TreeSim Tool Documentation

An object-oriented individual tree simulator

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1. Installation of external Python libraries

1.1 Installing the Visualization ToolKit (VTK) Python library

- To install using pip, run the following command,

```
python -m pip install --upgrade pip

python -m pip install vtk
```

1.2 Installing django-utils for using function get_random_string()

To generate a unique tree ID (random alphanumeric string), Django provides the function **get_random_string()** in the **django.utils.crypto** module which will satisfy the alphanumeric string generation requirement.

```
>>> from django.utils.crypto import get_random_string
```

- To install using pip, run the following command,

```
pip install django-utils
```

1.3 Installing Progress Bars tqdm

tqdm is a library in Python which is used for creating Progress Bars.

- To install using pip, run the following command,

```
pip install tqdm
```

1.4 Installing MoviePy, Python module for video editing

```
>>> from moviepy.editor import *
```

- To install using pip, run the following command,

```
pip install moviepy
```

1.5 Installing shutil module

To delete a directory and all files and subdirectories below it,

the **shutil.rmtree()** function was used.

```
>>> import shutil
>>> shutil.rmtree(path, ignore_errors=False, onerror=None)
```

- To install using pip, run the following command,

```
pip install shutil
```

1.6 Installing xlrd

xlrd is a library for reading data and formatting information from Excel files in the .xls format.

- To install using pip, run the following command,

```
pip install xlrd
```

1.7 Installing matplotlib

Matplotlib is an open-source low level graph plotting library in python that serves as a visualization utility.

- To install using pip, run the following command,

```
pip install matplotlib
```

1.8 Installing seaborn

Seaborn is a library that uses Matplotlib underneath to plot graphs. It provides a high-level interface for drawing attractive and informative statistical graphics.

- To install using pip, run the following command,

```
pip install seaborn
```

2. The simulator

TreeSim (Object-Oriented distance-independent Individual **Tree Sim**ulator) is an open source, user-extendable framework which is developed in Python programming language. TreeSim was developed to simulate growth, recruitment, and mortality of a set of tree species groups and was originally developed for Norwegian forestry but can easily be applied for other countries. Table 1 displays the species found in Norwegian forest which were divided into 6 groups. While the first three groups were defined due to their economic and ecological importance, ROS species are important food sources for ungulates, and the warm group of temperature-demanding deciduous species are particularly important for biodiversity. The planning horizon was set for 200 years and divided into 40 periods of equal 5-year length. This can be modified and adjusted from simulation module for any interval that users wish to simulate. (steps = 40, interval = 5)

Table 1. Species groups in the TreeSim

Species group	Species
Norway spruce	Norway Spruce (*Picea abies*), Sitka Spruce (*Picea sitchensis*), Silver Fir (*Abies alba*)
Scots pine	Scots pine (*Pinus Sylvestris*), Lodgepole Pine (*Pinus contorta*), Larch (*Larix spp.*), yew (*Taxus baccata*), other coniferous trees
Birch	Downy birch (*Betula pubescens)*, Silver Birch (*Betula pendula)*
Other broadleaves	Grey Alder *(Alnus incana)*, Common Alder (*Alnus glutinosa*), Bird Cherry (*Prunus padus*), other broad leaves
ROS	Common aspen (*Populus tremula*), Goat Willow (Salix caprea), Rowan (*Sorbus aucuparia*), Mountain-ash *(Sorbus spp.)*
warm	Oak (*Quercus spp.*), Beech (*Fagus sylvatica*), Common Ash (*Fraxinus excelsior*), Scots elm (*Ulmus glabra*), Small-leaved linden (*Tilia cordata*), Norway Maple (*Acer platanoides*), Sycamore (*Acer pseudoplatanus*), Common Hazel (*Corylus avellana*), European crab apple (*Malus sylvestris*), Wild cherry (*Prunus avium*), European Holly (*Ilex aquifolium*)

Tables 2 below provides an overview of the notation for indices used in TreeSim descriptions.

Table 2. Definition of indices

Indices	
k	Index for plot ID
j	Index for diameter class (5, 10, 15 etc.)
i	Index for tree ID in k
p	Index for periods (1, 2, 3, …, n_p*)
s	Index for species group (Norway spruce, Scots pine, Birch, Other broadleaves, ROS, warm)
sp	Index for dominant species in stand (Norway spruce, Scots pine, Birch, Other broadleaves, ROS, warm)
c	Index for tree component (foliage, branches, stem, bark, roots, fine roots and stumps)

* n_p: the number of periods

3. Simulation models

A set of models were employed to perform the simulation, and calculates volume, height, growth, mortality, and tree recruitment (Table 3). The functions that were built for group of

Other broadleaves are used to calculate the simulation tasks for both ROS and warm groups.

Table 3. Stand dynamics models

Simulation task	Dependent variable	Independent variables	Modeled species	Reference
Diameter Increment	$I_{i,s}^{DBH}$(mm) = Diameter growth of tree i, species s over 5 years	DBH (mm), BA (m^2ha^{-1}), SI (m), LAT (degrees)	Norway spruce Scots pine Birch Other broadleaves	(Bollandsås and Næsset 2009) (Bollandsås and Næsset 2009) (Bollandsås and Næsset 2009) (Bollandsås and Næsset 2009)
Height Increment	$I_{i,s}^{HEIGHT}$(dm) = Height growth of tree i, species s over 5 years	DBH (mm), Height (dm)	Norway spruce & Scots pine Birch Other broadleaves	(R. P. Sharma et al. 2011; Ram P. Sharma and Brunner 2017) (H. Eriksson, Johansson, and Kiviste 1997) (H. Eriksson, Johansson, and Kiviste 1997)
Tree natural mortality	m_{ijs} = Expected probability of death of tree i, size class j of species s over 5 years	DBH (mm), BA (m^2ha^{-1})	Norway spruce Scots pine Birch Other broadleaves	(Bollandsås, Buongiorno, and Gobakken 2008; Thurnher et al. 2016)
Tree Recruitment	R_{sp}= Expected number of recruits conditional on positive recruitment for each species sp over 5 years	BA (m^2ha^{-1}), SI (m), PBA (%)	Norway spruce Scots pine Birch Other broadleaves	(Bollandsås, Buongiorno, and Gobakken 2008) (Bollandsås, Buongiorno, and Gobakken 2008) (Bollandsås, Buongiorno, and Gobakken 2008) (Bollandsås, Buongiorno, and Gobakken 2008)
Tree height (recruited trees)	$H_{i,s}$ (m) = Height of tree i, species s	DBH (cm)	Norway spruce Scots pine Birch Other broadleaves	(Ram P. Sharma and Breidenbach 2015) (Ram P. Sharma and Breidenbach 2015) (Ram P. Sharma and Breidenbach 2015) (Ram P. Sharma and Breidenbach 2015)
Tree volume	$V_{i,s}(dm^3)$ = Volume under bark tree i, species s	DBH (mm), Height (dm)	Norway spruce Scots pine Birch Other broadleaves	(Vestjordet 1967) (Braastad 1967) (Braastad 1966) (Braastad 1966)

Decomposition of dead wood, fertilizer response, conversion of living tree into tree biomass, and conversion from biomass to carbon, and equivalent CO2 stocks of trees were estimated by the models illustrated in Table 4. To estimate tree biomass, a living tree was grouped into different components which includes foliage, living branches, dead branches, stem, bark, roots, fine roots and stumps.

Table 4. Tree biomass, Carbon, Deadwood decomposition and Fertilizer response functions

Simulation task	Dependent variable	Independent variables	Modeled species	Reference
Tree biomass	$B_{i,s,c}$ (kg) = Biomass of tree i, species s, compartment c	DBH (mm), Height (dm)	Norway spruce Scots pine Birch/Other broadleaves	(Marklund 1988) (Marklund 1988) (Marklund 1988)
Carbon content	$C_{i,s}$ (kg) = Carbon stored by tree i, species s	$B_{i,s,c}$ (kg)	All species	(Trømborg and Sjølie 2011)
CO2 equivalent of tree biomass	$CO2_{i,s}$ eq. (kg) = CO2 equivalent of the carbon stored in tree i, species s	$C_{i,s}$ (kg)	All species	(Bartlett et al. 2020)
Decomposition of dead wood	Total Carbon Deadwood (Kg)	DBH (cm), Height (dm)	All species	(Mäkinen et al. 2006)
Fertilizer response	$R_{i,s}$ $(m^3 ha^{-1})$ = Fertilizer response of tree i, species s	PAI, Latitude (degree), Altitude (m), site index (m), mean tree age (year)	All species	(Rosvall 1980)

TreeSim provides the simulation at tree level by using a representative tree. The representative tree is defined for each tree object to represent a certain number of trees per hectare. This variable is controlled by the survival rate in each interval. In TreeSim, a tree is removed from simulation if the condition in Table 5 is met. Thus, when a tree represents fewer than 0.5 trees per hectare, it is removed from simulation (Díaz-Yáñez et al. 2019). Removing a tree from simulation can be due to natural mortality or harvesting (thinning, clear cut or seed tree cut).

Table 5. The condition to remove a tree object from simulation

Tree Factor (TF)[ƒ]	**Representative tree (R_t)**	**Assumed threshold for removing from simulation**
TF = $\frac{\text{Unit Area}}{\text{Plot Area}} = \frac{10\,000\ m^2}{\text{Plot Area}}$	R_i = TF *survival rate [ᵡ]	$R_i < \frac{1}{2}$

ƒ: TF is used in conversion of measures from plot to unit area (ha); ᵡ: survival rate = 1- m_{ijs}

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4. Initial state data

The initial state data consists of tree level and plot level data that are located in folder <<**input**>>. The tree level data is named "**Individual_tree_ simulator.tr.csv**" and the plot level data is named "**Individual_tree_ simulator.pl.csv**". The initial tree level data can be generated and saved on the existing tree level csv file provided that the plot level data is available. To start the simulation, it is necessary to have both csv files in the <<**input**>> folder.

5. Simulation algorithm

Figure 1 shows the pseudo-code for the generation of the TreeSim output. Our proposed simulator is implemented in Python by parallel execution and by various site indices. The Python multiprocessing module was used to implement the multiprocessing in TreeSim which allows multiple processors to simultaneously process two or more programs with different site indices. The main advantage of parallelizing simulation code is to reduce the total execution time. The simulator can also be run for different site index with a serial structure code; however, the simulator's performance is more efficient when it is run as a parallelized computer program.

Figure 1. Pseudo-code for the generation of the TreeSim output.

Algorithm: TreeSim simulator

Simulate ()
Input:
1) Plot data (NFI data)
2) Tree data (NFI data)
3) Climate data (Norwegian Meteorological Institute)
4) n_p: the number of periods (n_p= 40)
5) n_i^k: the number of tree IDs in k
6) n_k: the number of plot IDs
7) S: the set of species group
Output: $\boldsymbol{\psi}$: a set of plot-level variables
Initialization:
Generate Scenarios
Initialize plot and tree level variables into separate objects:
Set $W_i = initial\ state\ of\ tree\ level\ variables$
Set $Q_k = initial\ state\ of\ plot\ level\ variables$
Set $G_{sp}^i = initial\ state\ of\ tree\ level\ variables\ for\ tree\ recruitment\ i$
Set $M = \emptyset$ (set of dead trees)
Set $p = 1$

for $k \leftarrow 1\ to\ n_k$ **do**
  while $p \le n_p$ (termination criteria is not met) **do**
    foreach $s \in S$ **do**
      for $i \leftarrow 1\ to\ n_i^k$ **do**
        Compute age and height of the dominant tree
        Compute$I_{i,s}^{DBH}$,$I_{i,s}^{HEIGHT}$, $V_{i,s}$, $B_{i,s,c}$, $C_{i,s}$ (Total Carbon Living Tree), tree basal area($ba_{i,s}$), $CO2_{i,s}\ eq.$, $R_{i,s}$, Total tree carbon stump and root, Total tree carbon stem, Total tree carbon stock
        Compute m_{ijs} and R_i
        If $R_i < \frac{1}{2}$ **then**
          Remove (inactivate) W_i from simulation
          Update $M = \{i\}$
        end if
      end for
      Update $n_i^k = n_i^k - length\ of\ M$
    end foreach
    Compute R_{sp}
    If $R_{sp} \ge 1$ **then**
      Return: Generate G_{sp}^i, R_{sp} times, with its corresponding variables such as $H_{i,s}$ and DBH = 50 mm
      foreach $recruitment\ \boldsymbol{i} \in R_{sp}$ **do**
        $i = recruitment\ \boldsymbol{i}$
        Update $W_i = G_{sp}^i$
      end foreach
      Update $n_i^k = n_i^k + R_{sp}$
    end if
    Before Applying Management Activities **do**
      Compute Volume, Basal Area, Total Carbon Deadwood, Total Carbon Living Trees, Total Soil Organic Carbon, Total Carbon Stems, Total Carbon Stumps and Roots, Total Carbon Stock, Biodiversity

    Implement Management Activities: Thinning, Clear Cut, Seed Tree Cut, No management

    After Applying Management Activities **do**
      Compute Volume, Basal Area, Number of trees per ha, Total Carbon Deadwood, Total Carbon Living Trees, Total Soil Carbon, Total Carbon Stems, Total Carbon Stumps and Roots, Total Carbon Stock
      Compute Biodiversity indicators
      Compute Sawtimber and Pulpwood products

    Update Q_k
    p += 1
  end while
  Export output $\boldsymbol{\psi}$ to a file
end for
Done

6. Biodiversity, and Carbon

Additional models and criteria were used for simulating biodiversity indices (Table 6), soil carbon (Figure 2) and sawlogs and pulpwood share (Table 7). To assess the level of biodiversity in Norwegian forests, a set of indices were put together. For each biodiversity indicator, a point was assigned for each NFI plot. These points could be 0, 50 or 100 for each indicator. To obtain the final score representing the biodiversity for each plot, the mean of corresponding points for each indicator applied to each NFI plot was calculated. The final score to represent the level of biodiversity for each specific was between 0 to 100.

$$Final\ score = \frac{\sum_{indicator=1}^{N} point_{indicator}}{N}$$

Table 6 illustrates these points for each biodiversity indicator.

Table 6. List of biodiversity Indicators, and criteria for assigning points

Biodiversity Indicators	Definition	100 points	50 points	0 points
Species richness	No. of species present in each plot	Species groups >=4	Species groups = 3	Species groups <=2
Shannon Index (α)	Combines species richness and evenness (Species diversity)	α >= 1	$1 < \alpha \leq 0.5$	α < 0.5
Deadwood in each plot	Volume ($m^3\ ha^{-1}$)	V > 20 $m^3\ ha^{-1}$	$5 \leq V \leq 20$	$V < 5\ m^3\ ha^{-1}$
Large deciduous trees other than birch	Volume ($m^3\ ha^{-1}$)	V > 50 $m^3\ ha^{-1}$	$10 \leq V \leq 50$	$V < 10\ m^3\ ha^{-1}$
Number of large trees	No. of trees (n ha^{-1})	tree > 40cm DBH	tree > 30cm DBH	not present

Table 7. Sawtimber and pulpwood share

Product	Independent variables	Modeled species	Reference
Sawtimber share	DBH (mm), Height (dm)	Norway spruce Scots pine	(Blingsmo and Veidahl 1992)
Pulpwood share	DBH (mm), Height (dm)	Norway spruce Scots pine	(Blingsmo and Veidahl 1992)
Sawtimber share of hardwood	DBH (mm), Height (dm)	Birch/Other broadleaves	(Gobakken 2000)

For measuring carbon stocks in TreeSim, 5 carbon pools were defined: Above-ground biomass, below ground biomass, dead wood, litter, and soil organic carbon.

The employed soil model in TreeSim is based on YASSO soil model (Liski et al. 2005).There are three litter components (two woody and one non-woody compartments) and five decomposition compartments in the soil module. Non-woody litter group consists of foliage and fine roots, fine woody litter group includes branches and coarse roots, and coarse woody litter group consists of stems and stumps.

The litter inputs to YASSO model were produced through biomass turnover, mortality due to competition and age, management activities and logging residues. The biomass turnover rates to litter compartments are shown in Table 8.

A fractionation rate was assigned to woody litter groups. These fractionation rates determine the proportion of litter contents released to the decomposition compartments in a unit time. The amount of litter distributed over decomposition compartments of Extractives, Cellulose, and Lignin-like compounds is based on the fractionation rates and its chemical composition. For non-woody litter compartment all of its contents are released to the decomposition compartments in one time step, which means that this rate is equal to one.

To determine the proportional mass loss of each decomposition compartment contents in a unit time, a specific decomposition rate was applied to each decomposition compartment. The fractionation rates of woody litter and the decomposition rates are dependent on temperature and moisture conditions. The climate data for calculating mean annual temperature were extracted from Norwegian Meteorological Institute (Meteorologisk institutt 2022).

Figure 2. Soil Organic Carbon

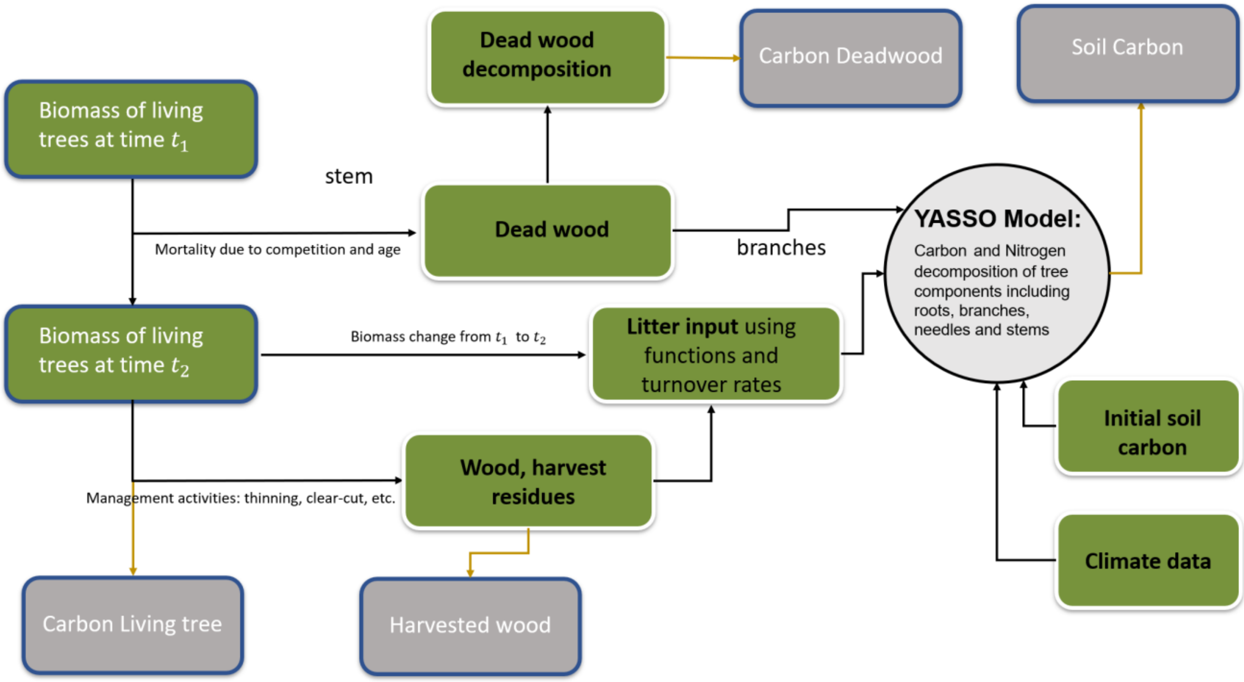

Table 8. Litter turnover functions and rates (proportion of dry mass shed annually as litter)

Parameter	Species	Turnover rates ($year^{-1}$)	Reference
Foliage (Needles)	Scots pine	1.656 - (0.0231) * Latitude	(Ågren, Hyvönen, and Nilsson 2007)
Foliage (Needles)	Norway spruce	0.489 - (0.0063) * Latitude	(Ågren, Hyvönen, and Nilsson 2007)
Foliage (Needles)	Birch/Other broadleaves	0.1	(Wit et al. 2006)
Branches	Scots pine	0.027	(Wit et al. 2006)
Branches	Norway spruce	0.0125	(Wit et al. 2006)
Branches	Birch/Other broadleaves	0.025	(Peltoniemi et al. 2004)
Roots (2-5 mm)	Scots pine	0.10	(E. Eriksson et al. 2007)
Roots (2-5 mm)	Norway spruce	0.10	(E. Eriksson et al. 2007)
Roots (2-5 mm)	Birch/Other broadleaves	0.10	(E. Eriksson et al. 2007)
Fine root (< 2 mm)	Scots pine	0.6	(Matamala et al. 2003)
Fine root (< 2 mm)	Norway spruce	0.6	(Matamala et al. 2003)
Fine root (< 2 mm)	Birch/Other broadleaves	0.6	(Matamala et al. 2003)

7. Forest Management Alternatives (FMAs)

Management alternatives were developed in TreeSim based on the criteria shown in Table 10. For forest management the following management prescriptions were defined: 1- Clear-cut, 2- Seed tree cut, 3- Thinning, 4- Establishment of seed-tree for pine, 5- Establishment of shelterwood for spruce, and 6- No management. Final harvest and Seed tree cut are always followed by regeneration of a new stand. There are two regeneration methods available for any plot, “intensive” option involving planting and “extensive” involving natural regeneration.

7.1 Scenario setting

To cover management that is done in practice, a number of simulation scenarios were introduced. Each scenario defines as one management intensity class (High Pine, Medium Pine, High Spruce, Medium Spruce, Low Spruce, Broadleaf, or No Management) that can be classified in one of the three ranges of site index (SI) (SI >= 15.5, 10.5 <= SI > 15.5, SI < 10.5). If the management intensity class (MIC) type differs from the species class of that plot, then the scenario will be considered as mismatched (infeasible) and will be labeled as “-1” in mgt column. For example, if the MIC is High Pine, the plot’s species should be dominant by pine. For the plots for which this criterion is met, harvesting methods (Clear cut and/or seed tree cut) are implemented for each defined scenario. Regeneration methods mentioned in Table 10 will be applied if the harvesting method is either clear cut or seed tree cut or if the plot is not regenerated initially. At least three rotation lengths are simulated for each feasible management intensity class in the specific site index. Table 9 shows the thinning age and the harvest age scenarios for each SI. In addition, all plots have one “no management” scenario, with no silviculture and no harvest. The name for scenarios consists of 2 or 3 digits. If it is a 2-digit name, the first digit and if it is a 3-digit name the first two digits refers to a management intensity class dependent on the plot’s site index and the last digit represents the minimum harvesting age (See Table 10). For example, knowing that the site index 11 for plot ID A94962 is between 10.5 and 15.5 and according to Table 9 and 10, scenario 21 means: the digit 2 refers to MIC_type: High_pine and digit 1 means that the minimum final harvest age is 80. Accordingly, scenario 22 represents: MIC_type: High_pine and the minimum final harvest age of 100. Scenario 131 represents that MIC_type: No management, No harvest (the minimum final harvest age of 80 is set as default).

Table 9. Minimum final harvest and thinning length are assumed based on type of forest plot

Site index $(\mathbf{H40})^1$	Minimum final harvest age	Thinning age
26	40, 60, 80, 100, 120, 140, 160	30
23	45, 65, 85, 105, 125, 145	35
20	50, 70, 90, 110, 130, 150	35
17	60, 80, 100, 120, 140, 160	45
14	70, 90, 110, 130, 150	55
11	80, 100, 120, 140, 160	60
8	85, 105, 125, 145	-
6	95, 115, 135, 155	-

1 Site index describes the productivity of the site. The H40 index refers to the average height of the one hundred largest trees per hectare at the breast height age of 40 years (Tveite 1977)

Table 10. Management alternatives criteria

Management Criteria					**Criteria for regeneration**						**Criteria for thinning**				
MIC	SI	Harvest Meth.	SP	Fert	Regen Meth.	Regen sp.	Regen density	WT	N R sp.	NR (ha^{-1})	Thin	Min Dom height	Max Dom height	Min BA Before thin	Max BA After thin
High pine	>= 15.5	CC	Yes	Yes	PL	Pine	2200	5	2	2200	Yes	12	15	35	22
High pine	>= 15.5	STC	Yes	No	NRST	Pine	2200	15	2	2200	No	-	-	-	-
High pine	>= 15.5	STC	Yes	No	NRST	Pine	2200	15	2	2200	Yes	12	15	35	22
ME. pine	>= 15.5	STC	No	No	NRST	Pine	1500	15	2	1500	No	-	-	-	-
ME. pine	>= 15.5	STC	No	No	NRST	Pine	1500	15	2	1500	Yes	12	15	35	22
High spruce	>= 15.5	CC	Yes	Yes	PL	Spruce	3000	10	1	3000	Yes	12	15	35	22
High spruce	>= 15.5	CC	Yes	No	PL	Spruce	3000	10	1	3000	No	-	-	-	-
High spruce	>= 15.5	CC	Yes	No	PL	Spruce	3000	10	1	3000	Yes	12	15	35	24
ME. spruce	>= 15.5	CC	No	No	PL	Spruce	2500	10	1	2500	No	-	-	-	-
ME. spruce	>= 15.5	CC	No	No	PL	Spruce	2500	10	1	2500	Yes	12	15	35	24
Low spruce	>= 15.5	CC	No	No	PL	Spruce	1800	10	1	1800	No	-	-	-	-
broadleaf	>= 15.5	CC	No	No	NR	Birch	2000	15	3	2000	No	-	-	-	-
No mgmt.	>= 15.5	None	No	No	None	None	0	10	-	0	No	-	-	-	-
High pine	10.5-15.5	CC	Yes	Yes	PL	Pine	1800	10	2	1800	Yes	12	15	35	22
High pine	10.5-15.5	STC	Yes	No	NRST	Pine	1800	20	2	1800	No	-	-	-	-
High pine	10.5-15.5	STC	Yes	No	NRST	Pine	1800	20	2	1800	Yes	12	15	35	20
ME. pine	10.5-15.5	STC	No	No	NRST	Pine	1200	20	2	1200	No	-	-	-	-
ME. pine	10.5-15.5	STC	No	No	NRST	Pine	1200	15	2	1200	Yes	12	15	35	20
High spruce	10.5-15.5	CC	Yes	Yes	PL	Spruce	2000	15	1	2000	Yes	12	15	35	22
High spruce	10.5-15.5	CC	Yes	No	PL	Spruce	2000	15	1	2000	No	-	-	-	-
High spruce	10.5-15.5	CC	Yes	No	PL	Spruce	2000	15	1	2000	Yes	12	15	35	20
ME. spruce	10.5-15.5	CC	No	No	PL	Spruce	1500	15	1	1500	No	-	-	-	-
ME. spruce	10.5-15.5	CC	No	No	PL	Spruce	1500	15	1	1500	Yes	12	15	35	20
Low spruce	10.5-15.5	CC	No	No	PL	Spruce	1200	15	1	1200	No	-	-	-	-
broadleaf	10.5-15.5	CC	No	No	NR	Birch	1000	20	3	1000	No	-	-	-	-

No mgmt.	10.5-15.5	None	No	No	None	None	0	15	-	0	No	-	-	-	-
High pine	< 10.5	CC	Yes	No	PL	Pine	1800	15	2	1800	No	-	-	-	-
High pine	< 10.5	STC	Yes	No	NRST	Pine	1800	25	2	1800	No	-	-	-	-
ME. pine	< 10.5	STC	No	No	NRST	Pine	1200	25	2	1200	No	-	-	-	-
High spruce	< 10.5	CC	Yes	No	PL	Spruce	2000	15	1	2000	No	-	-	-	-
High spruce	< 10.5	CC	Yes	No	PL	Spruce	2000	15	1	2000	No	-	-	-	-
ME. spruce	< 10.5	CC	No	No	PL	Spruce	1500	15	1	1500	No	-	-	-	-
Low spruce	< 10.5	CC	No	No	PL	Spruce	1200	15	1	1200	No	-	-	-	-
broadleaf	< 10.5	CC	No	No	NR	Birch	1000	25	3	1000	No	-	-	-	-
No mgmt.	< 10.5	None	No	No	None	None	0	25	-	0	No	-	-	-	-

MIC: Management intensity class; SI: site index; Harvest Meth.: Harvesting Method; Regen: Regeneration; SP: site preparation/soil scarification; Fert: Fertilization; NR: Natural regeneration; Thin: Thinning (Removing up to 35% of the volume from below, smallest diameter); sp.: species, 1: spruce; 2: Pine; 3: Birch; CC: clear cut (15% of the volume is left (not cut) with starting from below, saving small trees and saving broadleaves); STC: seed tree cut (about 83% of the volume is harvested on final felling); PL: planting; NRST: Natural regeneration under seed tree; WT: waiting time (number of years from clear-cut till new stand is established); Min BA before thin: Minimum Basal Area before thinning; Max BA After thin: Maximum Basal Area after thinning; ME.: Medium; No mgmt.: No management

8. Output files

SimTree generates two type of output files, tree level and plot level output files. The tree level file contains the characteristics of all simulated trees in a table format for one specific scenario. For each plot ID and each feasible scenario, a csv file representing tree level output will be created and placed in folder <<**Tree_Simulated_Data**>>. This folder is created by simulator in the same working directory and used for visualization task. The tree level files produced at the end of simulation are named XXXX_scenarioYYY_tree_simulation.csv, where XXXX is the plot ID and YYY is the mic number. In addition to the tree level output, for each plot, TreeSim also produces a txt file representing plot level output that will be placed in folder <<**outputs**>>. The plot level output files include all the scenarios (feasible and infeasible scenarios) and are named ZZZZ.txt, where ZZZZ is the plot ID. To visualize the simulated tree level data, a JSON file is required. Python module "convert_to_json.py" has been written to convert the tree level output to JSON file.

References

Ågren, Göran I., Riitta Hyvönen, and Torbjörn Nilsson. 2007. "Are Swedish Forest Soils Sinks or Sources for CO_2: Model Analyses Based on Forest Inventory Data." *Biogeochemistry* 82 (3): 217–27.

Bartlett, Jesamine, Graciela Rusch, Magni Kyrkjeeide, Hanno Sandvik, and Jenni Nordén. 2020. *Carbon Storage in Norwegian Ecosystems (Revised Edition)*.

Blingsmo, K., and A. Veidahl. 1992. "Funksjoner for Bruttopris Av Gran- Og Furutrær På Rot. Rapp.Skogforsk. 8/92:1-23."

Bollandsås, Ole Martin, and Erik Næsset. 2009. "Weibull Models for Single-Tree Increment of Norway Spruce, Scots Pine, Birch and Other Broadleaves in Norway." *Scandinavian Journal of Forest Research* 24 (1): 54–66. https://doi.org/10.1080/02827580802477875.

Bollandsås, Ole Martin, Joseph Buongiorno, and Terje Gobakken. 2008. "Predicting the Growth of Stands of Trees of Mixed Species and Size: A Matrix Model for Norway." *Scandinavian Journal of Forest Research* 23 (2): 167–78. https://doi.org/10.1080/02827580801995315.

Braastad. 1966. "Volumtabeller for Bjørk (Volume Tables for Birch). Communications of Norwegian Forest Research Institute, 1–53."

———. 1967. "Furu Sønnafjells. Kubering Av Stående Skog. Funksjoner Og Tabeller (Volume Functions and Tables for Scots Pine. South Norway). Meddelelser Fra Det Norske Skogforsøksvesen. 22, 695–739."

Díaz-Yáñez, Olalla, Manuel Arias-Rodil, Blas Mola-Yudego, José Ramón González-Olabarria, and Timo Pukkala. 2019. "Simulating the Effects of Wind and Snow Damage on the Optimal Management of Norwegian Spruce Forests." *Forestry: An International Journal of Forest Research* 92 (4): 406–16. https://doi.org/10.1093/forestry/cpz031.

Eriksson, E., A. Gillespie, L. Gustavsson, O. Langvall, M. Olsson, R. Sathre, and J. Stendahl. 2007. "Integrated Carbon Analysis of Forest Management Practices and Wood Substitution." https://doi.org/10.1139/X06-257.

Eriksson, Harry, Ulf Johansson, and Andres Kiviste. 1997. "A Site-index Model for Pure and Mixed Stands of Betula Pendula and Betula Pubescens in Sweden." *Scandinavian Journal of Forest Research* 12 (2): 149–56. https://doi.org/10.1080/02827589709355396.

Gobakken, Terje. 2000. "Models for Assessing Timber Grade Distribution and Economic Value of Standing Birch Trees." *Scandinavian Journal of Forest Research* 15 (5): 570–78. https://doi.org/10.1080/028275800750173555.

Liski, Jari, Taru Palosuo, Mikko Peltoniemi, and Risto Sievänen. 2005. "Carbon and Decomposition Model Yasso for Forest Soils." *Ecological Modelling* 189 (1): 168–82. https://doi.org/10.1016/j.ecolmodel.2005.03.005.

Mäkinen, Harri, Jari Hynynen, Juha Siitonen, and Risto Sievänen. 2006. "Predicting the Decomposition of Scots Pine, Norway Spruce, and Birch Stems in Finland." *Ecological Applications* 16 (5): 1865–79.

Marklund, L.G. 1988. "Biomass Functions for Pine, Spruce and Birch in Sweden. Swed. Uni. of Agric. Sciences, Dept. of For. Surv., Report, 45, 73."

Matamala, Roser, Miquel A. Gonzàlez-Meler, Julie D. Jastrow, Richard J. Norby, and William H. Schlesinger. 2003. "Impacts of Fine Root Turnover on Forest NPP and Soil C Sequestration Potential." *Science* 302 (5649): 1385–87.

Meteorologisk institutt. 2022. "Frost METADATA." 2022. https://frost.met.no/ex_portingwsklima.

Peltoniemi, Mikko, Raisa Mäkipää, Jari Liski, and Pekka Tamminen. 2004. "Changes in Soil Carbon with Stand Age - An Evaluation of a Modelling Method with Empirical Data." *Global Change Biology* 10 (December): 2078–91. https://doi.org/10.1111/j.1365-2486.2004.00881.x.

Rosvall, Ola. 1980. "Functions for the Prediction of Fertilizer Responses in Sweden. Foreningen Skogstradsforadling, Institutet for Skogsforbattring, Årsbok. 1979, 70-130. Uppsala."

Sharma, R. P., A. Brunner, T. Eid, and B. Øyen. 2011. "Modelling Dominant Height Growth from National Forest Inventory Individual Tree Data with Short Time Series and Large Age Errors." https://doi.org/10.1016/J.FORECO.2011.07.037.

Sharma, Ram P., and Johannes Breidenbach. 2015. "Modeling Height-Diameter Relationships for Norway Spruce, Scots Pine, and Downy Birch Using Norwegian National Forest Inventory Data." *Forest Science and Technology* 11 (1): 44–53. https://doi.org/10.1080/21580103.2014.957354.

Sharma, Ram P., and Andreas Brunner. 2017. "Modeling Individual Tree Height Growth of Norway Spruce and Scots Pine from National Forest Inventory Data in Norway." *Scandinavian Journal of Forest Research* 32 (6): 501–14. https://doi.org/10.1080/02827581.2016.1269944.

Thurnher, Christopher, Rasmus Astrup, Hanne Sjølie, and Hubert Hasenauer. 2016. "Comparison of Mortality Models for Norwegian Tree Species." *Austrian Journal of Forest Science* 133 (March): 63–86.

Trømborg, E., and Hanne K. Sjølie. 2011. "Data Applied in the Forest Sector Models NorFor and NTMIII. INA Fagrapport 17."

Tveite, Bjørn. 1977. "Bonitetskurver for Gran = Site-Index Curves for Norway Spruce : (Picea Abies (L.) Karst) - Nasjonalbiblioteket." 1977. https://www.nb.no/nbsok/nb/48043b42828a2b019511f41b92d2a4e2.

Vestjordet, E. 1967. "Funksjoner Og Tabeller for Kubering Av Stående Gran (Functions and Tables for Volume of Standing Trees)."

Wit, H. A. D., T. Palosuo, G. Hylen, and J. Liski. 2006. "A Carbon Budget of Forest Biomass and Soils in Southeast Norway Calculated Using a Widely Applicable Method." https://doi.org/10.1016/J.FORECO.2005.12.023.