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FORGENIUS

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Deliverable D1.3

Species ecophysiology

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1 Summary

The objective of this deliverable is to collect the missing parameters for tree species applied in the FORGENIUS project. Tree-specific parameters are important to enable modelling past and future conditions at Genome Conservational Units plots with process-based models.

The process-based models developed at the plot scale allow us to simulate the main processes of forest functioning (photosynthesis, respiration, carbon allocation, evapotranspiration, water cycle, etc.) and consequently assess the resilience of stands to disturbances, including water stress. Missing parameters for some species have been found in a literature review, through remote sensing or estimated such as parameters for respiration and photosynthesis. In the FORGENIUS project, we decided to use two models, CASTANEA and SurEau, which accurately represent the response of each species to disturbances such as water stress or frost. To this end, important preliminary work was to parameterize these two types of models on the 10 species included in the functional subset of species studied in detail in WP2.

For CASTANEA we managed to parameterize 7 of the 10 species by finding values for the 71 species-specific parameters in the literature. For SurEau, we estimated the values of 7 parameters that vary between species and that over-determine the hydraulic vulnerability of trees to water stress. In this deliverable we provide, values of all the parameters and the exhaustive list of literature that allowed us to estimate them (listed in the annex).

The deliverable consists of (2) tables describing the tree-specific parameters or tree ecophysiology for CASTANEA and SurEau models. CASTANEA parameters are separated into coniferous and broadleaved species.

2 Introduction

Significance of deliverable

The purpose of this deliverable is to compile, measure, or estimate missing tree-specific parameters for tree species applied in the FORGENIUS project. Tree-specific parameters are essential for modelling with process-based models the future forest functioning and ecological conditions in Genome Conservational Units plots. The process-based models developed at the plot scale make it possible to simulate the main processes of forest functioning (photosynthesis, respiration, carbon allocation, evapotranspiration, water cycle, etc.) and consequently assess the resilience. Species distribution models based on an empirical representation of the relationship between the presence or absence of a species and bioclimatic variables have been widely used to project the distribution of a large number of species. This will allow us to estimate the health status in terms of growth, leaf deficit level, survival and seed production, and the resilience of these state variables to past climate variation in the forest GenRes collection. Health can be assessed through changes in status variables such as total leaf area index, leaf deficit level, past growth, biomass, or mortality rate.

The resilience capabilities of the ecosystem can be estimated by the temporal response of these metrics to extreme events such as droughts, frosts, or fires. Climate change will lead to increased evapotranspiration and decreased precipitation, especially in the Mediterranean area, resulting in increased frequency and intensity of drought, heat waves, and fires. Warming can also lead to earlier budburst and, paradoxically, an increase in the frequency of late frost in certain areas. Schueler et al., (2014) have shown that, by 2100, species in 33–65 % of conservation units, mostly located in southern Europe, will be at the limit or outside the species' current climatic niche.

Description of the work carried out

Missing parameters for tree species have been assessed using data existing in the literature, new measurements, and through remote sensing. These are photosynthesis parameters (Vcmax, Vjmax), maximal conductance, optical properties, and construction costs for respiration. Other parameters for example nitrogen content, specific leaf area, and hydraulic and site-specific parameters are measured in WP2 and will be supplemented as measurements in WP2 proceed. The first step of our work was to list all parameters needed for simulations in process-based models. Then we collected existing data in the literature on species-specific parameters and proceed within new situ measurements and remote sensing. Leaf area index (LAI), soil water capacity (SWC), and biomass measurements were carried out on a subsample of plots by GIS and INRAE in relation to WP2. Moreover, the values of the various model parameters are by themselves also valuable indicators of the vulnerability of species to water stress, but also of the ecological strategies to face perturbations. Indeed. two species can have identical vulnerabilities, but thanks to different coordination of traits.

To be able to use the CASTANEA models simulating the carbon vulnerability/ resilience of trees to different perturbations and SUR-EAU simulating the hydraulic vulnerability of trees to water stress, we first had to estimate the values of each specific parameter.

3 Results

3.1 CASTANEA parameterization

CASTANEA is a generic process-based model used to simulate carbon and water fluxes and tree growth in forest ecosystems (Dufrêne et al., 2005). The canopy is divided into five layers of leaves, while branches, stem, coarse and fine roots, and NSC compartments compose the rest of the tree. Photosynthesis is hourly estimated for each canopy layer using the Farquhar et al., 1980) model analytically coupled to the stomatal conductance model proposed by Ball et al., 1987) that linearly relates stomata conductance to the product of photosynthesis and relative humidity. Maintenance and growth respiration are respectively estimated proportional to the nitrogen content of the considered organs (Ryan, 1991) and from growth increment combined with a construction cost specific to the type of tissue (De Vries et al., 1974). Transpiration is also hourly calculated using the Monteith (1965) equations. The dynamics of soil water content (WC; in mm) is estimated daily using a three-layers bucket model. Soil drought drives stomatal closure via a linear decrease in the Ball et al. (1987) slope when the relative soil water content is under 40% of field capacity (Sala and Tenhunen., 1996).

The model was originally developed and validated from organ to stand scales for Fagus sylvatica L. (Dufrêne et al., 2005). It was also successfully applied to Pinus sylvestris L., Pinus pinaster Aiton. Quercus ilex L., Quercus robur L. and Picea abies Karst (Davi et al., 2006; Delpierre et al., 2012)

For CASTANEA model three kinds of parameters are distinguished: (1) constant parameters through species and sites, (2) 71 species-specific parameters, and (3) site-specific parameters. Constant parameters are given in (Dufrêne et al., 2005). This complete parameterization of species in FORGENIUS project has been accomplished thanks to careful research upon material listed in the annex.

The site-specific parameters are more related to local-scale physical or biophysical coefficients describing the vegetation and the soil. In the study, these parameters were estimated using remote sensing data and are beyond the scope of that deliverable.

We focus on the following 7 of the 10 species belonging to the functional subset of the project species: *Picea abies*, *Pinus pinaster*, *Pinus sylvestris* for coniferous,

and *Quercus ilex*, *Quercus robur*, *Fagus sylvatica* and *Populus nigra* for broadleaves species. The parameterization of the model on Populus nigra is not fully finalized. However, a few parameters will be measured in WP2.

We did not make the parameterization for 3 species at this step: *Pinus pinea* and *Malus sylvestris*, because these two species represent a lower number of GCUs (respectively 10 - 20) and for which we have less knowledge of their physiology. For *Fraxinus excelsior*, the work must be done in the next future.

A table of tree-specific parameters is presented hereinafter. Parameters are divided between coniferous (Table 1.1.) and broadleaves species (Table 1.2.).

Table 1.1. Species ecophysiology: coniferous tree specific parameters

	Pinus pinaster	*Pinus sylvestris*	*Picea abies*
Leaf construction cost (gC/gC)	1.33	1.33	1.22
Coarse roots construction cost (gC/gC)	1.38	1.39	1.38
Fine roots construction cost (gC/gC)	1.42	1.42	1.4
Wood construction cost (gC/gC)	1.38	1.39	1.38
Fruit construction cost (gC/gC)	1.353	1.357	1.396
Sapwood (% in area)	81.3	26.5	38.7
Parenchyme cells in sapwood (%)	6.22	6.3	6.45
Initial NSC (%)	15.5	14.45	13.5
Nitrogen in leaves (%)	0.97	1.33	1.26
Nitrogen in coarse roots (%)	0.091	0.1	0.33
Nitrogen in fine roots (%)	0.81	0.42	1.29
Nitrogen in branches (%)	0.218	0.56	1.07
Nitrogen in stem (%)	0.08	0.098	0.33
Predawn potential for growth cessation (Mpa)			-0.66
Fine roots turnover (per year)	0.64	0.64	0.50
Ratio between branches and total aboveground wood biomass	0.197	0.131	0.11
Ratio between coarse roots and total wood biomass	0.28	0.279	0.182
Ratio between fine roots and leaves biomass	0.31	0.92	0.27
Branches mortality (per year)	0.035	0.025	0.013
Needle area (mm^2)	539.5	113.06	78.82
Leaf Mass per Area of sun leaves (g/m2)	246.7	246.7	229.2
Extinction coefficient of Leaf Mass per Area within the canopy	0.055	0.055	0.156
Leaf/needle angle (°)	35.4	35.4	42.4
Branch angle (°)	77	70.7	74.6
Slope of the crown radius to dbh relation	0.0923	0.0743	0.066
Intercept of the crown radius to dbh relation	1.0688	1.35	0.524
Intercept of the log relationship between leaf biomass and dbh	-4.3437	-3.5276	-2.7957
slope of the log relationship between leaf biomass and dbh	2.346	1.7471	1.8688
Slope of the height-dbh relationship	1.33	1.347	1.559
Power coefficient of the height-dbh relationship	0.679	0.783	0.756

	Pinus pinaster	*Pinus sylvestris*	*Picea abies*
Form coefficient of stem	0.489	0.473	0.484
Wood density (m3/Kg)	412	422	370
Slope self thinning equation	11.982	11.993	13.086
Intercept self thhinning equation	-1.711	-1.615	-1.878
Canopy clumping index	0.72	0.49	0.40
Wood reflectance in PIR domain	0.495	0.495	0.339
Wood reflectance in PAR domain	0.146	0.146	0.135
Leaf reflectance in PIR domain	0.279	0.311	0.314
Leaf transmittance in PIR domain	0.118	0.312	0.32
Leaf reflectance in PAR domain	0.09	0.062	0.080
Leaf transmittance in PAR domain	0.014	0.087	0.0503
Water storage capacity per unit of leaf area (mm/m^2)	0.11	0.2	0.3875
Water storage capacity per unit of bark area (mm/m^2)	0.17	2.20	0.4
Slope of the water interception coefficient	4.5	2.7	2.55
Intercept of the water interception coefficient	5.5	1.6	3.15
Ratio between stem flow and through fall	1	0.1	1
Intercept of ball and berry relation (mmol/m2/s)	0.0015	0.0015	0.0247
Slope of ball and berry relation	8.9	7.65	6.53
Capacitance of trunk		0.04	
Average soil resistance from soil to leaves	18000	17857	2000
Maximum whole plant conductivity			0.6
Water potential inducing 50% loss of conductivity (Mpa)	-3.73	-3.09	-3.61
Minimum midday soil water potential (Mpa)	-2	-2.3	-2.4
Dependency between Vcmax and leaf nitrogen density	14.86	16.5	20.73
Base temperature for forcing budburst	1	1	0
Base temperature for leaf growth	0	0	0
Base temperature for forcing leaf fall	-	-	
Date of onset of rest	10	1	10
Date of onset of ageing	-	-	
Critical value of state of forcing (from quiescence to active period)	400	1000	613

	Pinus pinaster	*Pinus sylvestris*	*Picea abies*
Critical value of state of forcing (from leaf development to maximum LAI)	350	200	350
Critical value of state of forcing (from leaf development to leaf maturity)	1000	1000	1000
Critical value of state of forcing (from nstart2 to leaf fall period)	-	-	-
Critical value of state of forcing from nstart2 to end of wood growth	300	150	300
Maximum needle or leaves lifespan		3	11
Minimal resistance to frost	-4.1	-4.1	-4.8
NSC biomass above which seeds are produced (gC/m2)		200	
NSC under which tree dies (%)		5.04	
Carbon cost to produce one seed		1.356	
Rate of carbon allocated to seed production at the end of the year		0.15	
Seed mass (mg)	33	11	6.585
Germination rate (%)			

Table 1.2. Species ecophysiology: broadleaves tree species specific parameters

	Populus nigra	*Fagus sylvatica*	*Quercus ilex*	*Quercus robur*
Leaf construction cost (gC/gC)	1.1	1.2	1.294	1.09
Coarse roots construction cost (gC/gC)		1.38	1.19	1.34
Fine roots construction cost (gC/gC)	1.25	1.25	1.25	1.25
Wood construction cost (gC/gC)		1.38	1.19	1.34
Fruit construction cost (gC/gC)		1.457	1.316	1.307
Sapwood (% in Area)	29.6	0	27.2	17.5
Alive cells in sapwood (%)	11.9	22.7	34.1	33.95
Initial NSC (%)	1.93	5.23	9.86	3.6
Nitrogen in leaves (%)	1.75	2.38	1.2	2.19
Nitrogen in coarse roots (%)	0.12	0.79	0.46	0.43
Nitrogen in fine roots (%)	1.28	0.88	0.59	0.97
Nitrogen in branches (%)		0.55	0.69	0.9
Nitrogen in stem (%)	0.141	0.16	0.182	0.427
Nitrogen in seeds (%)		2.43		1.08
Predawn potential for growth cessation (Mpa)		-2.5	-1	
Fine roots turnover (per year)		0.77	2.92	0.95
Ratio between branches and total aboveground wood biomass	0.19	0.29	0.45	0.19
Ratio between coarse roots and total wood biomass	0.237	0.133	0.85	0.13
Ratio between fine roots and leaves biomass		0.67	0.29	0.46
Branches mortality (per year)		0.013	0.008	0.0208
Leaf area (mm^2)	2834	1527	656.0	2221
Leaf Mass per Area of sun leaves (g/m2)	94.3	90.76	217	106
Extinction coefficient of Leaf Mass per Area within the canopy		0.18	0.14	0.18
Leaf/needle angle (°)	44.26	22	30	35.8
Branch angle (°)	53.9	55	54.5	56.8
Slope of the crown radius to dbh relation	0.1859	0.108	0.119	0.1561
Intercept of the crown radius to dbh relation	0.80	1.04	0.781	1.7173

	Populus nigra	Fagus sylvatica	Quercus ilex	Quercus robur
Intercept of the log relationship between leaf biomass and dbh	-4.1454	-4.4813	-4.4998	-4.4663
Slope of the log relationship between leaf biomass and dbh	1.948	1.7073	2.1018	2.1375
Slope of the height-dbh relationship	2.108	2.907	2.04	2.538
Power coefficient of the height-dbh relationship	0.70	0.572	0.41	0.564
Form coefficient of stem		0.515	0.62	0.512
Wood density (m3/Kg)	353	585	820	560
Slope self thinning equation		12.95	12.27	12.27
Intercept self thhinning equation		-1.779	-0.809	-0.809
Canopy clumping coefficient		0.64	0.63	0.74
Wood reflectance in PIR domain		0.339	0.339	0.339
Wood reflectance in PAR domain		0.135	0.135	0.135
Leaf reflectance in PIR domain		0.356	0.392	0.329
Leaf transmittance in PIR domain		0.377	0.242	0.357
Leaf reflectance in PAR domain		0.0877	0.123	0.0942
Leaf transmittance in PAR domain		0.055	0.0345	0.060
Water storage capacity per unit of leaf area (mm/m^2)		0.27	0.82	0.304
Water storage capacity per unit of bark area (mm/m^2)		0.3	0.7	0.3
Slope of the water interception coefficient		4.1	2.6	2.3
Intercept of the water interception coefficient		5.1	2	2.25
Ratio between stem flow and through fall		0.35	0.8	1
Intercept of ball and berry relation	0.0086	0.0032	0.004	0.0084
Slope of ball and berry relation	9.54	11.29	8.06	14.8
Capacitance of trunk		0.04	0.04	
Average soil resistance from soil to leaves		11465	20000	
Maximum whole plant conductivity				
Water potential inducing 50% loss of conductivity (Mpa)	-2.95	-3.15	-6.9	-6.88

	Populus nigra	Fagus sylvatica	Quercus ilex	Quercus robur
Minimum midday soil water potential (Mpa)	-1.65	-2.56	-6.54	-2.94
Dependency between Vcmax and leaf nitrogen density		26	22	34.04
Base temperature for forcing budburst		1	1	
Base temperature for leaf growth		0	0	
Base temperature for forcing leaf fall		20	-	
Date of onset of rest		78	48	40
Date of onset of ageing		213	-	
Critical value of state of forcing (from quiescence to active period)		250	600	385
Critical value of state of forcing (from leaf development to maximum LAI)		200	280	
Critical value of state of forcing (from leaf development to leaf maturity)		424	900	
Critical value of state of forcing (from nstart2 to leaf fall period)		100	230	
Critical value of state of forcing from nstart2 to end of wood growth		60	300	
Maximum leaves lifespan	1	1	3	1
NSC biomass above which seeds are produced (gC/m2)		100	250	
NSC under which tree die (%)		0.48	-	
Carbon cost to produce one seed		1.457	1.92	
Rate of carbon allocated to seed production at the end of the year		0.03	0.05	
Seed mass (mg)		178.1	2518	3023

3.2 SurEau parameterization

SurEau (Cochard et al., 2021) is a model based on the formalization of key physiological processes of plant response to water stress. The hydraulic and hydric functioning of the plant is at the core of this model, which focuses on both water flows (i.e., hydraulic) and water pools (i.e., hydric) using variable hydraulic conductances. The model considers the elementary flow of water from the soil to the atmosphere through different plant organs that are described by their symplasmic and apoplasmic compartments. For each organ, the symplasm is described by a pressure-volume curve and the apoplasm by its vulnerability curve to cavitation. The model is evaluated on mature oak trees exposed to water stress. The full parameterization of the SurEau model is given in Martin-StPaul et al. (2017).

Species	P50 (Mpa)	P12 (Mpa)	Slope (%/Mpa)	gs90 (Mpa)	tlp (Mpa)	Pclose (Mpa)	Gmin (mmol/m2 double sided/s)
Fagus sylvatica	-3.15	-2.5	36.2	-1.6	-2.5	-2.5	4
Fraxinus excelsior	-2.8	-2.1	63.3	-2.9	-2.1	-2.33	4
Malus sylvestris	-6.01	-4.78	30.9	NA	-2.6	-2.6	NA
Picea abies	-3.61	-2.8	46.6	NA	-2.5	-2.5	3
Pinus pinaster	-3.73	-3.01	69	NA	-2	-2	NA
Pinus pinea	-4.34	-3.78	89	NA	-2.21	-2.21	NA
Pinus sylvestris	-3.09	-2.62	69.3	-1.9	-2.1	-2	NA
Populus nigra	-2.95	-2.27		NA	-2.4	-2.4	NA
Quercus ilex	-6.9	-4.3	20.4	-3.2	-3.15	-3.175	2
Quercus robur	-4.74	-3.81	67.07	NA	-2.63	-2.63	4

Glosary for SurEau

P50 is the water potential causing 50% cavitation in the xylem

P12 is the water potential causing 12% cavitation in the xylem

Slope is the slope of the vulnerability curve at P50

gs90 is water potential causing 90% stomatal closure

Tlp is osmotic potential at turgor loss point

Pclose is water potential causing 100% stomatal closure

Gmin is the cuticular conductance or minimum transpiration

4 Conclusions

Tree-specific parameters are essential for modelling with process-based models. The two models CASTANEA and SurEau which will be used to assess the vulnerability and resilience of GCUs to droughts have been parameterized for 7 and 10 species respectively. This work is a crucial step for the FORGENIUS project and constitutes a scientific contribution in itself. Indeed, most process-based models operating on large scales do not distinguish species precisely and use Plant Functional Types. The precise distinction of species allows for more accurate and useful simulations for foresters and managers.

5 Partners involved in the work

Tree specific parameters has been collected, measured, or estimated in close cooperation with INRAE and GIS. Satellite remote sensing measurements has been provided by JRC. GIS was the main responsible for writing the report.

6 Annexes

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