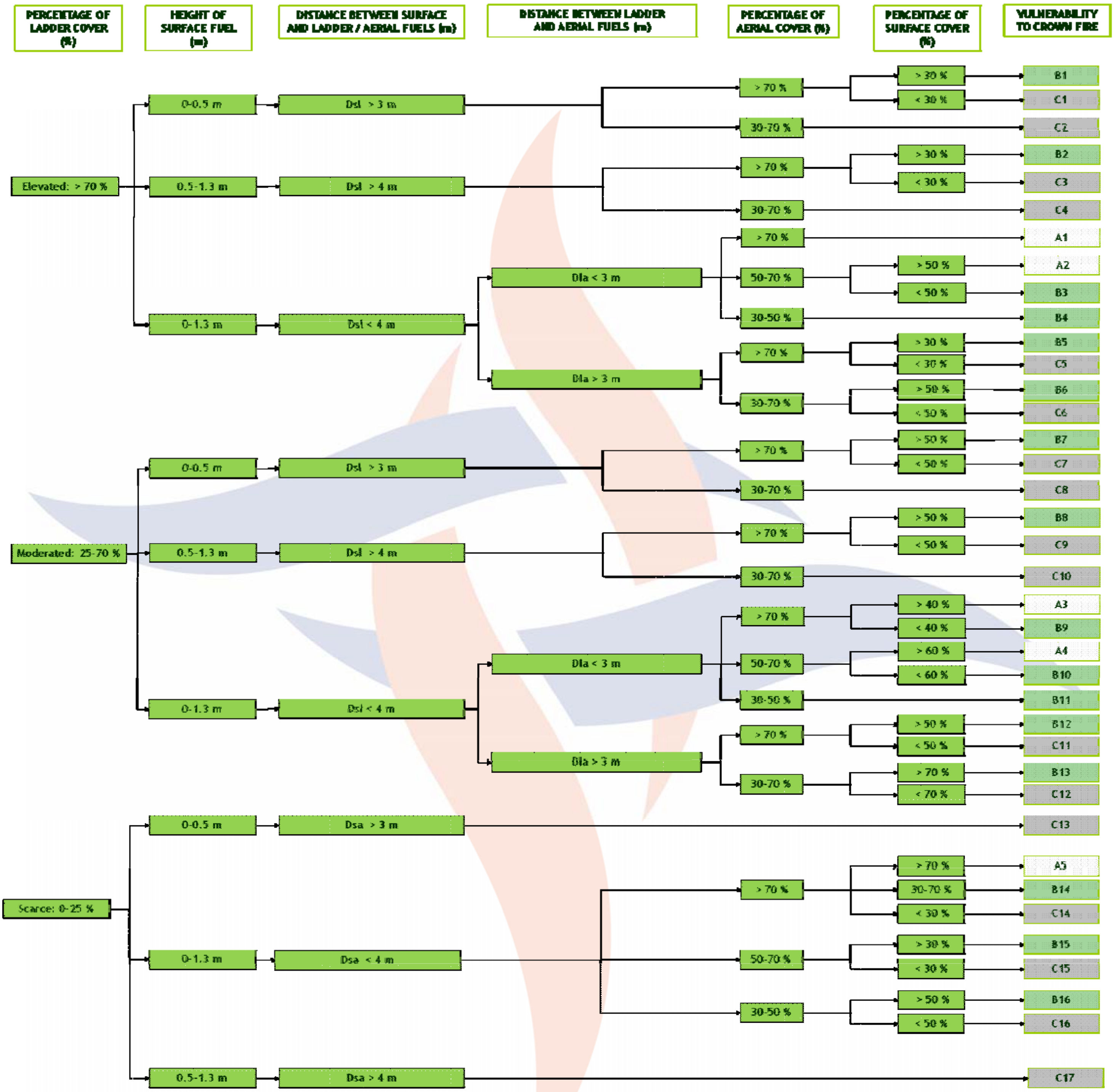
CVFoC Type 1.1: *Pinus pinea* and *Pinus pinaster* with litter (in case that surface fuel is less than 30%)



CVFoC Type 2: *Pinus halepensis*



CVFoC Type 3: *Quercus suber*, *Quercus ilex ilex*, *Quercus ilex ballota*, *Quercus faginea* and *Quercus humilis*



5. APPLICATION OF TOOLS FOR CROWN FIRE HAZARD ASSESSMENT

We focus in this type of tools because the user does not need excellent fire behaviour knowledge and are faster and simple to use for forest and fire managers. Some **general applications of the crown fire hazard assessment tools** would be:

- Assessment of crown fire occurrence at stand level and ranking the risk of a surface fire to climb to the canopy and advance to a crown fire.
- Improve knowledge about which forest structures are dangerous because their vulnerability to generate crown fires, both for fire prevention purposes and fire fighting operations.
- Give practical information to forests managers about which are the optimum forest structures and, so then, most efficient silvicultural treatments to reduce risk of crown fires and facilitate fire extinction tasks.
- Evaluate the effectiveness of different fuel treatments aiming at crown fire hazard reduction.
- Given areas with a high risk of forest fires, due to climatic or socioeconomic factors, to identify priority areas more vulnerable to crown fires, where proper forest management should be implemented in order to reduce risk of large forest fires

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ANNEX 1: Literature review about forest stand variables that influence fire behaviour and main tools to assess crown fire hazard risk

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