BioWood

D1.6: Refined high resolution land use map for Flanders, related to woody biomass production in forests and linking appropriate attributes and production models

Joachim Lopez, Sanne Verdonck, Ilié Storms, Pieterjan de Geest, Jos Van Orshoven, Bruno Verbist, Bart Muys

Content

Introduction

The bio-economy covers the use of renewable bio-resources such as wood, and their conversion into products, biofuels, feed and food via biorefinery technologies. Bio-based industries are a significant subsector of the bio-economy, and a strong bio-based industrial sector helps to reduce Europe's dependency on fossil-based products (Palahí et al., 2020). Sustainable forest management combined with sustainable wood conversion and use has a large potential to contribute to the circular bioeconomy (Weber-Blaschke, G., Muys, B. 2020). Nevertheless a single integrated Flemish, let alone European, bio-based industry sector does not yet exist and therefore a wide range of subsectors often work in isolation. This lack of value chains and the missing support for their development hampers growth of the biobased industry in Flanders and the EU.

The primary aim of the BioWood strategic basic research project is to support the development of a new wood-based value chain in Flanders. Reaching this goal relies on an integration of sustainable wood supply, feasible conversion processes and unique high-value bio-based products. To that end, a major scientific challenge related to woody biomass supply is the development of a reliable methodology for calculating its current and future availability in Flanders as a function of growth conditions and management choices.

A recently developed decision support system (DSS) Sim4Tree (Dalemans et al., 2015) can serve as the basis for tackling this challenge but is, in its current state, unable to predict the future biomass availability. Updating the system with (i) more recent yield tables and (ii) land-cover maps, (iii) ecological and technical restrictions for biomass harvesting, (iv) scaling factors accounting for productivity changes due to climate change and (v) inclusion of different land-use scenarios are necessary to make more accurate predictions on future biomass availability.

The goal of this deliverable is to present a new high-resolution land use map focussing on the current distribution of Flanders' forests. The new forest map (i) was constructed by manually checking points at a one-hectare resolution covering Flanders. This new map was (ii) compared with other existing forest maps to review its strong and weak points. Finally, the forested points were extended with location-dependent variables retrieved from the regional forest inventory, such as (iii) the occurring species and their age distribution of the different forest point locations using the regional forest inventory. The new map was designed to be used as the base layer in the improved Sim4Tree DSS. This deliverable D1.6 is one of the nine reports composed for this project:

- **D1.1**: License agreement between ANB-Naturinvest (owner) and Forecoman-LandInforMan (licensee) on the further development of the Sim4Tree software
- **D1.2**: Selection of existing growth models relevant for Flanders
- **D1.3**: Model- and species-specific scaling factors to account for impacts of global environmental change on growth/net annual increment of trees
- **D1.4**: Potential land use management scenarios, based on recent trends, policy developments and socio-economic trends
- **D1.5**: Set of correction factors to take into account legal, technical and ecological criteria for harvest of different biomass fractions
- ***D1.6: Refined high resolution land use map for Flanders, related to woody biomass production in forests and linking appropriate attributes and production models***
- **D1.9**: Analysis and interpretation of wood harvest simulations in Flanders until 2050
- **M1.1**: Development of a BioWood-DSS by upgrading of the Sim4Tree DSS
- **M1.2**: Application of the Biowood DSS to simulate the wood resource evolution in Flanders until 2050 under different socio-economic scenarios

1   Construction of the forest map

Accurate and up-to-date forest maps are crucial for detailed predictions of current and future biomass availability from forests. However as most existing forest maps of Flanders did not seem suitable for the purpose of this project and the previously used forest map already date from before 2010 an update was required. Therefore, a high-resolution forest map was constructed, which was then further extended with location-dependent variables for implementation in the Sim4Tree decision support system.

1.1   History of the Flemish forest maps

The previous forest map of Flanders incorporated in Sim4Tree was constructed in 2010. This forest map consists of a one-hectare grid based on the geodata set 'bosreferentielaag' for the year 2000. Point locations that intersect with the 'bosreferentielaag 2000' were indicated as forest. The 'bosreferentielaag 2000' is an updated version of the Flemish forest map of 1990 in which new forest areas were included and deforested areas excluded. This method previously resulted in 153,455 forest points. Although this forest map is an improved and updated version, it still dates from the year 2000 so an update is necessary. Below an overview of past mapping efforts is presented.

The first Flemish forest inventory was carried out between 1997-1999 (Govaere & Leyman, 2020). Since 2009, a continuous survey is made over a period of 10 years to gather statistical information about the forests in Flanders (forest cover, forest composition, forest standing stock, etc.). This inventory is currently accepted as the official forest reference for Flanders. Recently, the results of the second forest inventory have been published. The second Flemish forest inventory indicates that 140,279 (+/- 5000) ha of forest is present in Flanders. For this inventory, a 1000 x 500 m grid (26,730 points) was used. The methodology started with the re-inclusion of the measured points obtained from the first forest inventory. Those were based on orthophotographic images (infra-red) from the period 1981-1992. These points were completed with new forest areas from the 'bosreferentielaag' of 2000. For the remaining points, an evaluation was made whether these had to be implemented and so visited. This evaluation was based on orthophotos which were sometimes less recent. In the next phase, the owners of the parcels in which the points were located were contacted to plan a field visit. The field visits resulted in the exclusion of some points, which were inaccessible or for which the owner refused access. Another remark to be made is that if points were intersecting with roads through the forest and fire roads, they were excluded and thus also the forest that surrounds it was not accounted for. The third Flemish forest inventory however will include these locations.

Also other attempts have already been made to compile high-resolution forest maps, such as the "Boswijzer" in 2015 and the Copernicus high-resolution forest type map in 2018. The "Boswijzer" consists of a segment-based classification of the medium-scale summer flight orthophotos from 2015. Segment-based classification indicate the approach of classifying remotely sensed images where homogeneous pixels are defined into (spectrally) similar image segments. The goal is to facilitate the interpretation and classification process. Those orthophotos were digitally aggregated and processed based on predefined criteria

in order to locate and map forest cover in Flanders. This mission was carried out by a team of the Flanders Information Agency (AIV) on the commission of the ANB. The "Boswijzer" uses, after previous processing steps (Vlaamse Overheid, 2017), a combination of a 10 m x 10 m and a 70 m x 70 m resolution resampling strategy to construct forest pixels and obtain the best possible and applicable forest map. This method resulted in an estimated forest area in Flanders of 162,739 hectares. The "Boswijzer", however, is not used to determine the forest area in Flanders in official statistics. For this purpose, the Flemish Forest Inventory described above is used (Vlaamse overheid, 2015).

The Copernicus high-resolution forest map of 2018 indicates 236,082 ha of "forest". The input data were optical Sentinel-2A & Sentinel-2B L2A data from the reference year 2018 (European Environment Agency, 2020). This map seems to be more like a tree cover map than a "real" forest map. This is caused by the 10 m spatial resolution where only a Minimum Mapping Unit (MMU) of 0.5 hectares was applied, but no restrictions were placed on a minimal cross-section of forest patches or the actual land use of these places. This results in the inclusion of agricultural parcels such as (fruit) orchards, line elements, gardens and parks amongst others. This 10 m resolution error is the reason why the "Boswijzer" uses a combination of 10 m and 70 m resolution resampling so that amongst others, it becomes possible to filter out (most) narrow line elements.

The previously mentioned forest maps each have their own characteristics and applications. It was decided to create a new forest map that is suitable for the BioWood project in order to make as accurate as possible estimations of the current and future available biomass from the Flemish forests. The decision to construct a forest cover map instead of a forest land use map (such as the Flemish forest inventory) was based on the observation that 'non-forest vegetation', which meets the forest definition does yield harvestable biomass and so has to be accounted for in this project.

1.2   Forest definition

A clear definition of 'forest' is difficult to obtain. Depending on the domain from which is operated, the definition may vary. For example an ecological definition was given by Morosov (1922): "a forest is a community of woody crops characterised by resistance, mutual influence and effect on the environment". The term "forest" can be applied in a legislative framework through juridical definitions such as that of the Flemish Forestry Decree. However, the chosen forest definition by a country can have a major impact on the implementation of established forest guidelines. The chosen definition will also influence the reporting of the measured forest area of a country and their established afforestation or deforestation (Verchot et al., 2007).

For the creation of the new forest map, we applied the minimal requirements for a high green patch to be considered forest according to the "Bosdecreet". The "Bosdecreet" states: '*forests are the areas of land of which trees and woody shrub vegetation are the main constituents, which have their own fauna and flora and fulfil one or more functions*' (Vlaamse Overheid, 1990). Additionally to the forest definition, the Forest Decree ("bosdecreet") also provides a list of situations that may lead to confusion as to whether a specific case is classified as forest or non-forest. This list of potentially confusing situations is presented in Table 1.

Still, the Forest Decree resulted in a rather broad concept without a specific determined minimal area that is required to classify a high green patch as a forest. Therefore some additional statements were needed. Those statements were provided by the ANB (Agentschap Natuur en Bos, 2020). Additional to the previous restrictions, only parcels of land with a minimum area of 0.5 ha, a width of at least three rows of trees and a cross-section of 25 m are considered to be a forest. This forest definition with the additional conditions allows to distinguish in most cases forest and non-forest.

Table 1: A list to provide further clarification for specific, potentially confusing cases whether or not to be considered forest according to the Forest Decree (Vlaamse Overheid, 1990)

Forest	No Forest
1. Logged areas, previously occupied by forest, which remain part of the forest;	1. Fruit orchards and fruit plantations;
2. Non-forested areas necessary for the preservation of the forest, such as forest roads, firebreaks, adjoining or within the forest, service areas and official residences;	2. Gardens, public gardens and parks;
	3. Line plantations and hedgerows, along roads, rivers and canals;
3. Permanent forest-free areas or strips and recreational equipment within the forest;	4. Tree and ornamental shrub nurseries and arboreta situated outside the forest;
	5. Ornamental plants;
4. Plantations that are primarily intended for the production of wood, including poplar and willow, with the exception of short-rotation timber cultivation, the planting of which has taken place on land that is currently located outside the spatially sensitive areas as defined in Article 1.1.2, 10°, of the Flemish Spatial Planning Code;	6. Coniferous plantations intended exclusively for sale as Christmas trees. A planting shall be deemed no longer to meet this condition when the average height of the stock has reached 4 metres;
	7. All temporary plantings with woody plants in application of European Community Regulations as regards the set-aside of arable land;
5. The so called "Grienden".	8. All rotational crops whose surface mass is harvested periodically up to a maximum of three years after planting or after the previous harvest;
	9. Land use systems in which the cultivation of trees is combined with farming on the same land, applied to an agricultural parcel as referred to in Article 2, 12°, of the Decree of 22 December 2006 establishing a common identification of farmer, exploitation, and agricultural land within the framework of fertiliser and agricultural policy, and of which the notification via the single application and the planting of trees took place after the entry into force of the Decree of 20 April 2012 containing various provisions on the environment and nature.

1.3   Forest point selection

The new forest map was created by manually checking the centre points of a one-hectare (100 m x 100 m) grid, similar to the previous map used in Sim4Tree. It is assumed that the probabilities of identifying too much or too little forest average each other out through consistent use of centre points. At the same time, this facilitates the selection process without the need of determining percentages of coverage per grid cell. This grid was laid out over the extent of Flanders by means of QGIS 3.10.8 software. Further the most recent orthophotographic images obtained from the Copernicus Landsat satellite imagery (Google Earth 2020) were used to classify a point as forest or otherwise to exclude the point. Those images were obtained through the Google QuickMapServices plugin in QGIS 3.10.8 and are mostly dated from spring 2018 and summer 2019. The decision on whether a point was to be considered as forest or non-forest was supported by the combination of several additional maps. One of the maps is the Flemish land use map of 2016, which provided information on the land use at the time (agriculture, industry, forest, residential, …). The green map of 2015 on the other hand provided more information on the density and height of "green areas". This was especially useful to differentiate heathland or dune vegetation from higher and denser shrublands with growing trees. Finally, also the forest guide of 2015 and the forest reference layer of 2000 were used to have a comparison and indication of where forest previously occurred. An overview of the different layers that were used to determine whether a point was retained indicating forest or removed from the multi point layer is given in Figure 1. This methodology of manually checking centre points, resulted in 162 703 points that were retained and classified as 'forest' with each point representing a square of 1 hectare resulting in a forest cover map of 162 703ha.
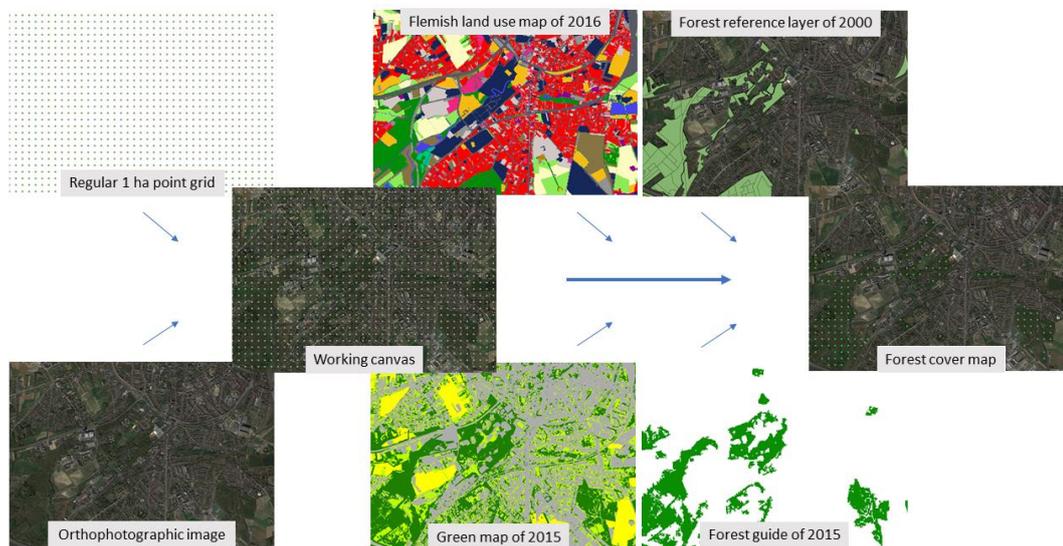
Figure 1: Systematic scheme of the used layers in QGIS for constructing the forest map of 2020

1.3.1   Ambiguities

Yet, during the preparation of the new forest cover map with the classification of the centre grid points to be forest or non-forest, there were some ambiguities which needed clarification. The type of the encountered ambiguities is listed below. This list was used for

the sake of clarity and consistency during the selection process. However, it is mostly an interpretation of the previously described forest definition with its restrictions (Agentschap Natuur en Bos, 2020) and additional cases given in Table 1.

- Dune vegetation: considered as forest if the area, vegetated by shrubs or trees (>3 m), covers at least 50% of the surface.
- Castle domains and golf resorts: if a grid point was located in a parcel with at least 0.5 ha and 25 m cross-section, it was considered as a forest. If a point was located on a single tree or group of trees in a park-like landscape, it was not considered as a forest.
- Villa parcels in a forest: gardens (lawn, shrubs, single trees) near a house in the woods were in general not considered as forest, even if the 'open area' was smaller than 0.5 ha. The parts of the garden that are covered with trees that match the 0.5 ha and a 25 m cross-section were considered as a forest.
- Recreation facilities: were treated in a similar way as the previous situation: Villa parcels in a forest.
- Heathland: not classified as forest, unless smaller than 0.5 ha and located inside a forest area.
- Line plantations: in general, not considered as forest except if there were at least three rows of trees with a cross-section of minimum 25 m.
- Clear cut areas: were considered as forest. The area was not classified as forest only if there had been already a clear change in land use type (e.g. industrial activities).
- Meadows planted with trees: considered as forest if the crown projection covered over 50% in addition to the 0.5 ha and three tree row restriction.
- Open areas and roads through a forest: areas bigger than 0.5 ha or a road more than 25 m wide were not considered forest.

1.4   Results and discussion

The manual selection of the forest points, following the previous explained forest definition and methodology resulted in an estimated forest cover of 162,703 hectares (Figure 2). The selection of the forest points was mainly carried out by one person in order to obtain a higher level of consistency. Notice that there may be some incorrect selections or removals of points could have occurred. Such inaccuracies occur in ambiguous situations where it was not clear if there was forest or not, due to the manual selection of points and because no in situ inspections or terrain validations were performed. Since the selection process took about two months, several additional quick controls of the selected points were performed. As Flanders is about 1 362 500 m², this forest cover map indicates that 11.9% of Flanders is covered by forest. When examining the forest cover map in more detail, 3 "zones" with more forest can be distinguished; the Campine region, the forest complexes in Flemish Brabant and the region between Bruges and Ghent relatively speaking. The different estimated forest areas for each of the five provinces are given in Table 2. Notice that the forest cover area in Limburg has decreased between the two maps. This can be explained by the fact that a large area (800+ ha) was classified as forest in the previous version and this is now clearly an area of heathland in the military domain of Houthalen-Helchteren and Oudsbergen.
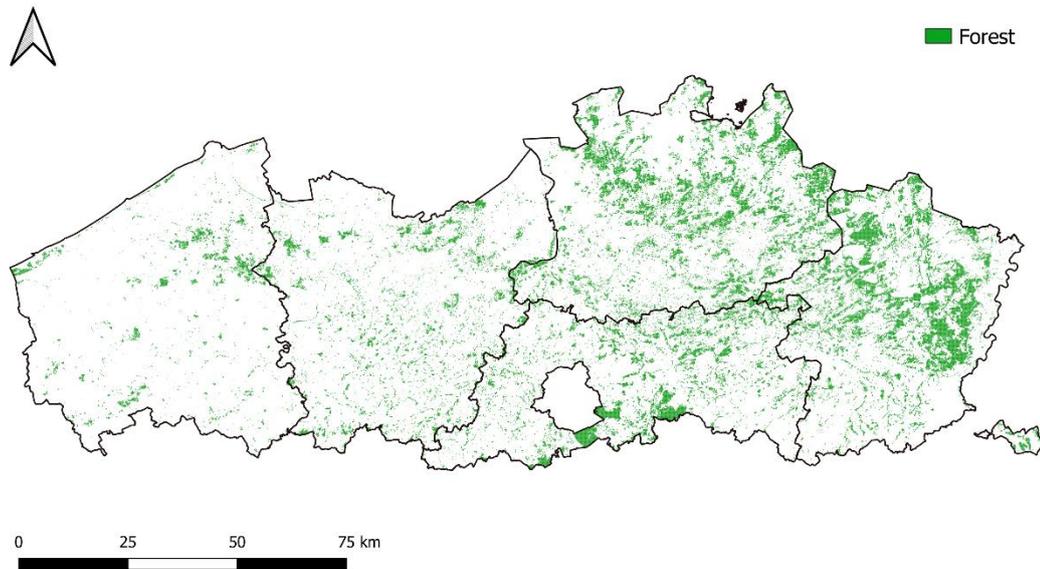
Figure 2: Biowood 2020 forest cover of map Flanders, indicating 162,703 ha of forest.

Table 2: Forest distribution in Flanders. This table shows the forest area in each province, according to the previous map, constructed in 2010, and the newly obtained forest map of 2020.

Province	Sim4Tree map 2010 (ha)	Sim4Tree map 2020 (ha)
West-Vlaanderen	8,220	10,277
Oost-Vlaanderen	17,540	20,780
Vlaams-Brabant	26,241	28,542
Limburg	52,307	51,505
Antwerpen	49,147	51,599
Total	153,455	162,703

It is important to compare the newly constructed forest cover map with existing maps to indicate it's strong- and weak points. The selected forest points of the new forest cover map of 2020 coincide for 82.5% with the forest points indicated by the "Boswijzer" of 2015. To compare both maps, the "Boswijzer" first needed to be transformed from a raster layer into a multi-point polygon. Therefore, the same initial 1 ha raster grid (100 m x 100 m) was used to sample the raster data on those centre points. The confusion matrix was calculated and given in Table 3. Overall, the accuracy of the new forest map with the "Boswijzer" reached 95.8%. Note that this new map has improved upon previous remarks on the forest guide, such as villa districts in forests but on the reverse also included smaller forest patches (but larger than 0.5 ha). Following a similar methodology, the comparison was made between the previous map used in Sim4Tree DDS and the new one. There 81.1% of the selected forest points coincides with the forest points indicated by the previous version. Again, a confusion matrix was calculated and given in Table 4. Overall, the accuracy of the new forest map with the old map reached 96.2%.

Two important comments should be made here. Note that the total number of hectares of forest for the new forest map differs somewhat between Table 3 and Table 4. This is because while comparing the raster layer of the "Boswijzer" with the new forest cover map

some boundaries were a bit differently located, causing some forest points to get a "NULL" value and therefore they could not be accounted for. The second comment is regarding the relatively high accuracy values. Although it reached twice about 96%, in practice this gives quite large differences, especially since there is little forest in Flanders as a few 100 ha to 1000 ha are making a big difference on ecological and political scale.

Table 3: Confusion matrix of the "Boswijzer" (2015) and the newly constructed forest cover map (2020)

	New forest map 2020		
Boswijzer 2015	**Forest points**	**No Forest points**	**Total**
Forest points	134,209	28,580	162,789
No Forest points	28,448	1,170,609	1,199,057
Total	162,657	1,199,189	1,361,846

Table 4: Confusion matrix of the previously used forest cover map in Sim4tree and the newly constructed map

	New forest map 2020		
Sim4Tree forest map	**Forest points**	**No Forest points**	**Total**
Forest points	132,000	21,484	153,484
No Forest points	30,703	1,177,659	1,208362
Total	162,703	1,199,143	1,361846

1.5   Further analysis

In this section a further analysis was performed. Because the new forest cover map (162,703 ha) differs quite significantly from the official statistics (140,279 ha) in Flanders, it seemed reasonable to investigate possible explanations for these differences. Some paths that were investigated are primarily technical differences between the two forest maps such as the resolution on which is worked but also the relative position of measuring points. In the next paragraphs, the sampling methods are further analysed and described.

1.5.1   Sampling unit resolution

An interesting hypothesis explaining differences in estimated/observed forest area could be the use of varying point sampling densities. It is expected that a lower sampling unit resolution, which corresponds with a coarser grid size, will be more variable and less accurate in the outcome than when using a smaller sampling grid. Stated in other words: the chance of correctly detecting forest is lower when using a coarser sampling grid. Therefore, a set of varying resolution sampling grids will be analysed. However, fluctuations in estimated forest cover are expected to decrease as the sampling grid becomes denser, resulting in a relatively constant forest area. In order to identify from which resolution the forest cover estimates become relatively accurate with small deviations, multiple sampling grids were created matching with the 1-hectare forest map of 2020. For the different sampling grids, the centre points were once again used as a control point to see if there was forest or not. To ensure that the different grids of varying sizes could be compared and to speed up the analysis, grids were chosen so that they were spatially coincided with the

extent of the 100 m x 100 m constructed forest cover map. Next, centre points were retained which coincide with forested points of the forest map, the other points were removed. An illustration of this procedure is given in Figure 3, as an example using a 500-meter grid size. The red points are indicating the centre points of the working grid, the dark green points are the forest points of the forest cover map and the light green points are the coinciding points that will be retained for further calculation.

Figure 4 illustrates the previously described method for multiple sample densities where the effect of an increasing sample density on the observed Flemish forest area is plotted. The grid sizes vary from a 20 km x 20 km resolution to a 100 m x 100 m resolution. The exact values underpinning the graph can be found in Appendix 1 where in the 'Forest area in %' column gives the ratio of the observed forest points to the total sample points in that resolution grid. Appendix 2 and 3 show the variable estimated forest cover averages and standard deviations resulting from the different sampling unit resolutions. Note that using a sampling unit resolution coarser than 5625 ha (or 7.5 km x 7.5 km) approximately returns an error of 8000 ha (or 5%) on the estimated total forest cover area, while using a sampling unit resolution of 64 ha (or 800 m x 800 m) approximately returns an error of 1500 ha (or 1%). Figure 5 provides a closer look at the higher sample densities where the grid size of 50 ha (1 km x 0.5 km) corresponds to the sampling resolution used in the Flemish Forest Inventory.
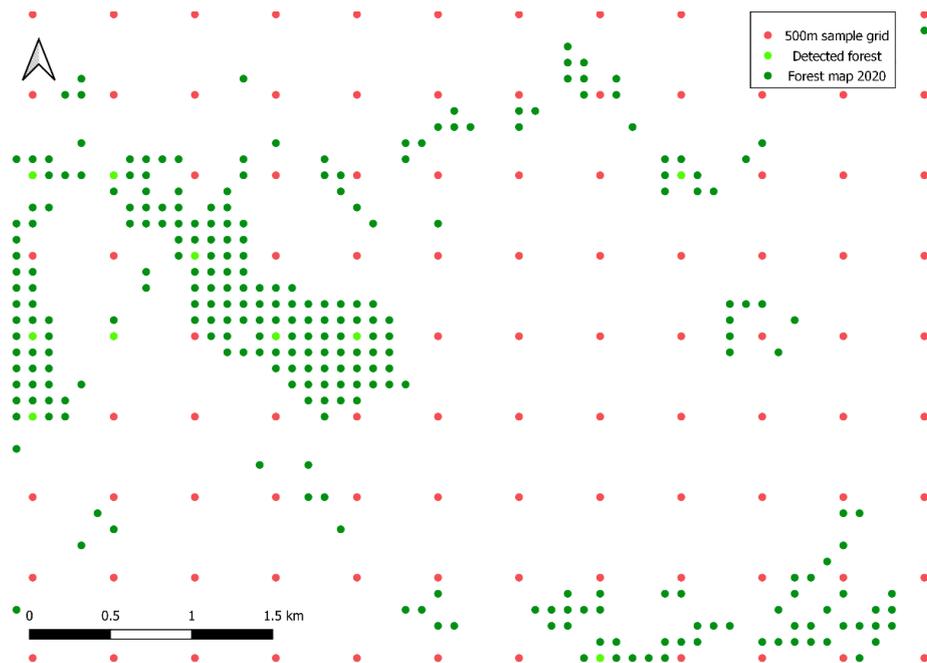
Figure 3: Sampling unit resolution example. The dark green dots (100 m x 100 m resolution) in this figure correspond to the observed forest of the forest map of 2020. The red and light green dots indicate a hypothetical sampling grid of 500 m by 500 m whereby the light green point locations indicate an intersection with the forest cover map. The sum of all the green dots over the whole of Flanders constitutes in turn the estimated forest cover area using a 25 ha resolution sampling grid. Note that this figure represents a relatively small area and serves purely for illustrative purposes, consequently no spatial boundaries are shown
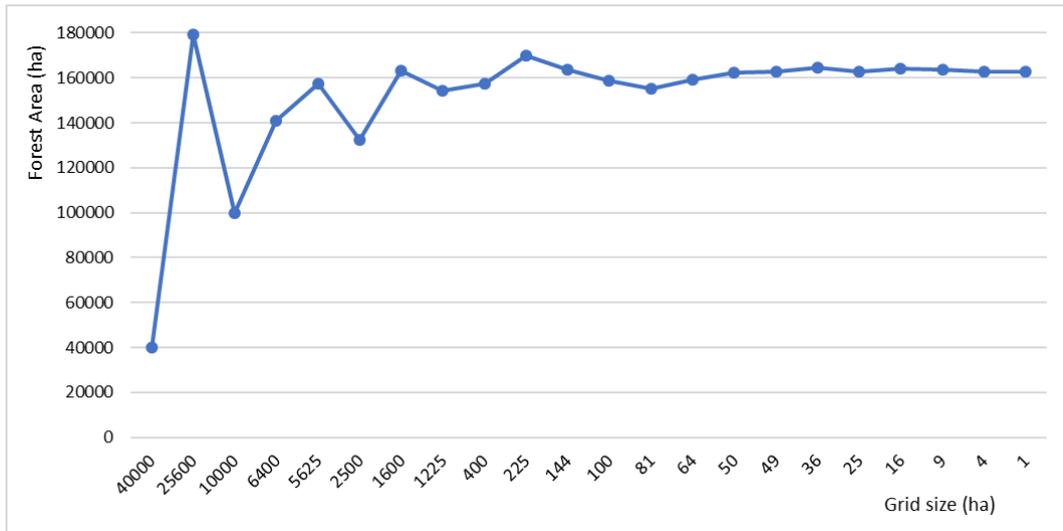
Figure 4: Effect of sampling unit resolution on the estimated forest area (ha) where a finer resolution or smaller sampling unit results in an increase in the number of sampling points. This figure shows all studied sampling unit resolutions. Because large variation of forest area for the low resolution grids a next figure is given where only the forest area for the smaller sampling unit resolution, starting from one km² till one hectare is displayed. As a result, the scale of the y axis could be reduced to highlight the smaller variations
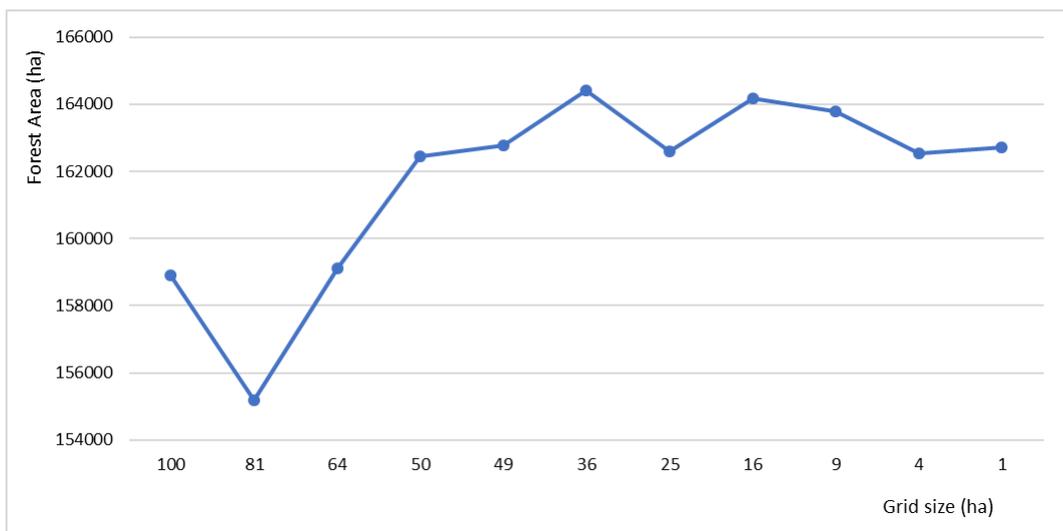
Figure 5: Effect of the sampling unit resolution on the estimated forest area, from a km² grid to a hectare grid where a finer resolution or smaller sampling unit results in an increase in the amount of sampling points.

1.5.2 Sampling strategy

Another potentially interesting factor that was investigated is the use of a random point sampling strategy instead of the systematic sampling of a regular grid. The number of sample points from the Flemish forest inventory, 27,236 points, were used here as an example. These points were randomly chosen on a one-hectare grid and this was replicated ten times. Selected points were counted if coinciding with forest points on the forest map. The resulting forest cover estimations are given in Figure 6 which resulted in an average of 163,115 ha forest cover and a standard deviation of 2634 ha.

When spatially comparing the newly obtained forest map of 2020 with the forest points of the forest inventory, a displacement was noticed. To investigate if a specific location of a sampling grid influences the observed forest cover, another experiment was set up.

To accommodate the spatial offset in the coordinates of the measured points from the Flemish forest inventory and the new constructed forest cover map, a 1000 m x 500 m point grid was created. This grid was subsequently moved each time 100 m over the x-axis and to subsequently also move along the y-axis matching the 1-hectare grid of the forest cover map. Points intersecting with this forest map were selected. The resulting 50 point layers are given in Figure 7. An average forest area of 162,892 ha with a standard deviation of 1988 ha was found. The coordinates of the 49th point grid are spatially located the closest to those of the forest inventory (about 20 m difference), resulting in an estimated 164,100 ha of forest.
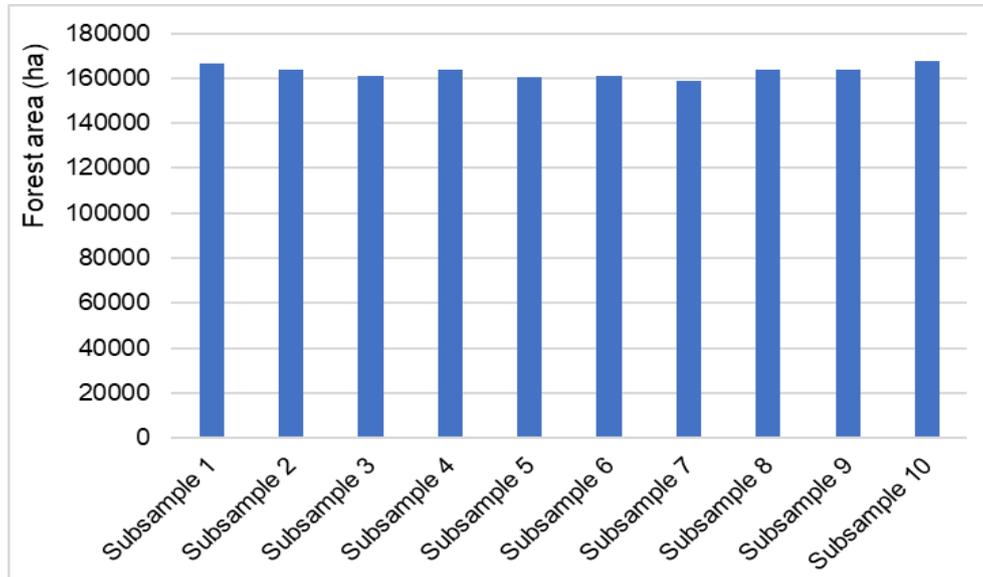
Figure 6: Effect of random sampling 27,236 points. This resulted in an average forest cover estimation of 163,115 ha. The minimum and maximum deviating values were observed in subsample 7 and 10, which varies about 4500 ha or 2.8% from the average value.
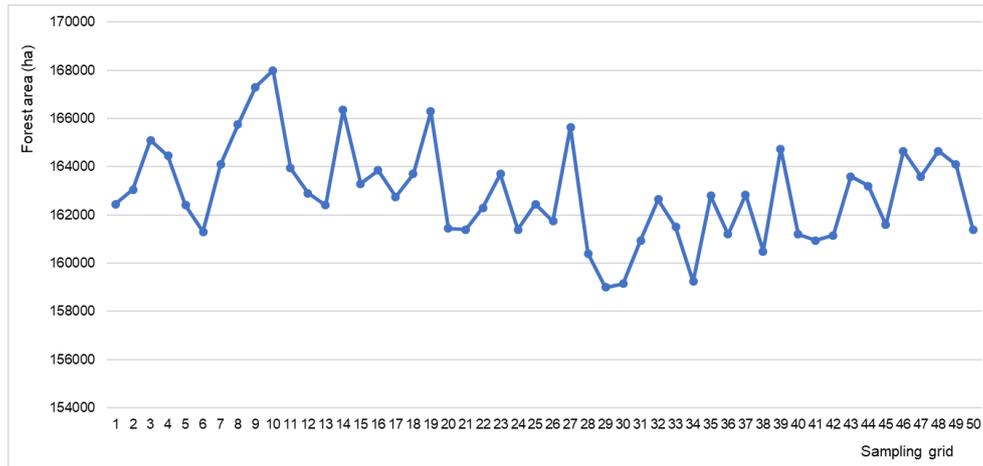
Figure 7: The effect of moving centre points of a 1000 m x 500 m grid over the one-hectare sample grid. This figure illustrates the effect of choosing a specific location for a larger grid size on the detected forest cover in Flanders. The used resolution grid corresponds to the 50 hectare sampling grid of the Flemish forest inventory. The minimum deviating value was observed in sampling grid 29, which varies about 3900 ha or 2.4% from the average value. The maximum deviating value was observed in sampling grid 10, which varies about 5100 ha or 3.1% from the average value

Remarkably, different mapping techniques result in relatively large differences in estimated forest area by using fairly similar forest definitions. Especially if the official forest statistics of Flanders (140,279 ha) is compared with the Copernicus forest map of 2018 (236,082 ha).

The previous exploratory analysis indicates that, as expected, different sampling techniques will lead to different estimations with varying accuracy, especially when using coarse grid sizes. However, even when the outermost measurements of both sampling density and the coordinate displacement are obtained, it cannot be confirmed that those are the most important variables explaining the large difference in the observed forest area in the grand order of 20,000 ha between the Flemish forest inventory and the newly designed forest map.

To explain the difference between the Flemish forest statistics and the new forest cover map, rather two alternative factors have to be taken into account. On the one hand there is a dissimilarity between the time scales used for the Flemish forest inventory (continuous recording of the situation 2009-2019) and de new forest cover map (snapshot of the situation in 2020). On the other hand, there is a fundamental difference between the concept of "forest" as a type of land use and "forest" as a land cover type. This distinction of concepts also expresses itself in the interpretation and application of the "forest" definition and associated dimensions. For example, the observed area of forest, which occurs on land labelled as land-use class forest, will often signifiable differ compared to the forest area including all the "forest" elements that meet the definition but also occur on all land use types such as (large) gardens, agricultural areas or public/private areas.

Besides a tree/forest canopy can extend beyond the footprint of the land use polygon, if not restricted, covering a larger area than the land-use map would indicate. This is however not measurable through land use maps as if this area was included, the total area would no longer be correct due to double counting with for example agriculture lands. This effect becomes particularly important when there are relatively many transitions between forest

and other land use types, so called forest edges which occur frequently in a fragmented landscape. As Flanders' forest area is very fragmented, with relatively few large forest complexes a lot of these edge effects could occur. In addition to this, Flanders is a very poorly wooded region, which means that including or excluding small fragments of forest have a significant effect on the total area of forest detected.

For this research project it is important to estimate the forest cover instead of the forest land-use in order to obtain estimates of the current and future available biomass as previously described situations will also produce significant amounts of biomass. However, for a more general use, it is important to use multiple sources and to communicate clearly on which sources are used when discussing forest area in Flanders. Depending on the situation, one or a combinations of forest maps will be the most suitable (Quataert et al., 2019).

2   Species and age allocation

2.1   Previous land use map

To each forest point a tree species, an age class (reference year 2010) and a soil type was assigned based on spatial overlays with the forest reference layer 2000 (Agentschap Natuur en Bos, 2000). Other attributes assigned were ecoregion, forest management group and owner category. The complete initialization process of the input map is described by Borremans et al. (2014). An update of the land use map was performed with the release of version 2.7. The species and age distribution were corrected, based on the first results from the second Flemish forest inventory. It is noted that the map is a generalization of earlier mapping results and the obtained results of Sim4Tree should be interpreted at a larger scale (e.g. provincial scale), not at an individual pixel level.

2.2   New land use map

The new land cover map delineates forests in Flanders in the year 2020. Knowing where forests is located is one side of the story, the other side is knowing what this forest looks like. Therefore, the new land cover map had to be initialized again, accounting for species and age distribution changes. The initialization process is described in this section. Each forest point was assigned one species and one age class and represents a homogenous even-aged stand of 1 ha.

The first step consisted in comparing the species-age distribution, based on basal area, of Sim4Tree version 2.1 (pre-update of the land use map with the release of version 2.7) to the distribution of the complete second Flemish forest inventory (VBI2). Figure 8 shows the overall species distribution in Flanders according to Sim4Tree and VBI2. Overall the proportional distribution across species remains similar. Common species in the land cover map of 2010 remain common in the VBI2, with Scots pine (*Pinus sylvestris*) being the species most present in Flemish forests.
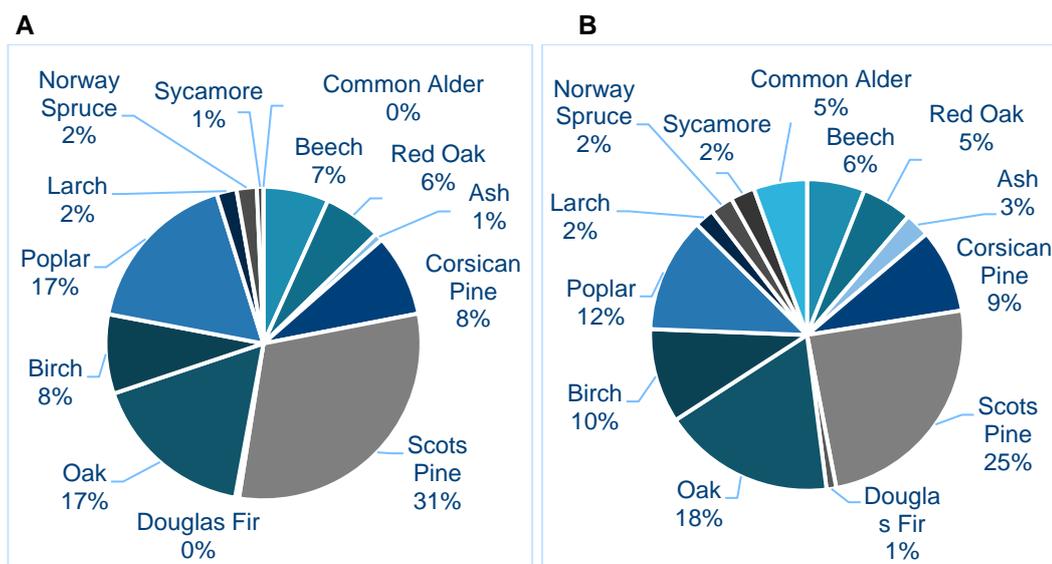
Figure 8: The species distribution across the forests in Flanders according to (A) Sim4Tree and (B) the second Flemish forest inventory.

A more detailed overview of the species distribution of both Sim4Tree and VBI2 are given in Appendix 2-6, representing the results per province. The level of detail is retained at the province level due to the interpretational limitations of Sim4Tree. As Sim4Tree works with homogenous, even-aged monocultures, only general statements can be made.

The main species per province are Scots pine (Antwerp, Limburg), poplar (*Populus sp.*) and oak (*Quercus robur* & *Quercus petraea*) (East-Flanders, West-Flanders) and poplar, oak and beech (*Fagus sylvatica*) (Flemish Brabant). The largest shift is observed in the province of Antwerp for areas which do not belong to the Flemish Ecological Network (FEN), where Scots pine accounts for 46% of the basal area in the old land cover map compared to 33% in VBI2.

The differences between VBI2 and Sim4Tree cannot solely be attributed to changes in species distribution. The first additional factor that partly explains the discrepancies between VBI2 and Sim4Tree is the methodology of creation. VBI2 is based on measurements in the field, while Sim4Tree was created through the bosreferentielaag 2000. The second factor is the choice of species included in Sim4Tree. Common alder was not included in Sim4Tree v2.1, but later on included during the update of version 2.7. In the initialization process of the new land cover map common alder was included, resulting in a shift in species distribution between Sim4Tree and VBI2 for all regions.

Besides changes in species distribution, shifts between age classes can occur due to e.g. management. It is expected that the age classes have moved up one class between Sim4Tree (reference of 2010) and VBI2 (taken as reference of 2020) as trees have aged. To account for this aging effect, the stand age recorded in Sim4Tree is increased with 10 years to make the distribution comparable to VBI2. Therefore, the youngest age class (10 years) is not present in the adjusted Sim4Tree distribution. Overall the distributions of VBI2 and Sim4Tree match quite well, however some general discrepancies exist. The older age classes are overrepresented in Sim4Tree, while the younger age classes are underrepresented compared to VBI2. A more detailed overview of the age distributions per province are provided in Appendix 2-6.
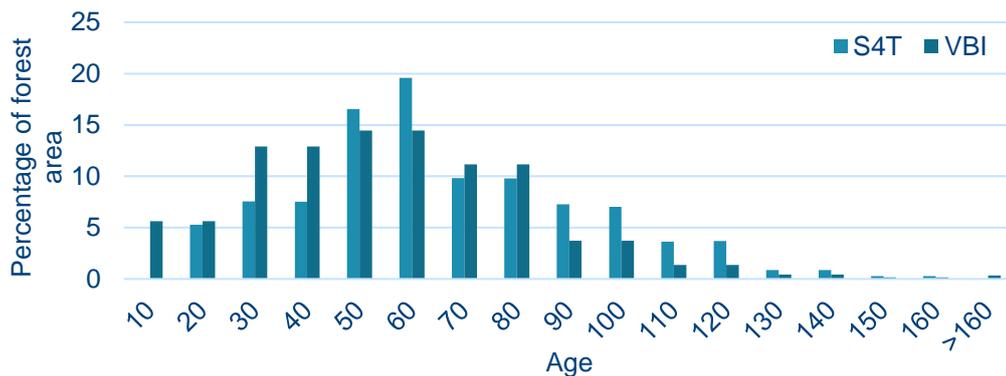
Figure 9: The age distribution across species of Sim4Tree and VBI2 for forests in Flanders expressed as the fraction of the total forest area per age class.

The shifts in age class distribution could partly be explained by the way the species distribution was handled (see above). An additional explanation of the changes could be management interventions which have occurred since the creation of Sim4Tree, such as a final harvest followed by regeneration. Adding 10 years to the stand age without assuming management, could explain the lack of young 10-year old stands. A last explanation is the fact that Sim4Tree works with homogenous even-aged stands. Each stand receives an age class, while the second Flemish forest inventory also allows the age to be defined as uneven-aged or unknown. To be comparable to Sim4Tree, these measured plots were distributed proportionally across the age distribution of VBI2, possibly introduction errors.

The found mismatches between VBI2 and Sim4Tree v2.1 indicate that corrections on species-age distribution are necessary. To update species-age distributions, an initial Sim4Tree map with reference year 2020 was created. The attributes of species and age were taken from the original Sim4Tree layer if the point was still considered forest in 2020. The age classes of the Sim4Tree layer (reference year 2010) were corrected by 10 years to account for the new reference year 2020. This preliminary map was then used to create correction tables, one for each province. An additional distinction was made between "present in Flemish ecological network" (FEN) and "not present in Flemish ecological network" (NFEN) based on the dataset by Agentschap Natuur en Bos (2016). The correction tables contain the amount of hectares, and thus the number of points, that need to be added to or removed from a species-age class for the distribution to match with that of VBI2 at the provincial level.

The implementation of the detected corrections was performed through two separate iterations. The first iteration corrected the share of species across the age classes. These adaptations followed a specific set of rules determined through four possibilities, which are described more in detail in Figure 1010. Four cases can be defined in the age class distribution, when comparing two adjacent age classes:

1. There are too many pixels in Sim4Tree compared to VBI2 for both age classes. The excess points of the older age class are randomly removed. These points could have been deforested, have experienced a species change or have regenerated after a final cut. The removed points are kept aside to fill in the gaps of age class 10 (possible regeneration after harvest).
2. There are too little pixels in Sim4Tree compared to VBI2 for both age classes. Points, which have no age or species attributes yet, are randomly selected and assigned to the older age class.

3. The older age class has an excess of points, while the younger age class has too few points. In this case, there might be an issue with age estimation for a species. Points are randomly selected from the older age class with excess points to compensate for the missing points in the younger age class. The species remains the same, while the age is changed.

4. The younger age class has an excess of points, while the older age class has too little points. In this case, there might be an issue with age estimation within a species. Points are randomly selected from the younger age class with excess points to compensate for the missing points in the older age class. The species remains the same, while the age is changed.
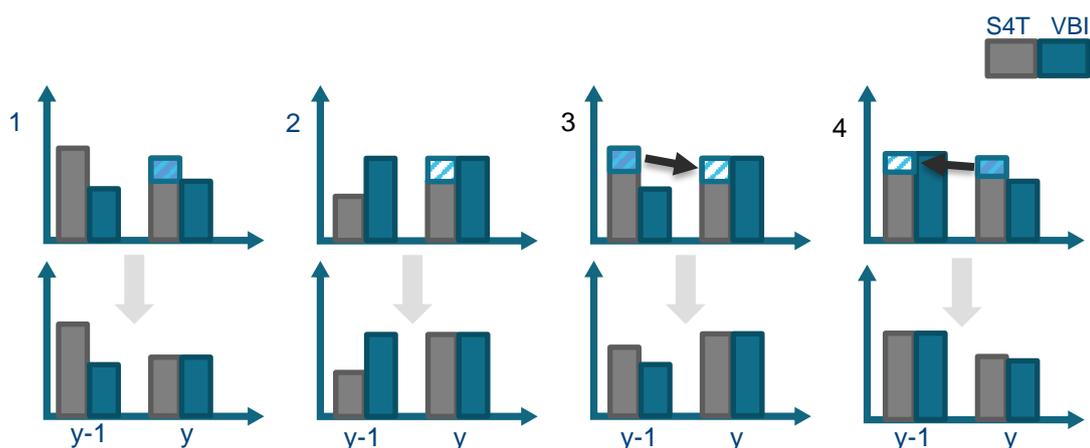
Figure 10: The graphs represent four different options which can occur when comparing the age class distribution of Sim4Tree to VBI2 for a specific species. By applying these rules, each point receives a species and age attribute. The final distribution than matches that of VBI2. In each situation an older age class (y, age class of adaptation) is compared to a younger age class (y-1).

The second iteration accounts for the differences in soil requirements that exist between certain species. Through the use of the BOBO forest site suitability tool by INBO (De Vos, 2000) each soil type and species combination receives a score of stand suitability (1 = very good suitability, 5 = very poor suitability). The goal of the iteration is to reduce the total score of the stand suitability to a minimum, meaning overall soil suitability is maximised. The idea behind this is that species are planted on the most suitable soils, resulting in overall good growth conditions. In reality this is not always the case, as other factors influence species choice as well. Therefore, the resulting map is only an approximation of reality.

After assigning the species and age, several additional attributes were assigned to the forest points. The attributes added were soil type, ecoregion, province, management region, forest group, owner information, conservation objectives (IHD), Flemish ecological network (FEN) and climate zone. The data sources are:

- Ecodistricten en Ecoregio's (Instituut voor Natuur- en bosonderzoek, 2002) *
- Digitale bodemkaart van het Vlaams Gewest: bodemtypes (Vlaamse Overheid Departement Omgeving, 2017) *
- Beheerregio's **
- Patrimonium of Agentschap Natuur en Bos **
- Habitatrichtlijn(deel)gebieden (Agentschap voor Natuur en Bos, 2013) *
- Gebieden van het VEN en het IVON (Agentschap voor Natuur en Bos, 2015) *

- Klimaatzones ***

* Available through Geopunt Vlaanderen
** Obtained through personal communication with Agentschap Natuur en Bos (ANB)
*** The climate zones were obtained from a previous Biowood deliverable (scaling factors).

2.3   Resulting forest map

With previous specifications on tree species distribution, age classes and other location dependent parameters the forest map illustrated in Figure 2 is now completely updated and will be implemented into the Sim4Tree software.

As a concluding illustration of the forests in Flanders, a distinction was be made between broadleaf and deciduous species and shown in Figure 11. Note that in this research homogeneous stands of 1 ha are used since Sim4Tree is not able to process species mixtures in the 1 ha stands on the scale of Flanders. No mixtures are indicated on this map, however neighbouring stands of different tree species can approximate or reflect mixed forest slightly.
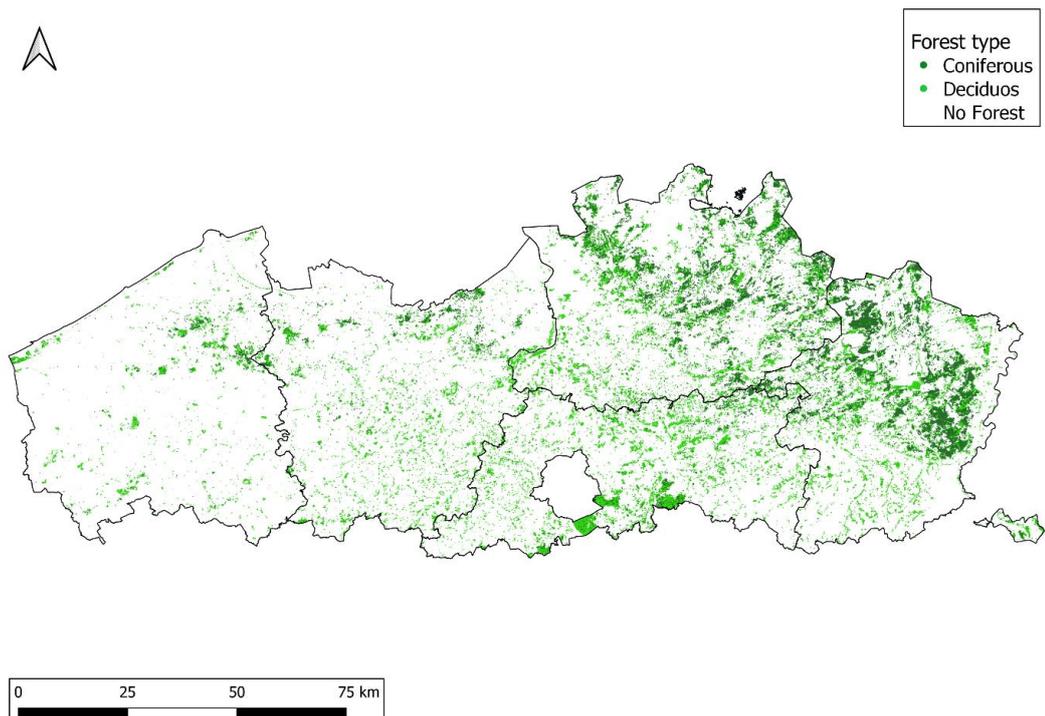
Figure 11: Forest map of Flanders 2020, indicating two groups of species, coniferous and deciduous

3   Summary

The previous forest map was used as a base layer in Sim4Tree and represented the Flemish forests distribution for the year 2010. However, an update of the forest map was required to improve the accuracy of simulations executed by the program. The construction of a new forest map was performed by manually selecting centre points on a 1-hectare grid covering Flanders. Forest points were selected while analysing a combination of information sources. As a starting point, Google Earth images (an orthophotographic satellite imagery) were used to obtain a visual representation of the landscape. To decide whether a point was selected as forest or excluded from the layer multiple other maps were combined to support the decision. Examples of the supporting data are the Flemish land use map of 2016, the "Boswijzer" of 2015, the high green map of 2015 and so on. These forest points comply with the forest definition as described in section 1.1 of this report. The subsequential selection of forest points resulted in a map, indicating 162,703 hectares of forest.

A remarkable finding was that different methods to construct forest maps may lead to large differences in estimated forest cover area. Multiple factors are thereby influencing the outcome. Here the effects of using different sampling techniques were analysed. Using different sampling densities (grid sizes) influenced the estimated forest cover, especially at low sampling density. Furthermore, there was an effect of the specific location of sample point and grid type (random point selection – regular point grid) on the estimated forest cover. However, these effects are too small to explain the large difference in the observed forest area between for example the Flemish forest inventory and the newly designed forest cover map.

After the selection of the forest points, the new forest cover map needed to be initialized again in order to be usable by the Sim4Tree tool. In this initializing process several attributes such as management region and owner category were assigned to the forest points. The most important step was the allocation of the species and age class to the forest points. The species-age class allocation was done to comply with the species-age class distribution within provinces, based on the second Flemish forest inventory. This initialisation step was realized by two iterative processes: (i) age correction and (ii) species preferences for stand conditions. The result of the iterations was a fully initialized forest map at a resolution of 1 hectare and covering a total of 162,703 hectares, ready for implementation in Sim4Tree.

4   Acknowledgements

5 References

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Appendix

Appendix 1: Absolute and relative forest area, number of surveyed forest points as a function of grid size.

Grid size (m x m)	Grid size (ha)	Total amount of sample points	Forest sample points	Forest area (ha)	Forest area in %
20,000 x 20,000	40,000	36	1	40,000	2.78%
16,000 x 16,000	25,600	54	7	179,200	12.96%
10,000 x 10,000	10,000	133	10	100,000	7.52%
8,000 x 8,000	6,400	215	22	140,800	10.23%
7,500 x 7,500	5,625	238	28	157,500	11.76%
5,000 x 5,000	2,500	541	53	132,500	9.80%
4,000 x 4,000	1,600	850	102	163,200	12.00%
3,500 x 3,500	1,225	1,112	126	154,350	11.33%
2,000 x 2,000	400	3,404	394	157,600	11.57%
1,500 x 1,500	225	6,053	756	170,100	12.49%
1,200 x 1,200	144	9,460	1,138	163,872	12.03%
1,000 x 1,000	100	13,614	1,589	158,900	11.67%
900 x 900	81	16,806	1,916	155,196	11.40%
800 x 800	64	21,290	2,486	159,104	11.68%
1,000 x 500	50	27,236	3,249	162,450	11.93%
700 x 700	49	27,801	3,322	162,778	11.95%
600 x 600	36	37,857	4,567	164,412	12.06%
500 x 500	25	54,485	6,504	162,600	11.94%
400 x 400	16	85,148	10,261	164,176	12.05%
300 x 300	9	151,370	18,200	163,800	12.02%
200 x 200	4	340,586	40,635	162,540	11.93%
100 x 100	1	1,362,425	162,703	162,703	11.94%

Appendix 2: Moving average of the different sampling unit resolution forest cover estimations with additional standard deviation. For each step on the x-axis an average and standard deviation of the corresponding value and the following smaller grid sizes is computed.
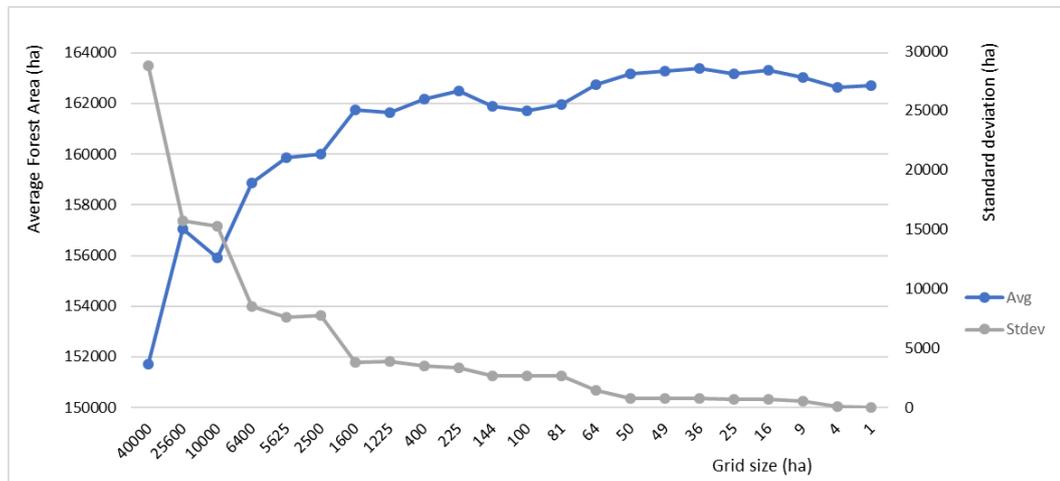
Appendix 3: Values underpinning the graph in Appendix 2. Note that using a sampling unit resolution smaller than 5625 ha (or 7.5km x 7.5km) returns an approximate error of 8000 ha (or 5%) on the estimated forest cover, while a sampling unit resolution of 64 ha (or 800m x 800m) returns an approximate error of 1500 ha (or 1%) on the estimated forest cover

Grid size (ha)	Avg	Stdev	Grid size (ha)	Avg	Stdev
40,000	151,717	28,815	100	161,696	2,680
25,600	157,037	15,722	81	161,976	2,654
10,000	155,929	15,289	64	162,729	1,466
6,400	158,873	8,530	50	163,182	755
5,625	159,877	7,593	49	163,287	751
2,500	160,017	7,791	36	163,372	780
1,600	161,736	3,770	25	163,164	685
1,225	161,639	3,874	16	163,305	698
400	162,159	3,466	9	163,014	560
225	162,510	3,349	4	162,622	82
144	161,878	2,636	1	162,703	0

Appendix 4: Area share of species and age classes for the province of Antwerp. An additional distinction was made between pixels within the Flemish ecological network (FEN) and pixels outside of the FEN area (NFEN). (A) The tree species distribution of Sim4Tree – FEN areas. (B) The tree species distribution of VBI2 – FEN areas. (C) The tree species distribution of Sim4Tree – NFEN areas. (D) The tree species distribution of VBI2 – NFEN areas. (E) The age distribution of FEN areas of both Sim4Tree and VBI2. (F) The age distribution of NFEN areas of both Sim4Tree and VBI2.

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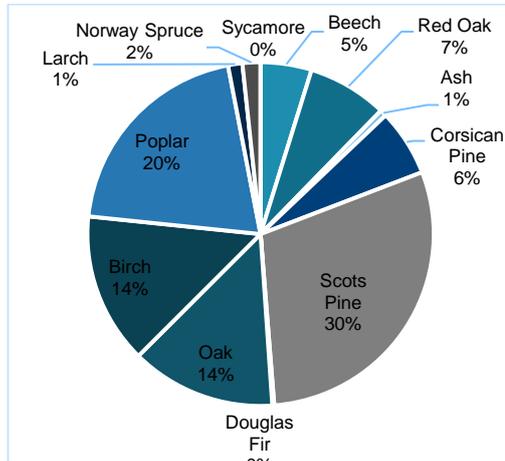
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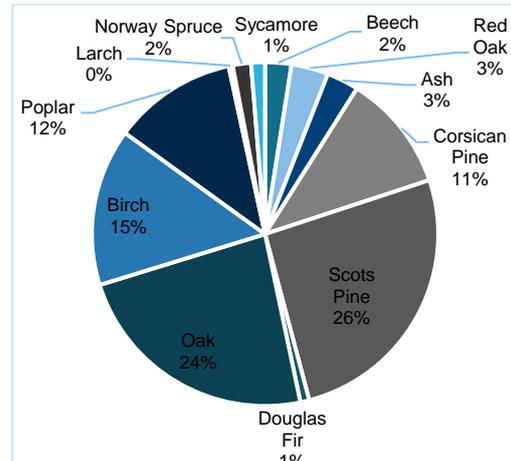
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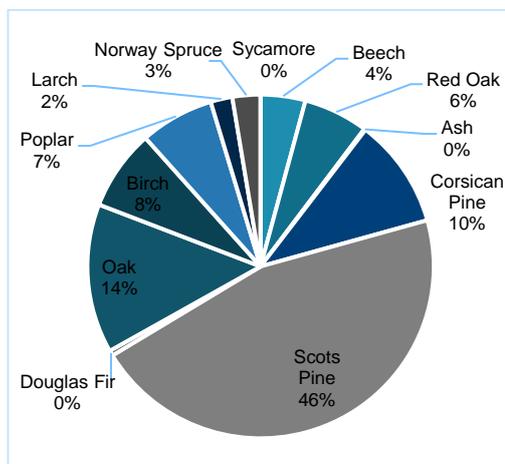
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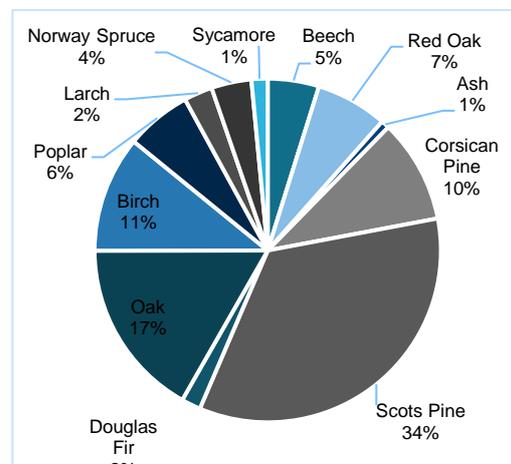
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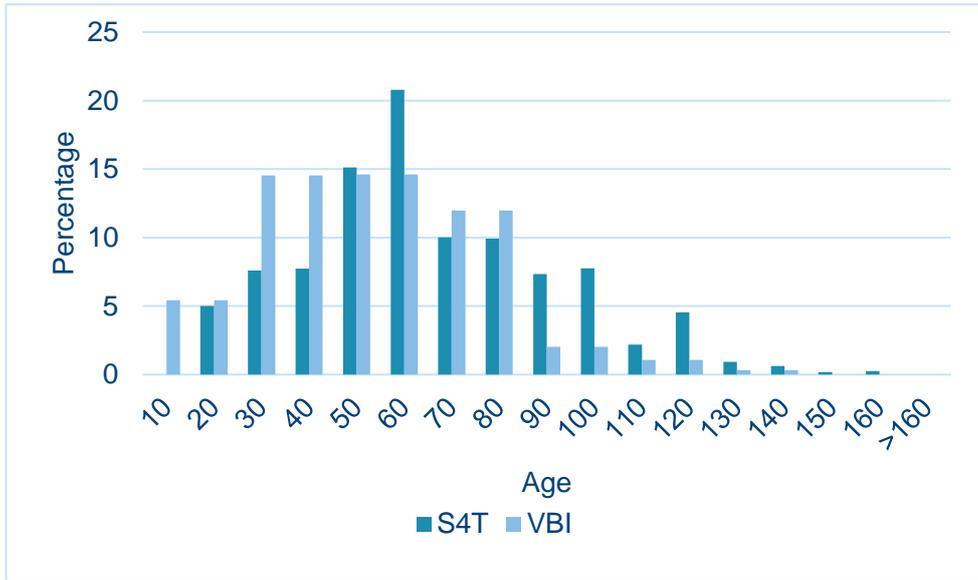
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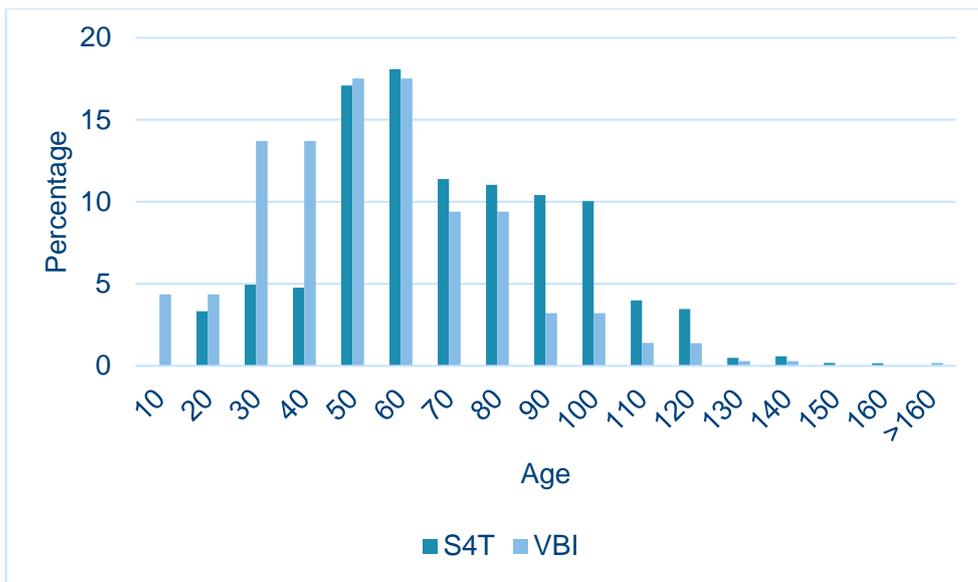
Appendix 5: Area share of species and age classes in the province of Limburg. An additional distinction was made between pixels within the Flemish ecological network (FEN) and pixels outside of the FEN area (NFEN). (A) The tree species distribution of Sim4Tree – FEN areas. (B) The tree species distribution of VBl2 – FEN areas. (C) The tree species distribution of Sim4Tree – NFEN areas. (D) The tree species distribution of VBl2 – NFEN areas. (E) The age distribution of FEN areas of both Sim4Tree and VBl2. (F) The age distribution of NFEN areas of both Sim4Tree and VBl2.

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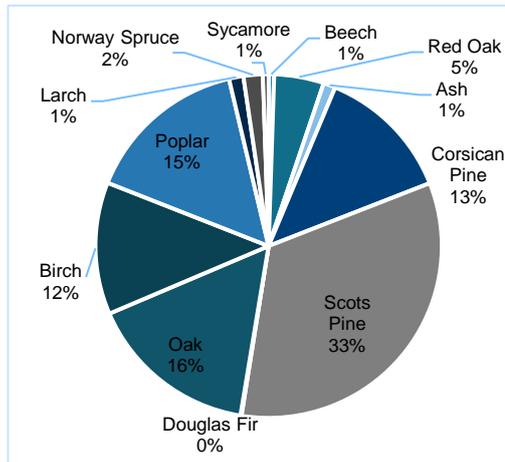
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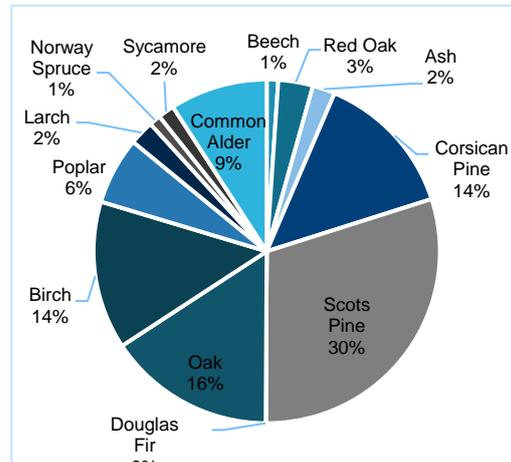
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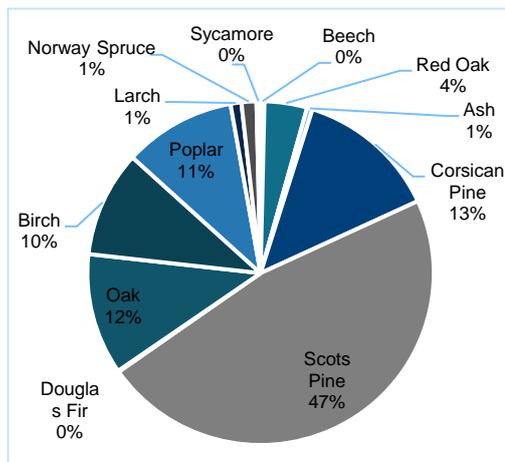
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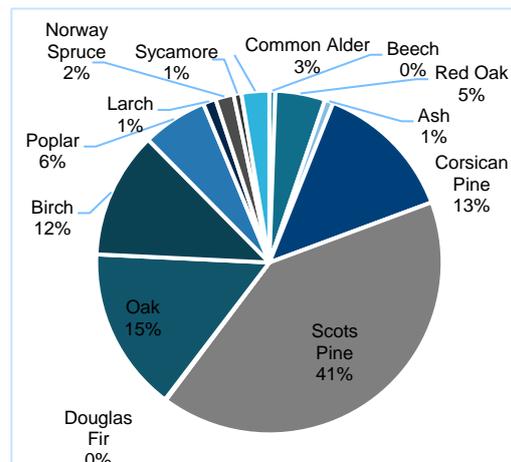
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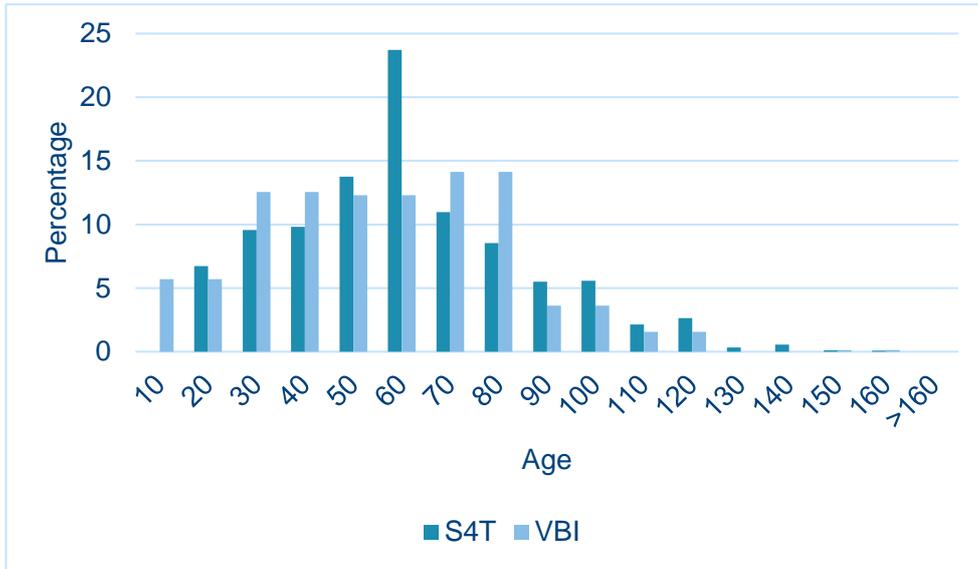
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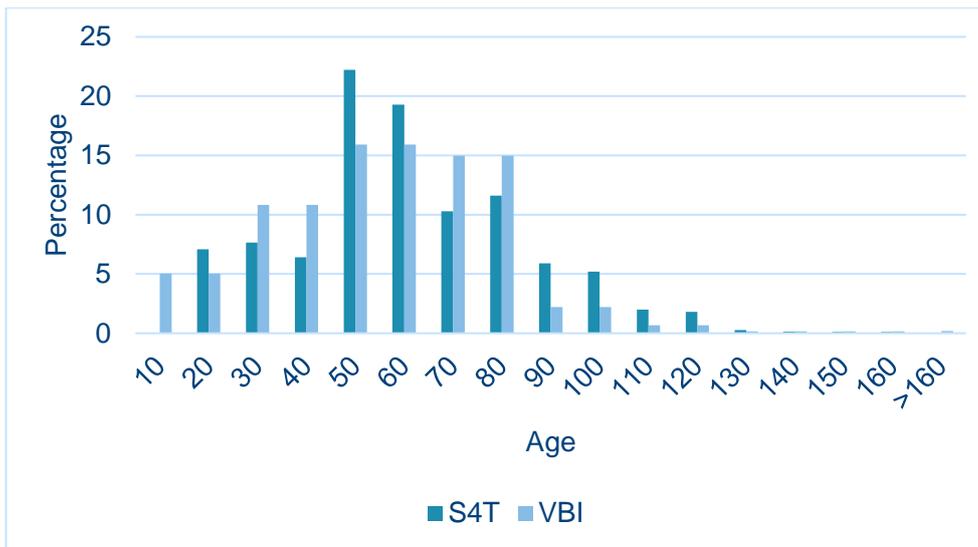
Appendix 6: Area share of species and age classes in the province of East-Flanders. An additional distinction was made between pixels within the Flemish ecological network (FEN) and pixels outside of the FEN area (NFEN). (A) The tree species distribution of Sim4Tree – FEN areas. (B) The tree species distribution of VBI2 – FEN areas. (C) The tree species distribution of Sim4Tree – NFEN areas. (D) The tree species distribution of VBI2 – NFEN areas. (E) The age distribution of FEN areas of both Sim4Tree and VBI2. (F) The age distribution of NFEN areas of both Sim4Tree and VBI2.

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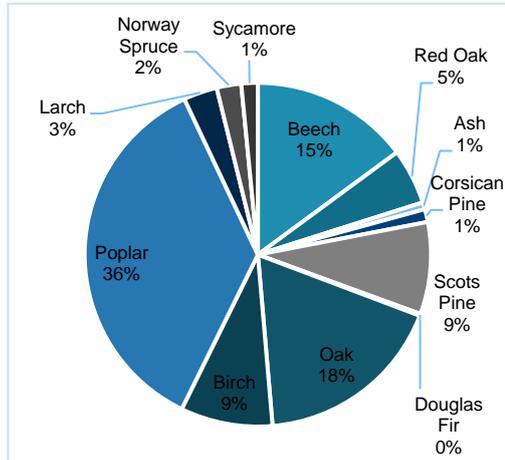
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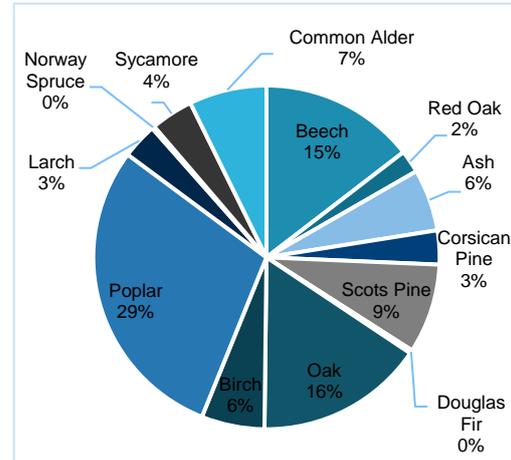
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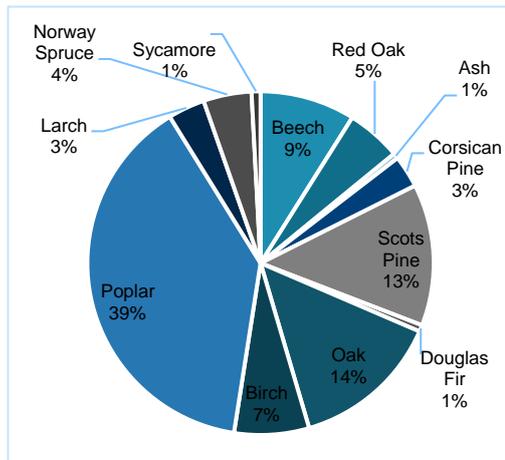
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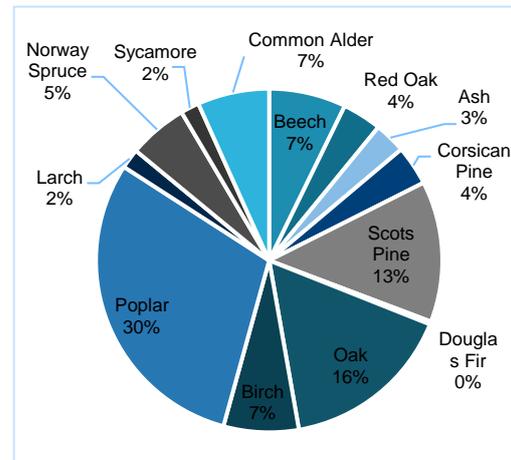
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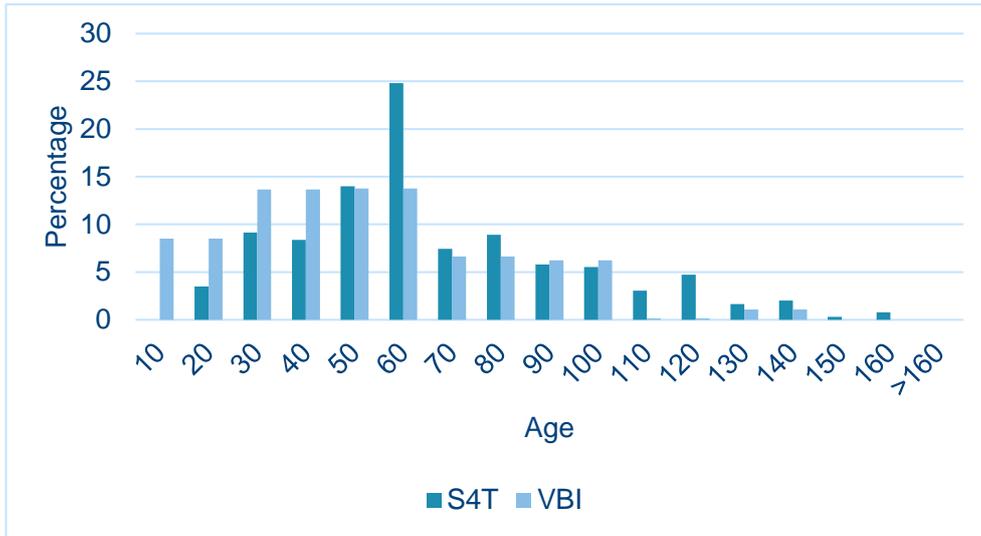
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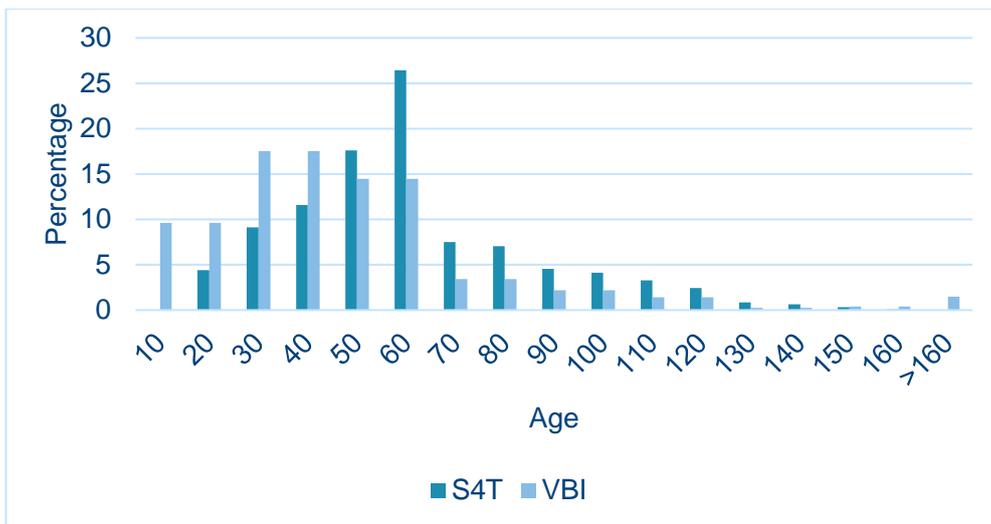
Appendix 7: Area share of species and age classes in the province of Flemish Brabant. An additional distinction was made between pixels within the Flemish ecological network (FEN) and pixels outside of the FEN area (NFEN). (A) The tree species distribution of Sim4Tree – FEN areas. (B) The tree species distribution of VBI2 – FEN areas. (C) The tree species distribution of Sim4Tree – NFEN areas. (D) The tree species distribution of VBI2 – NFEN areas. (E) The age distribution of FEN areas of both Sim4Tree and VBI2. (F) The age distribution of NFEN areas of both Sim4Tree and VBI2.

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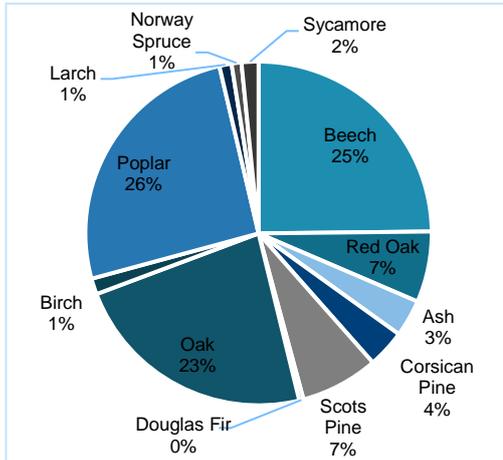
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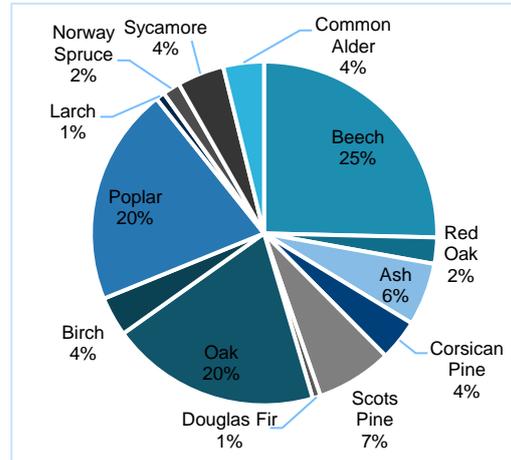
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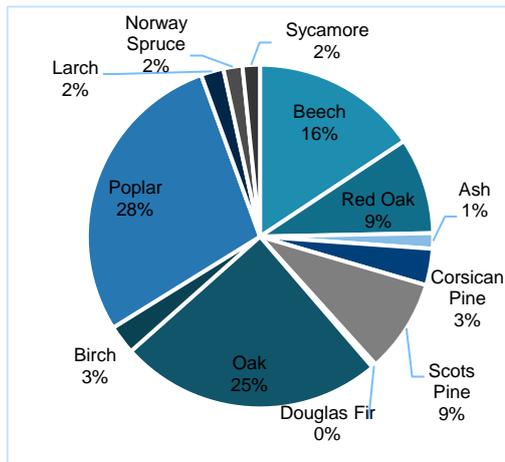
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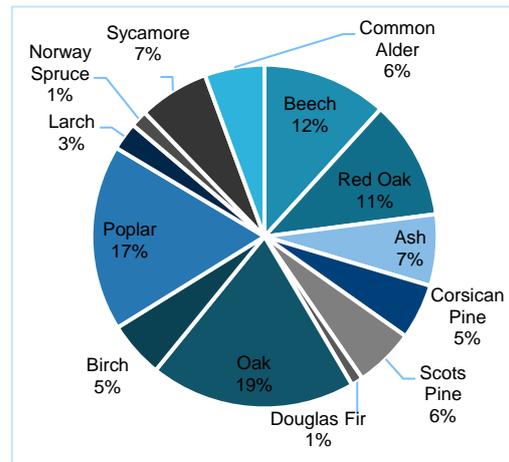
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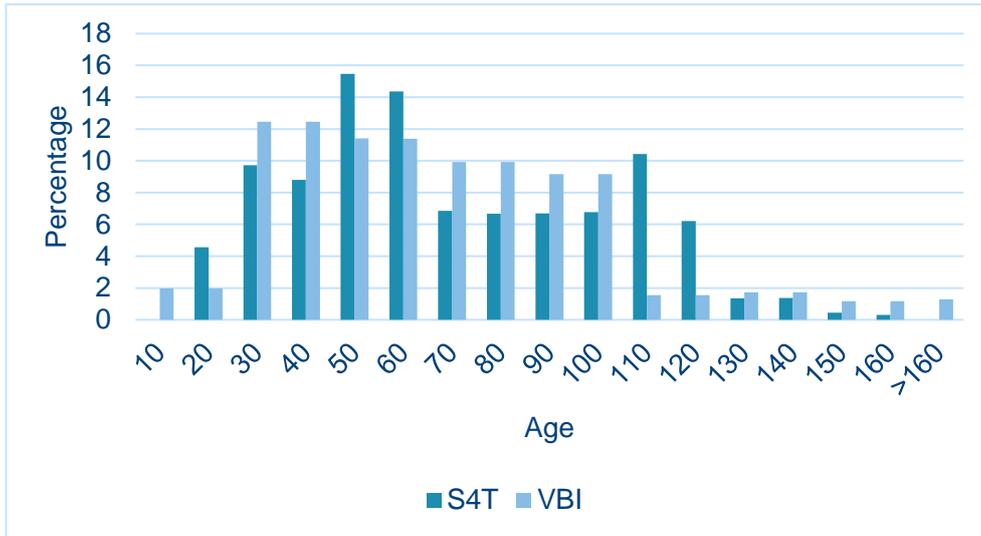
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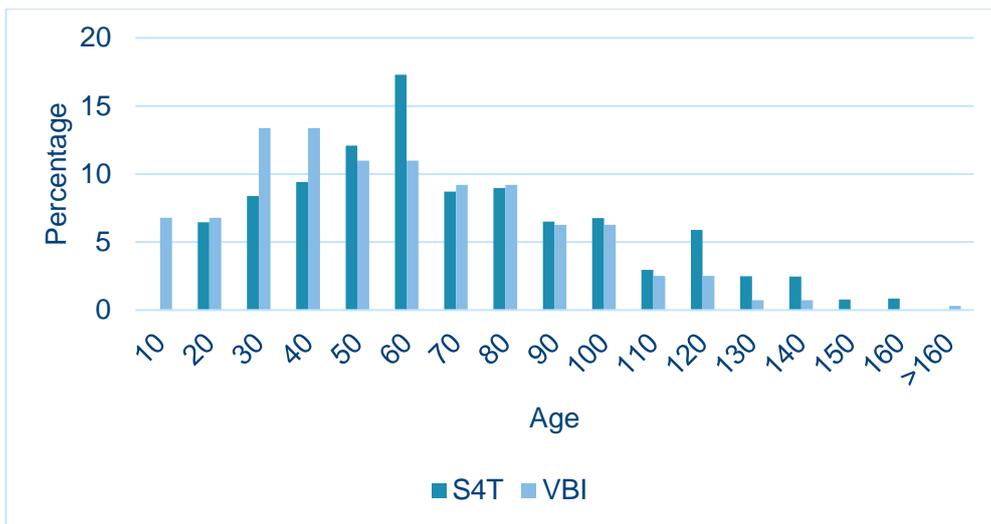
Appendix 8: Area share of species and age classes in the province of West-Flanders. An additional distinction was made between pixels within the Flemish ecological network (FEN) and pixels outside of the FEN area (NFEN). (A) The tree species distribution of Sim4Tree – FEN areas. (B) The tree species distribution of VBI2 – FEN areas. (C) The tree species distribution of Sim4Tree – NFEN areas. (D) The tree species distribution of VBI2 – NFEN areas. (E) The age distribution of FEN areas of both Sim4Tree and VBI2. (F) The age distribution of NFEN areas of both Sim4Tree and VBI2.

A

Norway Spruce 2%
Sycamore 3%
Beech 6%
Larch 9%
Red Oak 10%
Ash 1%
Corsican Pine 4%
Poplar 12%
Scots Pine 15%
Birch 7%
Oak 29%
Douglas Fir 2%

B

Sycamore 10%
Common Alder 2%
Red Oak 1%
Ash 1%
Norway Spruce 0%
Beech 7%
Corsican Pine 2%
Larch 3%
Scots Pine 18%
Poplar 10%
Birch 10%
Douglas Fir 7%
Oak 29%

C

Norway Spruce 2%
Sycamore 1%
Beech 8%
Red Oak 8%
Larch 6%
Ash 0%
Poplar 9%
Corsican Pine 5%
Birch 7%
Scots Pine 9%
Oak 43%
Douglas Fir 2%

D

Sycamore 5%
Common Alder 1%
Beech 4%
Red Oak 7%
Norway Spruce 3%
Ash 4%
Corsican Pine 4%
Larch 4%
Scots Pine 6%
Poplar 14%
Birch 10%
Douglas Fir 4%
Oak 34%

E

F

Department Earth and environmental sciences
Celestijnenlaan 200E bus 2411
3001 LEUVEN, België
phone + 32 16 32 97 26
fax + 32 16 3 29760
bart.muys@kuleuven.be

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