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TECHNICAL NOTE ON TOTAL AND BOLE VOLUMES TO THE CONSEIL SCIENTIFIQUE ET TECHNIQUE DE L'IGN

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Amaël Le Squin, Florence Gohon

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Context

The French National Forest Inventory (NFI) publishes statistics annually, such as basal area or wood resources, on both private and public forest. These statistics are derived from a sampling scheme in which about 6000 new plots are surveyed each year, along with 6000 plots that were first visited five years earlier. The published statistics are calculated using a moving five-year average; for instance, the published results for 2024 are based on campaigns spanning from 2020 to 2024.

Initially designed to assess forest area and produce estimates of standing timber stock, the French NFI is gradually evolving into more comprehensive tools for forest monitoring, incorporating a variety of indicators. Among this new information, the estimation of forest biomass and carbon is crucial, as it makes it possible to monitor biomass production and its use by different sectors, to estimate the contribution of forests to mitigating the effects of climate change as part of climate commitments monitoring (Citepa), and to develop forest strategies adapted to contemporary environmental and societal challenges (Commission Européenne 2018).

The European Union developed a New EU Forest Strategy for 2030 as part of the plan to adapt to and fight against climate change and make Europe a climate neutral continent by 2050. This strategy relies on improved monitoring of European forests to better understand their condition and respond accordingly. Specifically, it calls for assessing carbon sequestration in forests to evaluate whether or not Europe reached carbon neutrality. One bottleneck is the harmonisation of the forest monitoring methods between European member states, if not within them. The PathFinder project supports member states in implementing a European Forest Monitoring System in order to standardise or harmonise forest data collection and reporting across the EU. This

prompted the French NFI to update its methods for assessing forest carbon storage.

Three steps are necessary to estimate carbon storage from field data (see Fig. 1): (*i*) the total aerial volume is estimated from diameter at breast height (dbh) and height (Vallet et al. 2006), (*ii*) biomass is then derived by using a coefficient for wood density, and (*iii*) a factor is applied to convert the biomass into carbon content.

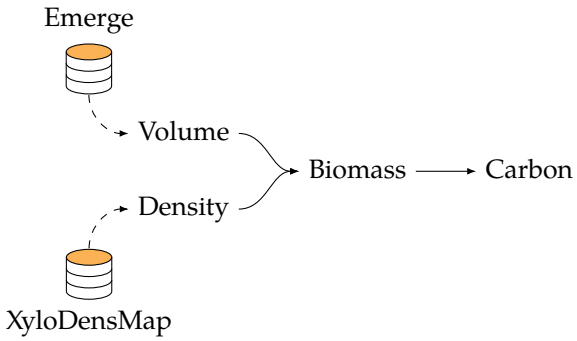

Figure 1: Computation chain for biomass and carbon content.

In this technical note, we explain the methods we foresee to estimate the two volumes computed at the French NFI for each tree: the bole volume (volume bois-fort tige), which is the reference volume since the creation of the French NFI (1958), and the total aerial volume. In the section Definitions and datasets, we define the different tree components and explain the origins of the data. Then, in the section Bole volume, we expose the method to compute the individual bole volume, and lastly we describe the model for total volume in the section Total aerial volume.

Definitions and datasets

Trees are partitioned into hierarchical elements with definitions that may vary between Forest Inventories and datasets (*e.g.*, Fig. 2).

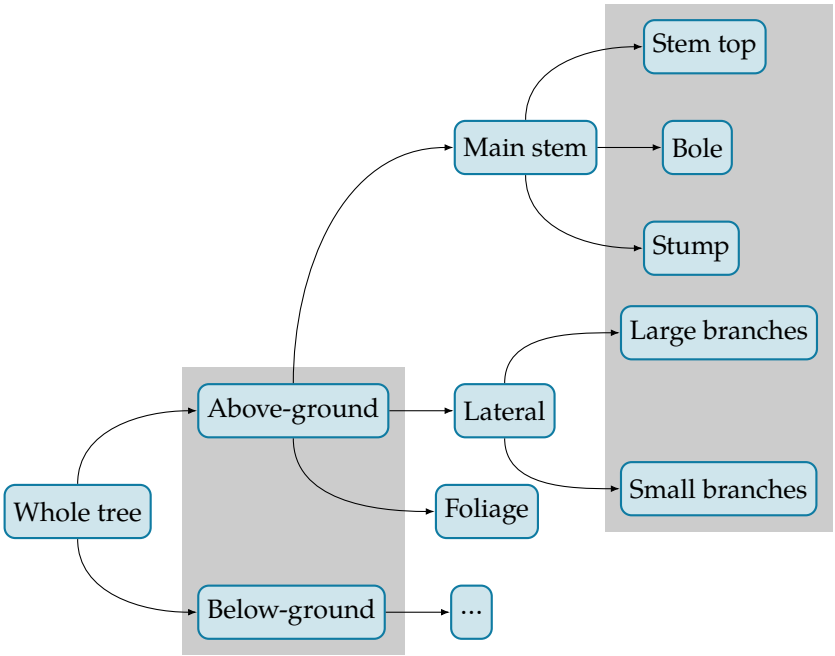

Figure 2: Hierarchical elements of trees, figure inspired by Gschwantner et al. 2009

In our case, the tree data come from different institutes, different periods of time, and do not all have the same tree components recorded:

1. 'Protocole Oudin', dataset preserved by INRAE, ranging from 1930 to 1980 (in red on Fig. 3). Recorded the bole volume, and the large and small branches. Hereafter, we name this dataset 'Emerge', which was the name of the

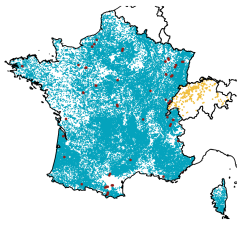

Figure 3: Plot location for French NFI, Emerge, and Swiss dataset.

project that digitalised this dataset in 2008 (Deleuze et al. 2013).

2. The French NFI(in blue on the Fig. 3). Data range from 1988 to 2007 (data before 1988 record diameter rather than circumference). Recorded the bole volume.

3. Experimental Forest Management project dataset (Didion et al. 2024, in yello on Fig. 3). Data range from 1888 to 1974, and bole volume, large branches, and small branches were recorded.

4. The 'Office National des Forêts (ONF)', with protocols from 1972 and from 1983 (not used as there is no coordinates)

5. Institut Technologique Forêt, Cellulose, Bois-construction, Ameublement (FCBA), not used so far for the aerial volume

6. L'Institut pour le développement forestier (IDF) which is the R&D of the Centre National de la Propriété Forestière and the Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture (IRSTEA, currently INRAE)

We decided to use the definitions from Gschwantner et al. 2009 (see Figs. 2 and 4):

- Main stem: The stem of a tree is the above-ground part of the main (off) shoot with apical dominance
  - Stem top: topmost part of the stem from an over-bark base-diameter of 7 cm (French NFI) to the stem tip
  - Bole: above-ground part of the stem between stump and the stem top
  - Stump: above-ground base part of the stem which would remain after a tree was cut under normal felling practices
- Lateral parts:
  - Large branches: portion of the above-ground lateral parts with a diameter of more than or equal to 7 cm (French NFI)
  - Large branches: portion of the above-ground lateral parts with a diameter of less than 7 cm (French NFI)

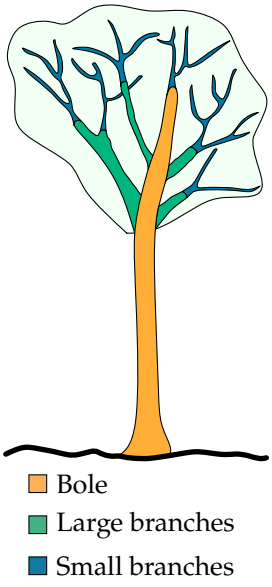

Figure 4: Scheme of tree components.

A total of 594 616 individuals were measured, with 98% coming from the NFI (bole volume only), 6% from the Swiss dataset

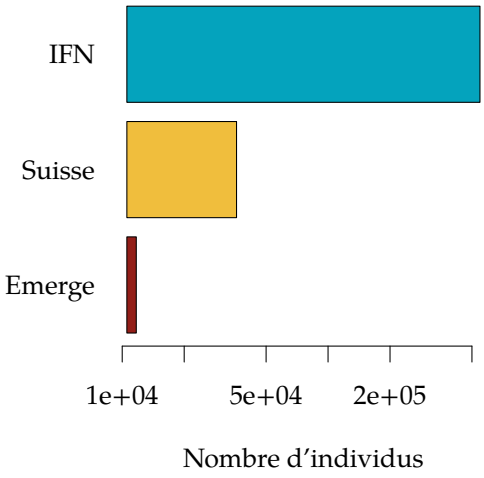

Figure 5: Composition of the used dataset for the bole volume and total aerial volume.

(bole, large and small branches), and 2% from Emerge (same components as the Swiss dataset; see Fig. 5). The difficulties in fitting the data are twofold: first, the data show high heteroskedasticity (see Fig 6), and second, the datasets are unbalanced.

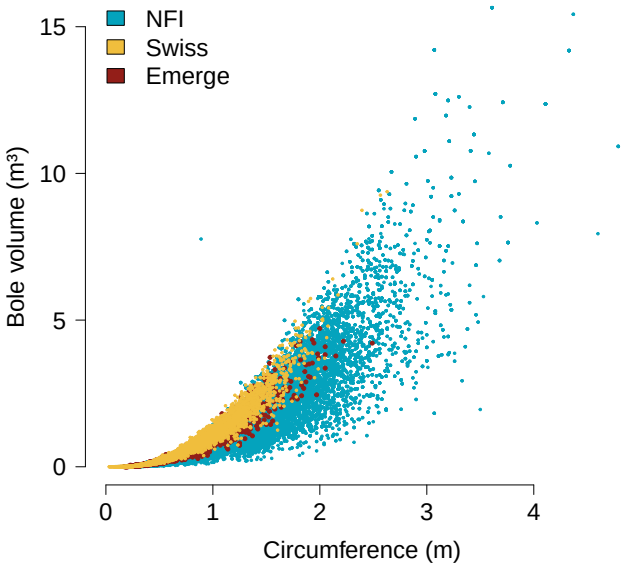

Figure 6: Typical response of bole volume to circumference (here displayed for *Fagus sylvatica*). We can see that both the Emerge and Swiss datasets (Deleuze et al. 2013; Didion et al. 2024) are quite similar and covers elongated trees, while the French NFI covers less regular trees.

Bole volume

Total aerial volume

In this section, I explore two possible paths to estimate the total aerial volume, V_{tot}. The first option, based on Longuetaud et al. 2013, uses the ratio:

$$r = \frac{V_{\text{bole}}}{V_{\text{tot}}} \tag{1}$$

and is comprised between 0 and 1 by construction. Therefore, a Beta-distribution is a good fit. The second option is to fit a multivariate normal distribution, MVN, to the *transformed* ratio, $\text{logit}(r)$, jointly with the log-transformed total volume, $\log(V_{\text{tot}})$:

$$\begin{pmatrix} \text{logit}(r) \\ \log(V_{\text{tot}}) \end{pmatrix} \sim \text{MVN}\left\{ \begin{pmatrix} f(c, h; \boldsymbol{\theta}) \\ g(c, h; \boldsymbol{\theta}) \end{pmatrix}, \boldsymbol{\Sigma} \right\}, \tag{2}$$

where f and g are functions to tailor for our specific needs, c is circumference at breast height, h, is tree height, and θ is a vector of parameters to estimate.

Ratio approach

Multivariate approach

Simulated data

In order to demonstrate the relevance of multivariate methods, I simulate two correlated random variables and then recover the generating parameters.

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