

Forest growth and dynamics (practice)

Miquel De Cáceres, Rodrigo Balaguer
Ecosystem Modelling Facility, CREAF

Outline

1. Forest growth inputs
2. Running forest growth
3. Evaluation of growth predictions
4. Forest dynamics
5. Forest dynamics including management



M.C. Escher - Up and down, 1947

1. Forest growth inputs

Creating the forest growth input object

We assume we have an appropriate forest object:

```
1 data(exampleforest)
```

a species parameter data frame:

```
1 data(SpParamsMED)
```

a soil data frame:

```
1 examplesoil <- defaultSoilParams(4)
```

and simulation control list:

```
1 control <- defaultControl("Granier")
```

With these four elements we can build our input object for function `growth()`:

```
1 x <- forest2growthInput(exampleforest, examplesoil, SpParamsMED, control)
```

Structure of the growth input object (1)

The growth input object is a `list` with several elements:

```
1 names(x)
[1] "control"           "soil"
[3] "snowpack"          "canopy"
[5] "herbLAI"           "herbLAImax"
[7] "cohorts"           "above"
[9] "below"             "belowLayers"
[11] "paramsPhenology"    "paramsAnatomy"
[13] "paramsInterception" "paramsTranspiration"
[15] "paramsWaterStorage" "paramsGrowth"
[17] "paramsMortalityRegeneration" "paramsAllometries"
[19] "internalPhenology"   "internalWater"
[21] "internalLAIDistribution" "internalCarbon"
[23] "internalAllocation"  "internalMortality"
[25] "internalFCCS"
```

Element `above` contains the above-ground structure data that we already know, but with an additional column `SA` that describes the estimated initial amount of *sapwood area*:

	SP	N	DBH	Cover	H	CR	SA	LAI_live
T1_148	148	168.0000	37.55	NA	800	0.6605196	383.4520992	0.84874773
T2_168	168	384.0000	14.60	NA	660	0.6055642	47.0072886	0.70557382
S1_165	165	749.4923	NA	3.75	80	0.8032817	0.9753929	0.03062604
	LAI_expanded	LAI_dead	LAI_nocomp	Loading	ObsID			
T1_148	0.84874773	0	1.29720268	0.32447403	<NA>			
T2_168	0.70557382	0	1.01943205	0.20102636	<NA>			
S1_165	0.03062604	0	0.04412896	0.01407945	<NA>			

Structure of the growth input object (2)

Elements starting with `params*` contain cohort-specific model parameters. An important set of parameters are in `paramsGrowth`:

	RERleaf	RERSapwood	RERfineroot	CCleaf	CCsapwood	CCfineroot
T1_148	0.01210607	5.15e-05	0.0009610199	1.5905	1.47	1.3
T2_168	0.01757808	5.15e-05	0.0072846640	1.4300	1.47	1.3
S1_165	0.02647746	5.15e-05	0.0072846640	1.5320	1.47	1.3

	RGRleafmax	RGRsapwoodmax	RGRcambiummax	RGRfinerootmax	SRsapwood
T1_148	0.09	NA	0.002628095	0.1	0.000135
T2_168	0.09	NA	0.002500000	0.1	0.000135
S1_165	0.09	0.002	NA	0.1	0.000135

	SRfineroot	RSSG	fHDmin	fHDmax	WoodC
T1_148	0.001897231	0.3725000	80	160	0.4979943
T2_168	0.001897231	0.9500000	40	100	0.4740096
S1_165	0.001897231	0.7804035	NA	NA	0.4749178

Elements starting with `internal*` contain state variables required to keep track of plant status. For example, the metabolic and storage carbon levels can be seen in `internalCarbon`:

	sugarLeaf	starchLeaf	sugarSapwood	starchSapwood
T1_148	0.4029239	0.00925123	0.5738487	3.201897
T2_168	0.3585751	0.00925123	1.0741383	3.100817
S1_165	0.7223526	0.00925123	0.2857655	2.654773

2. Forest growth

Forest growth run

The call to function `growth()` needs the growth input object, the weather data frame, latitude and elevation:

```
1 G <- growth(x, examplometeo, latitude = 41.82592, elevation = 100)
```

Initial plant cohort biomass (g/m2): 5068.34

Initial plant water content (mm): 4.73001

Initial soil water content (mm): 290.875

Initial snowpack content (mm): 0

Performing daily simulations

Year 2001:.....

Final plant biomass (g/m2): 5256.53

Change in plant biomass (g/m2): 188.193

Plant biomass balance result (g/m2): 188.193

Plant biomass balance components:

Structural balance (g/m2) 104 Labile balance (g/m2) 92

Plant individual balance (g/m2) 196 Mortality loss (g/m2) 8

Final plant water content (mm): 4.73794

Final soil water content (mm): 274.787

Final snowpack content (mm): 0

Change in plant water content (mm): 0.00793033

Plant water balance result (mm): -0.00116903

Change in soil water content (mm): -16.0878

Soil water balance result (mm): -16.0878

Change in snowpack water content (mm): 0

Snowpack water balance result (mm): 7.10543e-15

Water balance components:

Precipitation (mm) 513 Rain (mm) 462 Snow (mm) 51

Interception (mm) 00 Net rainfall (mm) 270

Growth output object

Function `growth()` returns an object of class with the same name, actually a list:

```
1 class(G)
[1] "growth" "list"
```

... whose elements are:

```
1 names(G)
[1] "latitude"      "topography"    "weather"
[4] "growthInput"   "growthOutput"  "WaterBalance"
[7] "CarbonBalance" "BiomassBalance" "Soil"
[10] "Snow"          "Stand"         "Plants"
[13] "LabileCarbonBalance" "PlantBiomassBalance" "PlantStructure"
[16] "GrowthMortality"
```

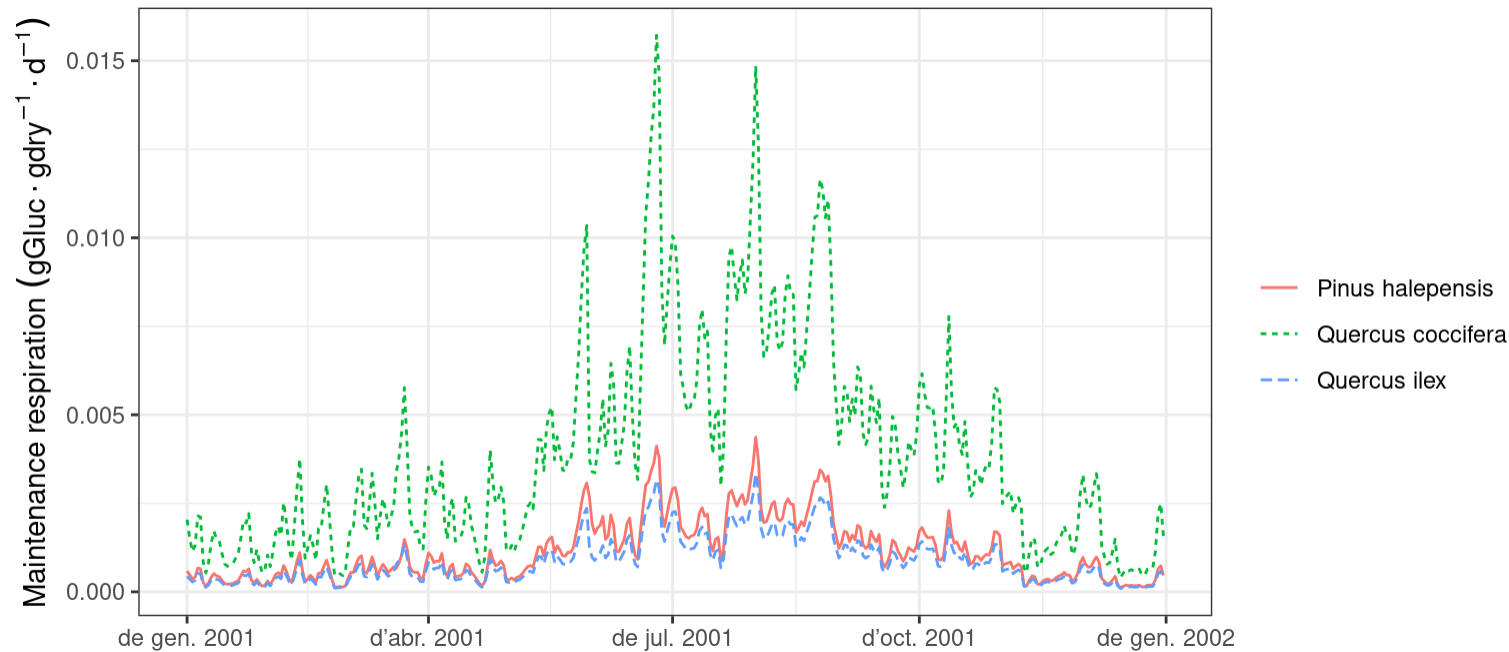
Elements	Information
<code>latitude</code> , <code>topography</code> , <code>weather</code> , <code>growthInput</code>	Copies of the information used in the call to <code>growth()</code>
<code>growthOutput</code>	State variables at the end of the simulation (can be used as input to a subsequent one)
<code>WaterBalance</code> , <code>Soil</code> , <code>Snow</code> , <code>Stand</code> , <code>Plants</code>	[same as <code>spwb</code> ...]
<code>CarbonBalance</code>	Stand-level carbon blance
<code>LabileCarbonBalance</code>	Components of the individual-level labile carbon balance
<code>PlantBiomassBalance</code>	Components of individual- and cohort-level biomass balance
<code>PlantStructure</code>	Structural variables (DBH, height, sapwood area...)
<code>GrowthMortality</code>	Growth and mortality rates

Post-processing

Users can inspect the output of `growth()` simulations using functions `extract()`, `summary()` and `plot()` on the simulation output.

Several new plots are available in addition to those available for `spwb()` simulations (see `?plot.growth`). For example:

```
1 plot(G, "MaintenanceRespiration", bySpecies = TRUE)
```



... but instead of typing all plots, we can call the interactive plot function `shinyplot()`.

3. Evaluation of growth predictions

Observed data frame

Evaluation of growth simulations will normally imply the comparison of predicted vs observed **basal area increment** (BAI) or **diameter increment** (DI) at a given temporal resolution.

Here, we illustrate the evaluation functions included in the package using a fake data set at *daily* resolution, consisting on the predicted values and some added error.

```
1 data(exampleobs)
2 head(exampleobs)
```

	dates	SWC	ETR	E_T1_148	E_T2_168	FMC_T1_148	FMC_T2_168
1	2001-01-01	0.3007733	2.2436218	0.09187857	0.14142950	125.9071	93.07915
2	2001-01-02	0.3091627	2.3236565	0.26480973	0.19095008	125.9137	93.07863
3	2001-01-03	0.2996498	0.7409083	0.15345643	0.17546363	125.8760	93.10512
4	2001-01-04	0.3042764	1.7173522	0.23470647	0.04643454	125.8643	93.07022
5	2001-01-05	0.3054886	2.0002562	0.37687792	0.10623552	125.8493	93.08487
6	2001-01-06	0.3062005	2.0722706	0.16342360	0.05550329	125.9367	93.07343

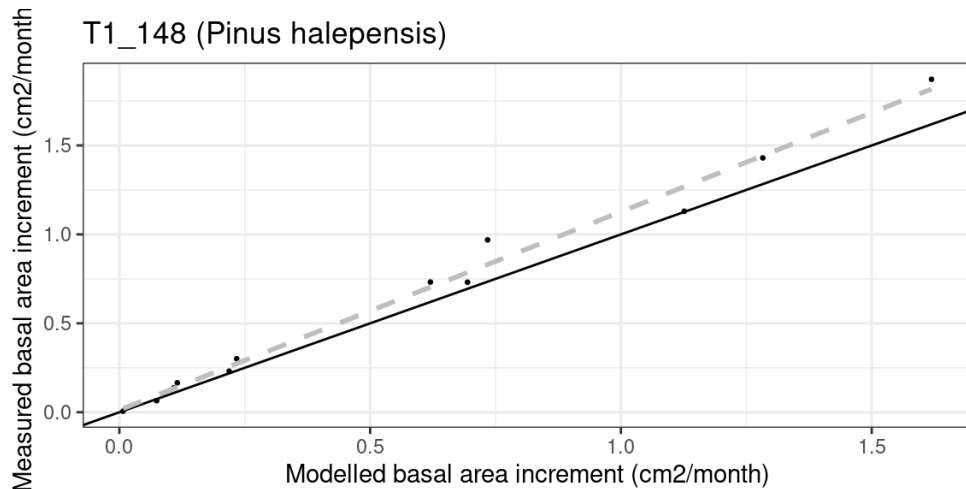
	BAI_T1_148	BAI_T2_168	DI_T1_148	DI_T2_168
1	6.222625e-06	0	9.948881e-08	0
2	3.091274e-10	0	1.071090e-11	0
3	1.298482e-13	0	0.000000e+00	0
4	2.886195e-11	0	5.552753e-13	0
5	1.287020e-03	0	1.367289e-05	0
6	1.471202e-03	0	1.000411e-05	0

To specify observed growth data at *monthly* or *annual scale*, you should specify the first day of each month/year (e.g. [2001-01-01](#), [2002-01-01](#), etc for years) as row names in your observed data frame.

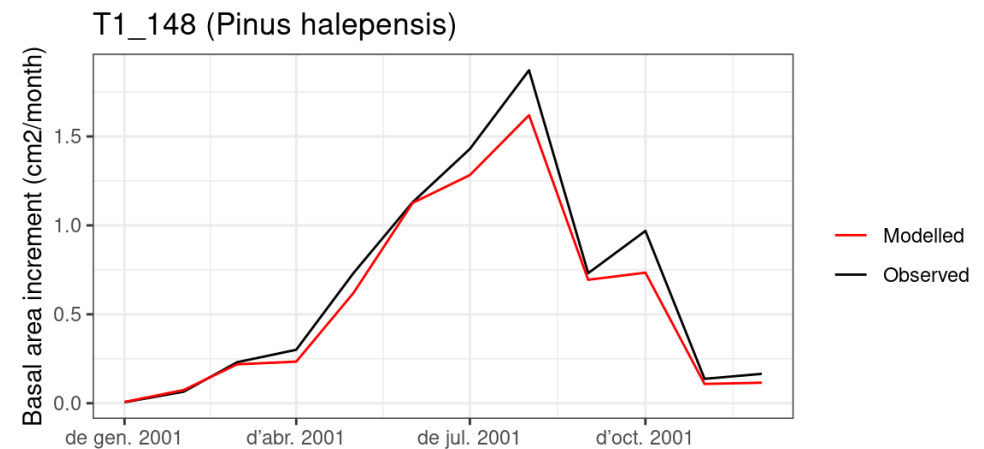
Evaluation plot

Assuming we want to evaluate the predictive capacity of the model in terms of monthly basal area increment for the *pine cohort* (i.e. T1_148), we can plot the relationship between observed and predicted values using `evaluation_plot()`:

```
1 evaluation_plot(G, exampleobs, "BAI",
2               cohort = "T1_148",
3               temporalResolution = "month",
4               plotType = "scatter")
```



```
1 evaluation_plot(G, exampleobs, "BAI",
2               cohort = "T1_148",
3               temporalResolution = "month",
4               plotType = "dynamics")
```



Using `temporalResolution = "month"` we indicate that simulated and observed data should be temporally aggregated to conduct the comparison.

The following code would help us quantifying the *strength* of the relationship:

```
1 evaluation_stats(G, exampleobs, "BAI", cohort = "T1_148", temporalResolution = "month")
```

n	Bias	Bias.rel	MAE	MAE.rel	r
12.000000000	-0.07781339	-12.01831387	0.07962106	12.29751007	0.99395791
NSE	NSE.abs				
0.95935190	0.83966426				

4. Forest dynamics

Forest dynamics run

Weather preparation

In this vignette we will fake a three-year weather input by repeating the example weather data frame four times:

```
1 meteo <- rbind(examplemeteo, examplemeteo, examplemeteo, examplemeteo)
```

we need to update the dates in row names so that they span four consecutive years:

```
1 meteo$dates <- seq(as.Date("2001-01-01"),
2                   as.Date("2004-12-30"), by="day")
```

Simulation

The call to `fordyn()` has the following form:

```
1 fd<-fordyn(exampleforest, examplesoil, SpParamsMED, meteo, control,
2           latitude = 41.82592, elevation = 100)
```

```
Simulating year 2001 (1/4): (a) Growth/mortality, (b) Regeneration nT = 2 nS = 1
Simulating year 2002 (2/4): (a) Growth/mortality, (b) Regeneration nT = 2 nS = 1
Simulating year 2003 (3/4): (a) Growth/mortality, (b) Regeneration nT = 2 nS = 1
Simulating year 2004 (4/4): (a) Growth/mortality, (b) Regeneration nT = 2 nS = 1
```



Important

- `fordyn()` operates on `forest` objects directly, instead of using an intermediary object (such as `spwbInput` and `growthInput`).
- `fordyn()` calls function `growth()` internally for each simulated year, but all console output from `growth()` is hidden.

Forest dynamics output (1)

As with other models, the output of `fordyn()` is a list, which has the following elements:

Elements	Information
<code>StandSummary</code> , <code>SpeciesSummary</code> , <code>CohortSummary</code>	<i>Annual</i> summary statistics at different levels
<code>TreeTable</code> , <code>ShrubTable</code>	Structural variables of living cohorts at each annual time step.
<code>DeadTreeTable</code> , <code>DeadShrubTable</code>	Structural variables of dead cohorts at each annual time step
<code>CutTreeTable</code> , <code>CutShrubTable</code>	Structural variables of cut cohorts at each annual time step
<code>ForestStructures</code>	Vector of <code>forest</code> objects at each time step.
<code>GrowthResults</code>	Result of internally calling <code>growth()</code> at each time step.
<code>ManagementArgs</code>	Management arguments for a subsequent call to <code>fordyn()</code> .
<code>NextInputObject</code> , <code>NextForestObject</code>	Objects <code>growthInput</code> and <code>forest</code> to be used in a subsequent call to <code>fordyn()</code> .

Forest dynamics output (2)

For example, we can compare the initial `forest` object with the final one:

```
1 exampleforest
```

```
$treeData
      Species    N   DBH Height Z50  Z95
1 Pinus halepensis 168 37.55   800 100  600
2   Quercus ilex 384 14.60   660 300 1000

$shrubData
      Species Cover Height Z50  Z95
1 Quercus coccifera 3.75    80 200 1000

$herbCover
[1] 10

$herbHeight
[1] 20

$seedBank
[1] Species Percent
<0 files> (o «row.names» de longitud 0)

attr(,"class")
[1] "forest" "list"
```

```
1 fd$NextForestObject
```

```
$treeData
      Species      DBH   Height      N Z50  Z95
1 Pinus halepensis 38.01410 824.7217 166.7796 100  600
2   Quercus ilex 15.04679 673.8471 382.6513 300 1000

$shrubData
      Species Height   Cover Z50  Z95
1 Quercus coccifera 75.4552 3.237287 200 1000

$herbCover
[1] 10

$herbHeight
[1] 20

$seedBank
      Species Percent
1 Pinus halepensis   100
2   Quercus ilex    100
3 Quercus coccifera   100

attr(,"class")
[1] "forest" "list"
```

Forest dynamics output (3)

The output includes **summary statistics** that describe the structural and compositional state of the forest corresponding to *each annual time step*.

For example, we can access *stand-level* statistics using:

```
1 fd$StandSummary
```

	Step	NumTreeSpecies	NumTreeCohorts	NumShrubSpecies	NumShrubCohorts
1	0	2	2	1	1
2	1	2	2	1	1
3	2	2	2	1	1
4	3	2	2	1	1
5	4	2	2	1	1
	TreeDensityLive	TreeBasalAreaLive	DominantTreeHeight	DominantTreeDiameter	
1	552.0000	25.03330	800.0000	37.55000	
2	551.3663	25.20814	806.2122	37.66571	
3	550.7269	25.38313	812.4144	37.78185	
4	550.0818	25.55825	818.5877	37.89804	
5	549.4309	25.73303	824.7217	38.01410	
	QuadraticMeanTreeDiameter	HartBeckingIndex	ShrubCoverLive	BasalAreaDead	
1	24.02949	53.20353	3.750000	0.00000000	
2	24.12711	52.82391	3.092051	0.03917375	
3	24.22476	52.45105	3.139858	0.03983747	
4	24.32243	52.08602	3.188231	0.04050957	
5	24.41991	51.72923	3.237287	0.04118879	
	ShrubCoverDead	BasalAreaCut	ShrubCoverCut		
1	0.000000000	0	0		
2	0.005308898	0	0		
3	0.004784468	0	0		
4	0.004858342	0	0		
5	0.004933117	0	0		

Forest dynamics output (4)

Another useful output of `fordyn()` are tables in long format with cohort structural information (i.e. DBH, height, density, etc) for each time step:

```
1 fd$TreeTable
```

	Step	Year	Cohort	Species	DBH	Height	N	Z50	Z95	ObsID
1	0	NA	T1_148	Pinus halepensis	37.55000	800.0000	168.0000	100	600	<NA>
2	0	NA	T2_168	Quercus ilex	14.60000	660.0000	384.0000	300	1000	<NA>
3	1	2001	T1_148	Pinus halepensis	37.66571	806.2122	167.6992	100	600	<NA>
4	1	2001	T2_168	Quercus ilex	14.71218	663.4915	383.6671	300	1000	<NA>
5	2	2002	T1_148	Pinus halepensis	37.78185	812.4144	167.3956	100	600	<NA>
6	2	2002	T2_168	Quercus ilex	14.82389	666.9588	383.3314	300	1000	<NA>
7	3	2003	T1_148	Pinus halepensis	37.89804	818.5877	167.0890	100	600	<NA>
8	3	2003	T2_168	Quercus ilex	14.93552	670.4135	382.9928	300	1000	<NA>
9	4	2004	T1_148	Pinus halepensis	38.01410	824.7217	166.7796	100	600	<NA>
10	4	2004	T2_168	Quercus ilex	15.04679	673.8471	382.6513	300	1000	<NA>



Note

The `NA` values in `Year` correspond to the initial state.

Forest dynamics output (5)

The same information can be shown for trees that are predicted to die during each simulated year:

```
1 fd$DeadTreeTable
```

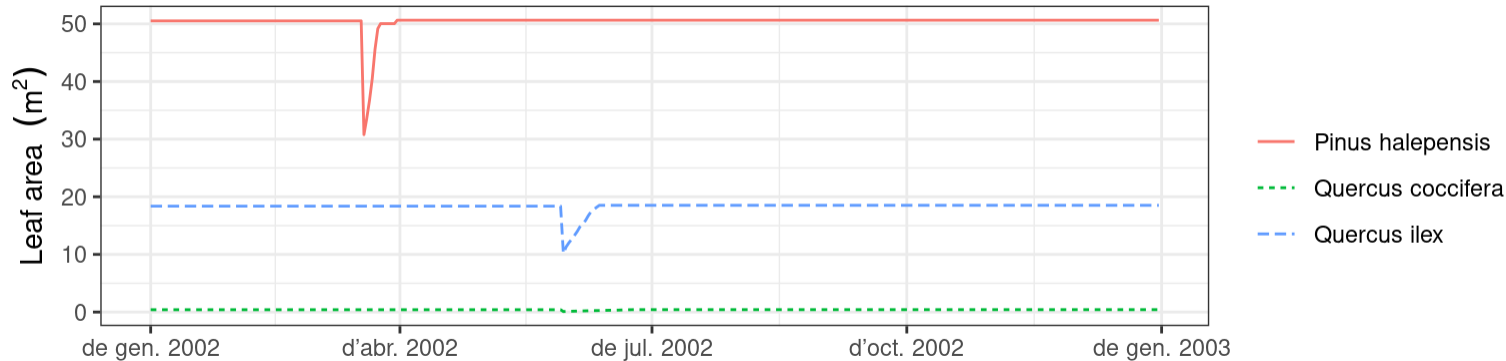
	Step	Year	Cohort	Species	DBH	Height	N	N_starvation
1	1	2001	T1_148	Pinus halepensis	37.66571	806.2122	0.3007828	0
2	1	2001	T2_168	Quercus ilex	14.71218	663.4915	0.3328893	0
3	2	2002	T1_148	Pinus halepensis	37.78185	812.4144	0.3036481	0
4	2	2002	T2_168	Quercus ilex	14.82389	666.9588	0.3357419	0
5	3	2003	T1_148	Pinus halepensis	37.89804	818.5877	0.3065253	0
6	3	2003	T2_168	Quercus ilex	14.93552	670.4135	0.3386082	0
7	4	2004	T1_148	Pinus halepensis	38.01410	824.7217	0.3094089	0
8	4	2004	T2_168	Quercus ilex	15.04679	673.8471	0.3414828	0

	N_dessication	N_burnt	Z50	Z95	ObsID
1	0	0	100	600	<NA>
2	0	0	300	1000	<NA>
3	0	0	100	600	<NA>
4	0	0	300	1000	<NA>
5	0	0	100	600	<NA>
6	0	0	300	1000	<NA>
7	0	0	100	600	<NA>
8	0	0	300	1000	<NA>

Post-processing

Accessing elements of `GrowthResults`, we can extract, summarize or plot simulation results for a particular year:

```
1 plot(fd$GrowthResults[[2]], "LeafArea", bySpecies = TRUE)
```



It is also possible to plot the whole series of results by passing a `fordyn` object to the `plot()` function:

```
1 plot(fd, "LeafArea", bySpecies = TRUE)
```



Finally, we can create interactive plots using function `shinyplot()`, in the same way as with other simulations.

5. Forest dynamics including management

Running simulations with management

`fordyn()` allows the user to supply an *arbitrary* function implementing a desired management strategy for the stand whose dynamics are to be simulated.

The package includes an in-built default function called `defaultManagementFunction()` along management parameter defaults provided by function `defaultManagementArguments()`.

To run simulations with management we need to define (and modify) management arguments...

```
1 # Default arguments
2 args <- defaultManagementArguments()
3 # Here one can modify defaults before calling fordyn()
4 #
```

... and call `fordyn()` specifying the management function and its arguments:

```
1 fd<-fordyn(exampleforest, examplesoil, SpParamsMED, meteo, control,
2           latitude = 41.82592, elevation = 100,
3           management_function = defaultManagementFunction,
4           management_args = args)
```

When management is included, tables `CutTreeTable` and `CutShrubTable` will contain extraction data:

```
1 fd$CutTreeTable
2 fd$CutShrubTable
```

Forest management parameters (1)

Function `defaultManagementArguments()` returns a list with default values for *management parameters* to be used in conjunction with `defaultManagementFunction()`:

Element	Description
<code>type</code>	Management model, either ‘regular’ or ‘irregular’
<code>targetTreeSpecies</code>	Either "all" for unspecific cuttings or a numeric vector of target tree species to be selected for cutting operations
<code>thinning</code>	Kind of thinning to be applied in irregular models or in regular models before the final cuts. Options are "below", "above", "systematic", "below-systematic", "above-systematic" or a string with the proportion of cuts to be applied to different diameter sizes
<code>thinningMetric</code>	The stand-level metric used to decide whether thinning is applied, either "BA" (basal area), "N" (density) or "HB" (Hart-Becking index)
<code>thinningThreshold</code>	The threshold value of the stand-level metric causing the thinning decision
<code>thinningPerc</code>	Percentage of stand’s basal area to be removed in thinning operations
<code>minThinningInterval</code>	Minimum number of years between thinning operations
<code>finalMeanDBH</code>	Mean DBH threshold to start final cuts
<code>finalPerc</code>	String with percentages of basal area to be removed in final cuts, separated by ‘-’ (e.g. “40-60-100”)
<code>finalYearsBetweenCuts</code>	Number of years separating final cuts

Forest management parameters (2)

The same list includes *state variables* for management (these are modified during the simulation):

Element	Description
<code>yearsSinceThinning</code>	State variable to count the years since the last thinning occurred
<code>finalPreviousStage</code>	Integer state variable to store the stage of final cuts ('0' before starting final cuts)
<code>finalYearsToCut</code>	State variable to count the years to be passed before new final cut is applied.



Tip

Instead of using the in-built management function, you could code your own management function and specify its own set of parameters!



M.C. Escher - Up and down, 1947