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Technical Note TN 2.3
Fuel load sampling of a *Cupressus sempervirens* hedge in Parc de Cervantes, Barcelona

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Abstract	In this document, data from three destructive samplings performed in a *Cupressus sempervirens* hedge in Parc de Cervantes (Barcelona) are shown; the methodology applied is also described. Measurements of fuel load have been taken, and moisture content, mass distribution and bulk density have been calculated. Different fuel classes (according to status and diameter) have been taken into account.

(1) *Draft / Final*
(2) *Public / Restricted / Internal*

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1. Introduction

In this Technical Note we gather data on fuel load and fuel distribution of a *Cupressus sempervirens* hedge located in Parc de Cervantes (Barcelona). This hedge could be destructively sampled thanks to a collaboration with the Ecology, Urban Planning and Mobility Area from the Municipality of Barcelona.

The general objective of this activity is similar to the one stated in TN2.2, i.e. to obtain quantitative information about this fuel structure because it has a high probability of being ignited in a wildfire scenario. However, a more specific objective for this technical note is to compare data obtained from this *C. sempervirens* hedge (80 years old) with data described in TN2.2 for a *C. sempervirens* hedge 25 years old.

As in TN2.2, we describe the methodology and report experimental results. Data gathered will be used to perform CFD preliminary simulations of pattern scenarios involving hedges.

2. Methods

2.1. Fence description

The fence is located in the Parc de Cervantes (Barcelona, 41°23'05.04"N, 2°06'17.07"E), a park with a rose garden, large grass areas, wide paths and gentle slope. The park has an entrance near the ring road “Ronda de Dalt”. At this side there is a wire fence limiting the park and the hedge fence of *C. sempervirens* masks it completely.

Trees in the area where the sampling was performed are about 80 years old, 2 m high and have a depth of about 2-2.5 m (Figure 1). Sampling was performed during the morning of September 17, 2019.

Figure 1. Hedge fence to be sampled

2.2. Vegetation sampling in the field

Three spots were selected to do the destructive sampling of the *C. sempervirens* hedge. At each located spot a tubing structure (Figure 2) was used to define two hexahedrons 0.5 m wide (dimension parallel to the ground not crossing the hedge) and as deep as half of the width of the hedge approximately (dimension across de hedge). It was assumed that the fence was symmetric.

Figure 2. Tubing structures used to define the volumes of interest.

The tubing structure had a total height of 2 m and it was divided in two parts of 1 m each one. So the height of the hexahedrons was set as shown in Eqs. 1-2:

$$H_D = 1 - H_{clear\_trunk} \quad (1)$$

$$H_U = H_{hedge} - 1 \quad (2)$$

Where:

H_D: Height of the hexahedron located near the ground; D stands for 'down' (m)

H_U: Height of the hexahedron located above the one located near the ground; U stands for 'up' (m)

$H_{clear\ trunk}$: Distance between the ground and the base of the "canopy" of the hedge (m)

H_{hedge}: Distance between the top of the hedge and the ground level (m)

A sketch of the sampling volumes at the sampling point #1 is shown in Figure 3.

The sampling was done using pruning shears. All the fuel present in the volumes was removed and collected in bags, except most tree stems and branches with diameter >10 mm. These were not cut but left in-situ (Figure 4). We assumed that these stems had the shape of a truncated cone and we measured their length and their diameter at two points: at the beginning and at the end of the branch. These data were used to estimate their volume and we calculated their weight considering a density value obtained experimentally from several samples that were taken to the lab and characterized.

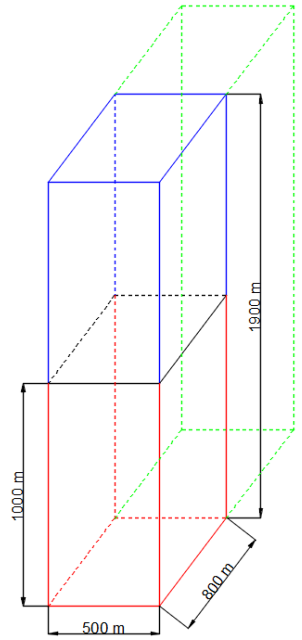

Figure 3. Sketch showing the position and dimensions of the sampling hexahedrons at sampling point #1. 'Down' hexahedron in red and 'Up' hexahedron in blue. Green dashed lines indicate the symmetric volume of the hedge that was not sampled.

Figure 4. Frontal view of the hedge at the sampling points a few weeks afterwards (17 October 2019): a) Sampling point #1; b) Sampling point #2; c) Sampling point #3.

Fuel samples were taken for moisture content analysis. They were collected at three locations of the fence near the sampling points. They were gathered in sealed cans and 5 types of samples were collected with a mean dry weight of about 17 g: live foliage, live roundwood < 3 mm, live roundwood 3-6 mm, live roundwood 6-10 mm, and dead roundwood < 3 mm. Three replicates per type of sample were taken (15 samples in total).

The debris present on the ground underneath the hedge were characterized. A sample of known area and depth was taken to the lab to obtain its dry weight and its bulk density.

Due to the particular arrangement of fuels observed during the fuel sampling, we visually inspected the void area that was left after the destructive sampling to estimate the area occupied by green leaves on the boundary of the hedge and by “brown” roundwood and dead leaves in the core of the sampled volume.

2.3. Laboratory measurements

Fuel sampled was transported to the FlamesLab laboratory (CERTEC-UPC) and classified the days after the sampling according to whether it was live or dead fuel, and also according to the following size classes: foliage (only for live fuel), roundwood of diameter <3 mm, roundwood 3–6 mm in diameter, roundwood 6–10 mm in diameter and roundwood 10-14 mm. After classification, fuel samples were oven-dried (BINDER APT. line ED 720) at 90°C for at least 24h, and weighted to get the fuel load.

The 15 fuel moisture samples were weighted (Mettler Toledo PB153-S/FACT) the same day of the sampling, oven-dried for 24h (BINDER APT. line ED 720) at 90°C, and then weighted again. The same procedure was employed with the debris sampled.

To estimate the dry weight of the tree stems and branches wider than 10 mm that were not sampled but left in-situ, nine samples of roundwood fuel > 10 mm were oven-dried (BINDER APT. line ED 720) for 24h at 90°C, weighted (Mettler Toledo BL600) and measured in length and diameter (several measurements at different points of the sample).

3. Results

3.1. Geometry of the hedge at the sampling points

The three points of the hedge where the destructive samplings where done had the dimensions specified in Table 1.

Table 1. Geometry at the sampling points. Outer and core refer to the parts of the hedge with live foliage and dead fuel, respectively, as sketched in Figure 5. Down (D) and up (U) refer to the vertical location of the hexahedrons in each sampling point.

		1D	1U	2D	2U	3D	3U
H_D / H_U (m) [1]		0.65	0.9	0.5	1.05	0.8	1.05
$H_{no\_branches}$ (m) [1]		0.35		0.5		0.2	
Sampled depth (cm)		0.8	0.8	1	1	0.75	0.75
Volume	Outer (m³)	0.03	0.10	0.03	0.12	0.04	0.10
	Core (m³)	0.23	0.26	0.23	0.41	0.26	0.29
	Total (m³)	0.26	0.36	0.25	0.53	0.30	0.39

[1] H_D, H_U and $H_{no\_branches}$ are defined in Eqs. 1-2.

During the sampling it was observed that dead fuels were mainly present in the core of the hexahedrons and green foliage was only present in the boundary of the hedgerow. So the hedge had an outer layer of variable thickness (depending on the orientation of green foliage), as depicted in Figure 5. The rest of the volume (core volume) consisted basically of dead foliage and dead roundwood. Live roundwood was distributed throughout the whole hedge volume (outer and core volumes).

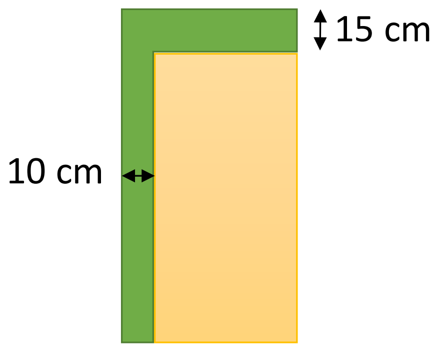

Figure 5. Lateral view of the sampled hedge considering fuel distribution within the volume. Green area: Live foliage and live roundwood. Yellow area: Dead foliage, and live and dead roundwood. This sketch represents half of the hedgerow, assumed symmetric.

3.2. Fuel moisture

Fuel moisture content values obtained from samples specifically collected to compute this variable are shown in Table 2. As expected, live foliage had a very high moisture content (157%). However, fine live roundwood fuel (< 3 mm in diameter) had a mean value close to 30% because one of the replicates had a very low moisture content (12%). If this replicate were not considered, the moisture content of this diametric class would increase to 47%. Dead fine samples were very dry, with moisture values around 15%. Debris accumulated on the ground had a very low moisture content (11%) because they were dead fuel.

Table 2. Fuel moisture content determined on a dry basis.

Classification	Replicate	Dry mass (kg)	Moisture (%)	Weighted mean moisture (%)
Dead < 3 mm	1	24.250	14%	15%
	2	15.933	15%	
	3	25.280	16%	
Live foliage	1	20.356	160%	157%
	2	18.348	162%	
	3	20.922	150%	
Live < 3 mm	1	14.333	12%	47% [1]
	2	10.576	29%	
	3	13.440	61%	
Live 3 - 6 mm	1	12.027	76%	82%
	2	12.431	54%	
	3	20.801	103%	
Live 6 - 10 mm	1	19.197	106%	91%
	2	20.421	76%	
	3	14.034	94%	
Debris	-	282.8	11%	11%

[1] Value obtained considering only replicates 2 and 3.

3.3. Wood density

The size, weight and density of nine samples of roundwood > 10 mm were measured in the lab (Table 3). The average density was 479 kg/m^3 (s.d. 117 kg/m^3), in agreement with common values used for *Cupressus sempervirens* (460-640 kg/m^3)[1].

Table 3. Dimensions, geometry, weight and density for nine dry samples of roundwood of Cupressus sempervirens (S: sample).

	S1	S2	S3	S4	S5	S6	S7	S8	S9
Length (cm)	26.6	30.5	7	32.5	19.7	13	14.3	7.5	64
Avrg. diameter (cm)	2.01	2.13	1.88	1.38	1.15	1.22	2.09	1.60	2.70
Dry Mass (g)	52.5	53.9	12.1	28.2	11.7	10.7	24.5	5.8	158.6
Section (cm^2)	3.2	3.3	3.0	2.2	1.8	1.9	3.3	2.5	4.2
Volume (cm^3)	83.9	102.1	20.7	70.6	35.6	25.0	46.8	18.8	271.2
Density (kg/m^3)	626	528	585	399	328	429	523	308	585

3.4. Fuel load > 10 mm in diameter

As mentioned above, most stems and branches with a diameter wider than 10 mm were left in-situ. At the first sampling point 9 of these stems were left. We calculated the total volume they occupied was 7537 cm^3. The sampling point #2 had 4 of these stems, with a total volume of 19363 cm^3, and the third sampling point had 6 of these stems, with a total volume of 13567 cm^3.

[1] Bolza, Eleanor, and William G. Keating. "African timbers-the properties, uses and characteristics of 700 species." *African timbers-the properties, uses and characteristics of 700 species.* (1972).

Assuming that the density obtained in section 3.3 is constant, at sampling point #1 we left in-situ 3.6 kg of > 10 mm stems, at sampling point #2 there were 9.3 kg left and at sampling point #3 there were 6.5 kg left.

In the lab we found a certain amount of fuel > 10 mm in diameter. The load we found for each hexahedron is shown in Table 4. There was much more amount of fuel left in the field than classified in the lab (i.e. 0.2 kg at sampling point #1; 0.5 kg at sampling point #2; 1.2 kg at sampling point #3).

Table 4. Mass (in grams) of the classes > 10 mm in diameter classified in the lab (L: live; W: roundwood; D: dead; +10: diameter > 10 mm).

	1D	1U	2D	2U	3D	3U
LW+10 - lab	44.7	95.0	34.4	393.7	284.1	732.3
D+10	88.7	0.0	87.4	0.0	23.5	174.4

3.5. Fuel load and mass distribution (< 10 mm diameter)

The mass of fuel sampled in each hexahedron from each sampling point is shown in Figures 6-8. Fuel > 10 mm is not included here since this fuel class would not ignite in a flaming fire front. Mass distribution of the different classes is shown in Table 5. According to these figures and the numbers included in Table 5, several observations can be provided.

Dead fraction < 3 mm in diameter (D3) has the highest average presence. It is worth to note that the dead fraction < 3 mm clusters all dead fuels with diameter lower than 3 mm, including dead foliage. In live fuels, a distinction is done between foliage (LF) and roundwood with diameter lower than 3 mm (LW3). Regarding all those fuels with diameter greater than 3 mm, live fuels have a larger presence than dead fuels.

There are differences between the upper hexahedron (U) and the hexahedron sampled from the ground (D). There is more live foliage in the upper hexahedron. This was expected since the upper volume includes two live foliage layers, one parallel to the ground and a portion of the layer normal to the ground. However, the hexahedron sampled from the ground contains only the portion of the live foliage layer normal to the ground.

There are also differences in fuel distribution between the three sampling points. The sampling points #1 and #2 are quite similar, probably because they were very close. However, sampling point #3 shows a slightly different distribution.

In #1 and #2 there is more live fuel in the upper hexahedron than in the one near the ground, and there is more dead fuel > 3 mm near the ground than in the upper hexahedron.

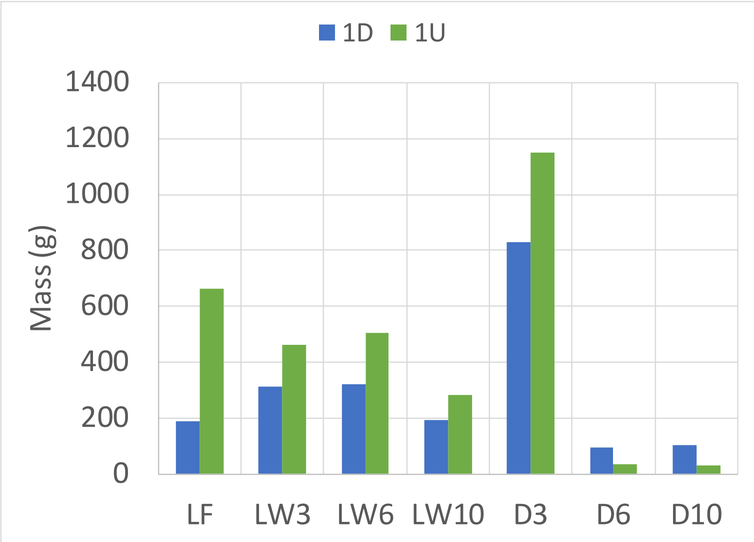

Figure 6. Mass of fuel classes sampled at point #1 according to height (U: Up; D: Down). L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm.

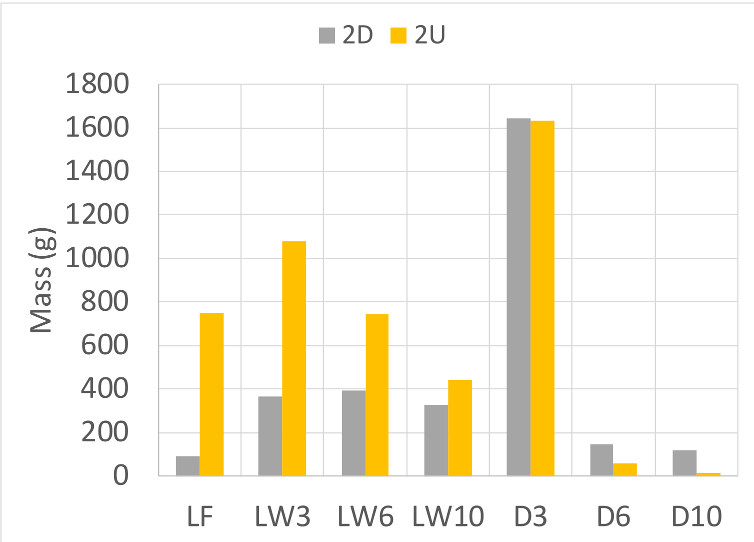

Figure 7. Mass of fuel classes sampled at point #2 according to height (U: Up; D: Down). L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm.

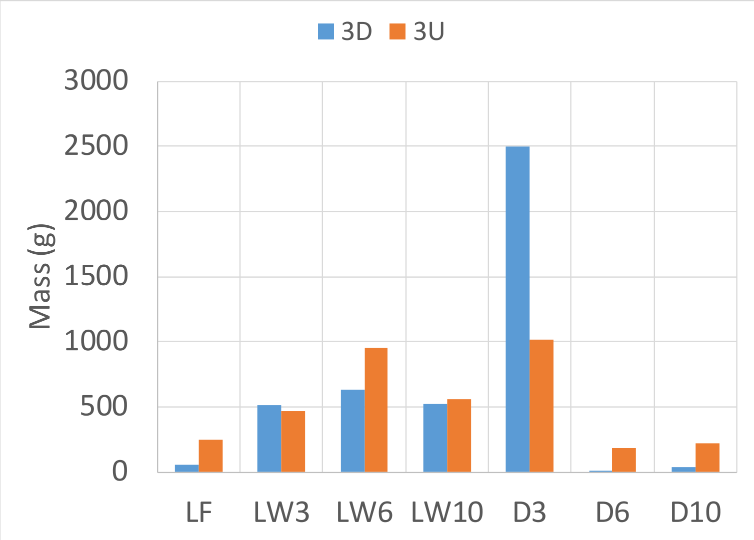

Figure 8. Mass of fuel classes sampled at point #3 according to height (U: Up; D: Down). L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm.

In #3 all the fuels with a diameter greater than 3 mm have a larger presence in the upper hexahedron than in the one near the ground. The amount of fuel classified as dead fraction < 3 mm in diameter (D3) for the hexahedron near the ground is extremely high in comparison with those values obtained in #1 and #2. This may suggest that debris from the ground were collected by mistake and classified as if they were part of this class.

Table 5. Mass distribution (in percentage) of the different classes (L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm).

	1D	1U	2D	2U	3D	3U
LF	9.3%	21.2%	3.0%	15.9%	1.4%	6.8%
LW3	15.2%	14.8%	11.9%	22.9%	12.0%	12.9%
LW6	15.7%	16.2%	12.7%	15.8%	14.7%	26.1%
LW10	9.5%	9.0%	10.7%	9.3%	12.3%	15.2%
D3	40.6%	36.8%	53.2%	34.6%	58.5%	27.8%
D6	4.6%	1.1%	4.7%	1.2%	0.3%	5.1%
D10	5.0%	0.9%	3.8%	0.3%	0.9%	6.1%

3.6. Bulk density

The fuel bulk density calculated for every hexahedron is shown in Table 6. Bulk densities have been calculated in this case assuming that all fuels are uniformly distributed all along the hexahedron. Regarding overall burnable fuels (< 10 mm) and making a distinction between fuel status, average bulk densities are 1.88 kg/m^3 (#1), 2.33 kg/m^3 (#2) and 2.05 kg/m^3 kg/m^3 (#3; 3U hexahedron only considered due to the problem with D3 fraction stated in section 3.5) for dead fuels, and 2.36 kg/m^3 (#1), 2.71 kg/m^3 (#2) and 2.85 kg/m^3 kg/m^3 (#3) for live fuels.

*Table 6. Bulk density (in kg/m³) of the different classes (L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm). Bulk densities have been calculated assuming that **all fuels are uniformly distributed all along the prism**.*

	1D	1U	2D	2U	3D	3U
LF	0.31	1.07	0.12	0.97	0.09	0.36
LW3	0.50	0.74	0.47	1.39	0.74	0.68
LW6	0.52	0.81	0.51	0.96	0.91	1.38
LW10	0.31	0.45	0.42	0.57	0.75	0.80
D3	1.34	1.85	2.12	2.11	3.60	1.46
D6	0.15	0.06	0.19	0.07	0.02	0.27
D10	0.17	0.05	0.15	0.02	0.05	0.32

The bulk densities of the fuels in the outer volume are shown in Table 7. Table 8 shows the fuel bulk density of the core volume. Note that dead fuels are not present in the outer volume. Considering this discretization of the sampled volumes, it can be observed that average dead fuel bulk density in the **core volume** is 4.57 kg/m³ (#1), 6.34 kg/m³ (#2) and 4.68 kg/m³ (#3; 3U hexahedron only considered due to the problem with D3 fraction in 3D stated in section 3.5). These values are around 2.5 times higher than the value obtained without discretising the sampled volume.

In addition, average live fuel bulk density in the **outer volume** is 7.99 kg/m³ (#1), 7.14 kg/m³ (#2) and 4.6 kg/m³ (#3), on average about 2.5 times higher than without considering discretization.

*Table 7. Bulk density (in kg/m³) of the different classes in the **outer volume** (L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm).*

	1D	1U	2D	2U	3D	3U
LF	5.83	6.80	3.72	6.24	1.49	2.47
LW3	0.50	0.74	0.47	1.39	0.74	0.68
LW6	0.52	0.81	0.51	0.96	0.91	1.38
LW10	0.31	0.45	0.42	0.57	0.75	0.80

*Table 8. Bulk density (in kg/m³) of the different classes in the **core volume** (L: live; F: foliage; W: roundwood; D: dead; 3: diameter < 3 mm; 6: diameter 3-6 mm; 10: diameter 6-10 mm).*

	1D	1U	2D	2U	3D	3U
LW3	0.50	0.74	0.47	1.39	0.74	0.68
LW6	0.52	0.81	0.51	0.96	0.91	1.38
LW10	0.31	0.45	0.42	0.57	0.75	0.80
D3	3.65	4.37	7.31	4.04	9.60	3.47
D6	0.41	0.13	0.65	0.14	0.05	0.63
D10	0.45	0.11	0.53	0.03	0.14	0.76

4. Conclusions

The destructive samplings performed on a hedge of *C. sempervirens* in Parc de Cervantes (Barcelona) have shown that the thinnest (0-3 mm) dead fraction represents the main portion of the total mass available to burn (27.8% - 53.2%). Live foliage only represents a small amount (3.0% - 21.2%) and it is concentrated in a small volume around the boundaries of the hedge.

The distribution of lower diameter fractions (0-3 mm) of dead and live fuels is predominant in this vegetation structure, rising up to 47.6% - 73.4% of the total mass available to burn.

We have also observed that differences between sampled points and hexahedrons sampled at different heights are important. In fact, sampling points #1 and #2 were very closely located and fuel load, mass distribution and bulk densities are quite similar. However, at sampling point #3 mass distribution is different. Contrary to what was observed in sampling points #1 and #2, dead fuels with a diameter > 3 mm have a larger presence in the upper hexahedron than in the one near the ground.

Large amounts of fine dead fuel (< 3 mm) are observed all along the tree and no clear relation can be inferred from the results obtained at the three sampling points. It could be stated that once they die, fine dead fuels fall down and accumulate in mulch beds under the tree canopy base and in the lowest part of the tree. However, if there are large amounts of live woody fuel in the core volume of the hedge, they can block the fall of fine dead fuel from the top layer, thereby making them accumulate at higher levels.

The hedge sampled here is illustrative of an old fence in which intensive clipping and watering has been applied. The hedge described in TN2.2. was younger (25 years old) and the main difference between both hedgerows is that the live fuel bulk density was twice the density calculated for this hedge regardless of the discretization of the volume.