Developing a Basal Area Growth model
(R-Studio – Application)

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▪How do we build a forest growth model?

✓ Stages in model development:

- Selection of the model type (e.g. empirical, process-based, tree level, stand level, etc)
- Data collection / gathering (data pre-analysis: graphs, summary statistics)
- Designing the structure of the model (e.g. selecting the variables and defining their relationships)
- Evaluation of the model
- Implementation of the model in a computer program/integration of the model in a forest simulator

▪How do we build a forest growth model?

✓ Stages in model development:

These are the stages for developing a whole model (covering all important tree/stand variables)

In this class we'll focus on the development of two equations:

Basal area growth

(to be integrated into the growth module of the model)

Basal area initialization

(to be integrated into the initialization module of the model)

Selection of the model type

- ✓ Empirical stand level basal area growth model

Data collection / gathering

- ✓ Maritime pine ForChange Database
  - Thinning trials
    - São Salvador
    - Leiria National Forest – Group A
    - Leiria National Forest – Group B
    - Pinhal da Cré
  - Pre-analysis of the data set to detect some inconsistencies, missing values etc
    - Graphs of variables: over time (e.g. (t, G)), as a function of one another (e.g. (d, h))
    - Calculus of summary statistics: nr of observations, nr of non-null observations, min, mean and max values of the variables

Data collection / gathering

✓ Maritime pine ForChange Database

– Thinning trials

- São Salvador
- Leiria National Forest – Group A
- Leiria National Forest – Group B
- Pinhal da Cré

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Cod_Par	Cod_Par_Med	Area	Id_status	Status	t	hdom	N	G	dgdom	dg	V	Ww	Wb	Wbr	Wl	Wr
2	L2B101	L2B1011992	1000	1	BT	22	12.89	1640	33.29	20.97	16.08	156.40	42.37	9.18	12.05	8.46	19.86
3	L2B101	L2B1011992	1000	2	AT	22	12.89	1080	25.52	20.97	17.34	156.40	42.37	9.18	12.05	8.46	19.86
4	L2B101	L2B1011993	1000	1	BT	23	13.24	1080	26.29	21.50	17.61	164.65	45.44	9.65	12.58	8.61	21.02
5	L2B101	L2B1011994	1000	1	BT	24	13.7	1080	26.26	21.55	17.60	167.52	47.23	9.84	12.56	8.48	21.53
6	L2B101	L2B1011995	1000	1	BT	25	14.1	1080	28.68	22.43	18.39	190.72	54.05	10.91	14.22	9.09	24.33
7	L2B101	L2B1011996	1000	1	BT	26	14.57	1080	30.00	22.88	18.81	204.34	58.69	11.60	15.12	9.38	26.12
8	L2B101	L2B1011997	1000	1	BT	27	15.04	1080	31.14	23.30	19.16	186.58	53.44	10.14	13.66	7.92	23.47
9	L2B101	L2B1011997	1000	2	AT	27	15.04	810	25.95	23.30	20.20	186.58	53.44	10.14	13.66	7.92	23.47
10	L2B101	L2B1012000	1000	1	BT	30	16.32	810	30.85	25.48	22.02	239.88	70.60	12.55	17.40	9.07	30.21
11	L2B102	L2B1021992	1000	1	BT	22	10.86	2000	29.03	18.49	13.66	116.35	33.57	8.01	9.49	7.87	16.24
12	L2B102	L2B1021992	1000	2	AT	22	10.86	1200	21.91	18.49	15.25	116.35	33.57	8.01	9.49	7.87	16.24
13	L2B102	L2B1021993	1000	1	BT	23	11.52	1200	22.74	18.87	15.53	127.66	37.12	8.47	10.00	7.86	17.49

Data collection / gathering

✓ Maritime pine ForChange Database

– Thinning trials - data description

Ensaio	Name of the thinning trial
Cod_Par	Id of the plot in the thinning trial
Cod_Par_Med	Id of the plot in the thinning trial containing the year of management
Area	Plot area m^2
Id_status	Id of thinning occurrence (1 if not thinned; 2 if thinned)
Status	Thinning status (AT if after thinned; BT if before thinned)
t	Stand age (years)
hdom	Dominant height (m)
N	Number of trees per hectare (ha^{-1})
G	Stand basal area (m^2 ha^{-1})
dgdom	Quadratic mean dbh of dominant trees (cm)
dg	Quadratic mean dbh (cm)
V	Stand volume (m^3 ha^{-1})
Wi	Stand biomass by tree component: w – wood; l – leaves; b-bark; br- branches; r – roots (ton ha^{-1})

Designing the structure of the model

✓ Expressing the parameters as a function of stand variables
(*these were calculated in the excel file **Sheet: All** before the file was imported to R-Studio*)

– N (already in the original excel file)

– Fw - *Wilson factor*

$$Fw = \frac{\sqrt{1000/N}}{hdom} = \frac{100}{hdom\ \sqrt{N}}$$

– S - site index

Choose the stand age closest to pine base age (50 years) to **estimate S** and assign the same S values for all ages (Vlookup excel function)

– ImpT - thinning impact (G_{AT}/G_{BT})
– tst - time since last thinning
– dummyT - after 5 years thinning ceases to impact growth

For the variables related to thinning, follow what I did in excel (if excel function)

Data collection / gathering

✓ For pairing the data

(*this was done after sorting by plot, and t in excel file* ***Sheet: lag****, follow the green rows that break for the blue headers and look at the G values (e.g.)*

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Cod_Par	Cod_Par	Area	Id_statu	Status	tst	dummyT	ImpT	S	t1	FW1	N1	G1	Cod_Par	t2	FW2	N2	G2	id
2	L2B101	L2B101199	1000	1	BT	0	1	#VALUE!	23.23946	22	0.191569	1640	33.2948	L2B101	22	0.236067	1080	25.51789	1
3	L2B101	L2B101199	1000	2	AT	0	1	0.766423	23.23946	22	0.236067	1080	25.51789	L2B101	23	0.229827	1080	26.29167	0
4	L2B101	L2B101199	1000	1	BT	1	1	0.689781	23.23946	23	0.229827	1080	26.29167	L2B101	24	0.22211	1080	26.26337	0
5	L2B101	L2B101199	1000	1	BT	2	1	0.613138	23.23946	24	0.22211	1080	26.26337	L2B101	25	0.215809	1080	28.68453	0
6	L2B101	L2B101199	1000	1	BT	3	1	0.536496	23.23946	25	0.215809	1080	28.68453	L2B101	26	0.208847	1080	29.99911	0
7	L2B101	L2B101199	1000	1	BT	4	1	0.459854	23.23946	26	0.208847	1080	29.99911	L2B101	27	0.202321	1080	31.14257	0
8	L2B101	L2B101199	1000	1	BT	5	1	0.383211	23.23946	27	0.202321	1080	31.14257	L2B101	27	0.23362	810	25.95132	1
9	L2B101	L2B101199	1000	2	AT	0	1	0.833307	23.23946	27	0.23362	810	25.95132	L2B101	30	0.215297	810	30.85258	0
10	L2B101	L2B101200	1000	1	BT	3	1	0.583315	23.23946	30	0.215297	810	30.85258	L2B102	22	0.205899	2000	29.03484	1
11	L2B102	L2B102199	1000	1	BT	0	1	0.833307	20.91094	22	0.205899	2000	29.03484	L2B102	22	0.265815	1200	21.91253	1
12	L2B102	L2B102199	1000	2	AT	0	1	0.754698	20.91094	22	0.265815	1200	21.91253	L2B102	23	0.250586	1200	22.73606	0
13	L2B102	L2B102199	1000	1	BT	1	1	0.679228	20.91094	23	0.250586	1200	22.73606	L2B102	24	0.245055	1200	22.77495	0
14	L2B102	L2B102199	1000	1	BT	2	1	0.603758	20.91094	24	0.245055	1200	22.77495	L2B102	25	0.232803	1200	24.60031	0
15	L2B102	L2B102199	1000	1	BT	3	1	0.528288	20.91094	25	0.232803	1200	24.60031	L2B102	26	0.227303	1200	25.57468	0
16	L2B102	L2B102199	1000	1	BT	4	1	0.452819	20.91094	26	0.227303	1200	25.57468	L2B102	27	0.219358	1200	26.64912	0
17	L2B102	L2B102199	1000	1	BT	5	1	0.377349	20.91094	27	0.219358	1200	26.64912	L2B102	27	0.270353	790	20.13067	1
18	L2B102	L2B102199	1000	2	AT	0	1	0.755397	20.91094	27	0.270353	790	20.13067	L2B102	30	0.24776	790	23.95664	0
19	L2B102	L2B102200	1000	1	BT	3	1	0.528778	20.91094	30	0.24776	790	23.95664	L2B103	22	0.243883	1830	26.18681	1
20	L2B103	L2B103199	1000	1	BT	0	1	0.755397	18.87053	22	0.243883	1830	26.18681	L2B103	22	0.268485	1510	23.40875	1
21	L2B103	L2B103199	1000	2	AT	0	1	0.893914	18.87053	22	0.268485	1510	23.40875	L2B103	23	0.258896	1510	24.07585	0
22	L2B103	L2B103199	1000	1	BT	1	1	0.804522	18.87053	23	0.258896	1510	24.07585	L2B103	24	0.249968	1510	23.90761	0
23	L2B103	L2B103199	1000	1	BT	2	1	0.715131	18.87053	24	0.249968	1510	23.90761	L2B103	25	0.234374	1510	26.04909	0
24	L2B103	L2B103199	1000	1	BT	3	1	0.62574	18.87053	25	0.234374	1510	26.04909	L2B103	26	0.233841	1510	26.80791	0

Data collection / gathering

- ✓ After pairing – eliminate bad pairs

  (*an id to identify rows with the same age and different plots paired were identified, follow the red values*)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Cod_Par	Cod_Par	Area	Id_statu	Status	tst	dummyT	ImpT	S	t1	FW1	N1	G1	Cod_Par	t2	FW2	N2	G2	id
2	L2B101	L2B101199	1000	1	BT	0	1	#VALUE!	23.23946	22	0.191569	1640	33.2948	L2B101	22	0.236067	1080	25.51789	1
3	L2B101	L2B101199	1000	2	AT	0	1	0.766423	23.23946	22	0.236067	1080	25.51789	L2B101	23	0.229827	1080	26.29167	0
4	L2B101	L2B101199	1000	1	BT	1	1	0.689781	23.23946	23	0.229827	1080	26.29167	L2B101	24	0.22211	1080	26.26337	0
5	L2B101	L2B101199	1000	1	BT	2	1	0.613138	23.23946	24	0.22211	1080	26.26337	L2B101	25	0.215809	1080	28.68453	0
6	L2B101	L2B101199	1000	1	BT	3	1	0.536496	23.23946	25	0.215809	1080	28.68453	L2B101	26	0.208847	1080	29.99911	0
7	L2B101	L2B101199	1000	1	BT	4	1	0.459854	23.23946	26	0.208847	1080	29.99911	L2B101	27	0.202321	1080	31.14257	0
8	L2B101	L2B101199	1000	1	BT	5	1	0.383211	23.23946	27	0.202321	1080	31.14257	L2B101	27	0.23362	810	25.95132	1
9	L2B101	L2B101199	1000	2	AT	0	1	0.833307	23.23946	27	0.23362	810	25.95132	L2B101	30	0.215297	810	30.85258	0
10	L2B101	L2B101200	1000	1	BT	3	1	0.583315	23.23946	30	0.215297	810	30.85258	L2B102	22	0.205899	2000	29.03484	1
11	L2B102	L2B102199	1000	1	BT	0	1	0.833307	20.91094	22	0.205899	2000	29.03484	L2B102	22	0.265815	1200	21.91253	1
12	L2B102	L2B102199	1000	2	AT	0	1	0.754698	20.91094	22	0.265815	1200	21.91253	L2B102	23	0.250586	1200	22.73606	0
13	L2B102	L2B102199	1000	1	BT	1	1	0.679228	20.91094	23	0.250586	1200	22.73606	L2B102	24	0.245055	1200	22.77495	0
14	L2B102	L2B102199	1000	1	BT	2	1	0.603758	20.91094	24	0.245055	1200	22.77495	L2B102	25	0.232803	1200	24.60031	0
15	L2B102	L2B102199	1000	1	BT	3	1	0.528288	20.91094	25	0.232803	1200	24.60031	L2B102	26	0.227303	1200	25.57468	0
16	L2B102	L2B102199	1000	1	BT	4	1	0.452819	20.91094	26	0.227303	1200	25.57468	L2B102	27	0.219358	1200	26.64912	0
17	L2B102	L2B102199	1000	1	BT	5	1	0.377349	20.91094	27	0.219358	1200	26.64912	L2B102	27	0.270353	790	20.13067	1
18	L2B102	L2B102199	1000	2	AT	0	1	0.755397	20.91094	27	0.270353	790	20.13067	L2B102	30	0.24776	790	23.95664	0
19	L2B102	L2B102200	1000	1	BT	3	1	0.528778	20.91094	30	0.24776	790	23.95664	L2B103	22	0.243883	1830	26.18681	1
20	L2B103	L2B103199	1000	1	BT	0	1	0.755397	18.87053	22	0.243883	1830	26.18681	L2B103	22	0.268485	1510	23.40875	1
21	L2B103	L2B103199	1000	2	AT	0	1	0.893914	18.87053	22	0.268485	1510	23.40875	L2B103	23	0.258896	1510	24.07585	0
22	L2B103	L2B103199	1000	1	BT	1	1	0.804522	18.87053	23	0.258896	1510	24.07585	L2B103	24	0.249968	1510	23.90761	0
23	L2B103	L2B103199	1000	1	BT	2	1	0.715131	18.87053	24	0.249968	1510	23.90761	L2B103	25	0.234374	1510	26.04909	0

Data collection / gathering

- ✓ Final dataset

  (*delete all rows with id=1 to get the good dataset excel file* ***Sheet: delete_bad***)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Cod_Par	Cod_Par	Area	Id_statu	Status	tst	dummyT	ImpT	S	t1	FW1	N1	G1	Cod_Par	t2	FW2	N2	G2	id
2	L2B101	L2B101199	1000	2	AT	0	1	0.766423	23.23946	22	0.236067	1080	25.51789	L2B101	23	0.229827	1080	26.29167	0
3	L2B101	L2B101199	1000	1	BT	1	1	0.689781	23.23946	23	0.229827	1080	26.29167	L2B101	24	0.22211	1080	26.26337	0
4	L2B101	L2B101199	1000	1	BT	2	1	0.613138	23.23946	24	0.22211	1080	26.26337	L2B101	25	0.215809	1080	28.68453	0
5	L2B101	L2B101199	1000	1	BT	3	1	0.536496	23.23946	25	0.215809	1080	28.68453	L2B101	26	0.208847	1080	29.99911	0
6	L2B101	L2B101199	1000	1	BT	4	1	0.459854	23.23946	26	0.208847	1080	29.99911	L2B101	27	0.202321	1080	31.14257	0
7	L2B101	L2B101199	1000	2	AT	0	1	0.833307	23.23946	27	0.23362	810	25.95132	L2B101	30	0.215297	810	30.85258	0
8	L2B102	L2B102199	1000	2	AT	0	1	0.754698	20.91094	22	0.265815	1200	21.91253	L2B102	23	0.250586	1200	22.73606	0
9	L2B102	L2B102199	1000	1	BT	1	1	0.679228	20.91094	23	0.250586	1200	22.73606	L2B102	24	0.245055	1200	22.77495	0
10	L2B102	L2B102199	1000	1	BT	2	1	0.603758	20.91094	24	0.245055	1200	22.77495	L2B102	25	0.232803	1200	24.60031	0
11	L2B102	L2B102199	1000	1	BT	3	1	0.528288	20.91094	25	0.232803	1200	24.60031	L2B102	26	0.227303	1200	25.57468	0
12	L2B102	L2B102199	1000	1	BT	4	1	0.452819	20.91094	26	0.227303	1200	25.57468	L2B102	27	0.219358	1200	26.64912	0
13	L2B102	L2B102199	1000	2	AT	0	1	0.755397	20.91094	27	0.270353	790	20.13067	L2B102	30	0.24776	790	23.95664	0
14	L2B103	L2B103199	1000	2	AT	0	1	0.893914	18.87053	22	0.268485	1510	23.40875	L2B103	23	0.258896	1510	24.07585	0
15	L2B103	L2B103199	1000	1	BT	1	1	0.804522	18.87053	23	0.258896	1510	24.07585	L2B103	24	0.249968	1510	23.90761	0
16	L2B103	L2B103199	1000	1	BT	2	1	0.715131	18.87053	24	0.249968	1510	23.90761	L2B103	25	0.234374	1510	26.04909	0
17	L2B103	L2B103199	1000	1	BT	3	1	0.62574	18.87053	25	0.234374	1510	26.04909	L2B103	26	0.233841	1510	26.80791	0
18	L2B103	L2B103199	1000	1	BT	4	1	0.536348	18.87053	26	0.233841	1510	26.80791	L2B103	27	0.226534	1510	27.78183	0
19	L2B103	L2B103199	1000	2	AT	0	1	0.860501	18.87053	27	0.25846	1160	23.90629	L2B103	30	0.232558	1150	28.32965	0
20	L2B104	L2B104199	1000	2	AT	0	1	0.87891	19.60438	22	0.278178	1510	21.57807	L2B104	23	0.251311	1510	22.74183	0
21	L2B104	L2B104199	1000	1	BT	1	1	0.791019	19.60438	23	0.251311	1510	22.74183	L2B104	24	0.25009	1510	22.45663	0
22	L2B104	L2B104199	1000	1	BT	2	1	0.703128	19.60438	24	0.25009	1510	22.45663	L2B104	25	0.232259	1510	24.91302	0
23	L2B104	L2B104199	1000	1	BT	3	1	0.615237	19.60438	25	0.232259	1510	24.91302	L2B104	26	0.227938	1510	25.52682	0
24	L2B104	L2B104199	1000	1	BT	4	1	0.527346	19.60438	26	0.227938	1510	25.52682	L2B104	27	0.22223	1510	26.64111	0

Designing the structure of the model

✓ Lundqvist function

$$G_2 = A\left(\frac{G_1}{A}\right)^{\left(\frac{t_1}{t_2}\right)^{m}}$$

growth function

(*Lundqvist - k*)

$$G = A\, e^{-k\frac{1}{t^{m}}}$$

initialization function

Designing the structure of the model

✓ Guarantee the consistency between growth and initialization equations

- Fisrt, fit the growth function (with the K parameter free)
- Then, after selecting the best growth model with A and m expressed by a set of stand variables

$$G_2 = A\left(\frac{G_1}{A}\right)^{\left(\frac{t_1}{t_2}\right)^m}$$

- Use the parameter values obtained for the growth model and fix them
- Finally, find the K parameter values (with K expressed as a function of stand variables) for the initialization

$$G = A\, e^{-k\frac{1}{t^m}}$$

De … del

✓ Lundq

Table 2. Basal area: initialization function (1) and growth projection function (2).

Basal Area

$$(1)\quad G = A_G \, e^{-k_G \left(\frac{1}{t}\right)^{(n_{Gp} + n_{GN})}}$$

$$(2)\quad G_2 = A_G \left(\frac{G_1}{A_G}\right)^{\left(\frac{t_1^{\,n_{GN1}}}{t_2^{\,n_{GN2}}}\right)\left(\frac{t_1}{t_2}\right)^{(n_{Gp})}}$$

$$A_G = (a_{G0} + a_{G1}\ DR)$$

$$K_G = k_{G0} + k_{G1}\ SI + k_{G2}\ \frac{100}{SI\ \sqrt{Npl}} + k_{G3}\ rot$$

$$n_{Gp} = n_{G0} + \frac{n_{G1}}{\left(1 - \left(\frac{cota}{2000}\right)\right)} + n_{G_2} rot$$

$$n_{GNi} = n_{G3}\ \frac{N_i}{1000}$$

model	a_{G0}	a_{G1}	k_{G0}	k_{G1}	k_{G2}	k_{G3}	n_{G0}	n_{G1}	n_{G2}	n_{G3}
(1)	80.1683	0.2354	8.8294	-0.1876	3.3759	0.1180	0.4493	-0.0441	-0.0164	0.0655
(2)	80.1683	0.2354	-	-	-	-	0.4493	-0.0441	-0.0164	0.0655

Designing the structure of the model

✓ Consistency between growth and initialization equations – Globulus 3.0 model

	Inicialization		Prediction/Growth			Calculus				
t	**hdom**	**Nst**	**N**	**G**	**G_ini**	**Vu**	**Vu_st**	**Vb**	**Vs**	**dg**
1	2.2	1234	1234	0.7	0.7	0.6	0.5	0.2	0.1	2.7
2	5.9	1217	1217	2.9	2.9	6.1	5.8	1.7	0.3	5.5
3	9.1	1201	1201	5.4	5.4	17.6	17.0	4.6	0.6	7.6
4	11.8	1185	1185	7.9	7.9	33.1	32.2	8.1	0.9	9.2
5	14.2	1170	1170	10.3	10.3	51.1	49.8	11.9	1.3	10.6
6	16.2	1154	1154	12.5	12.5	70.3	68.7	15.9	1.6	11.7
7	18.0	1139	1139	14.5	14.5	90.0	88.1	19.9	1.9	12.7
8	19.6	1124	1124	16.3	16.3	109.7	107.6	23.8	2.2	13.6
9	21.0	1109	1109	18.0	18.0	129.3	126.9	27.5	2.4	14.4
10	22.3	1095	1095	19.6	19.6	148.5	145.8	31.2	2.7	15.1

Designing the structure of the model

✓ Expressing the parameters as a function of stand variables (*these were calculated in the excel file **Sheet: All** before the file was imported to R-Studio*)

- N (already in the original excel file)
- Fw - *Wilson factor*
- S - site index
- ImpT - thinning impact (G_{AT}/G_{BT})
- tst - time since last thinning
- dummyT - after 5 years thinning ceases to impact growth

$$Fw = \frac{\sqrt{1000/N}}{hdom} = \frac{100}{hdom\ \sqrt{N}}$$

Choose the stand age closest to pine base age (50 years) to **estimate S** and assign the same S values for all ages (Vlookup excel function)

For the variables related to thinning, follow what I did in excel (if excel function)

Evaluation of the model

- ✓ Testing its application,
- ✓ Checking whether the signs of the parameters make sense,
- ✓ etc

Using R-Studio

✓ Adapt the code of the previous class

✓ Copy/paste an existing R file (FittingFamiliesGrowthCurves.R)

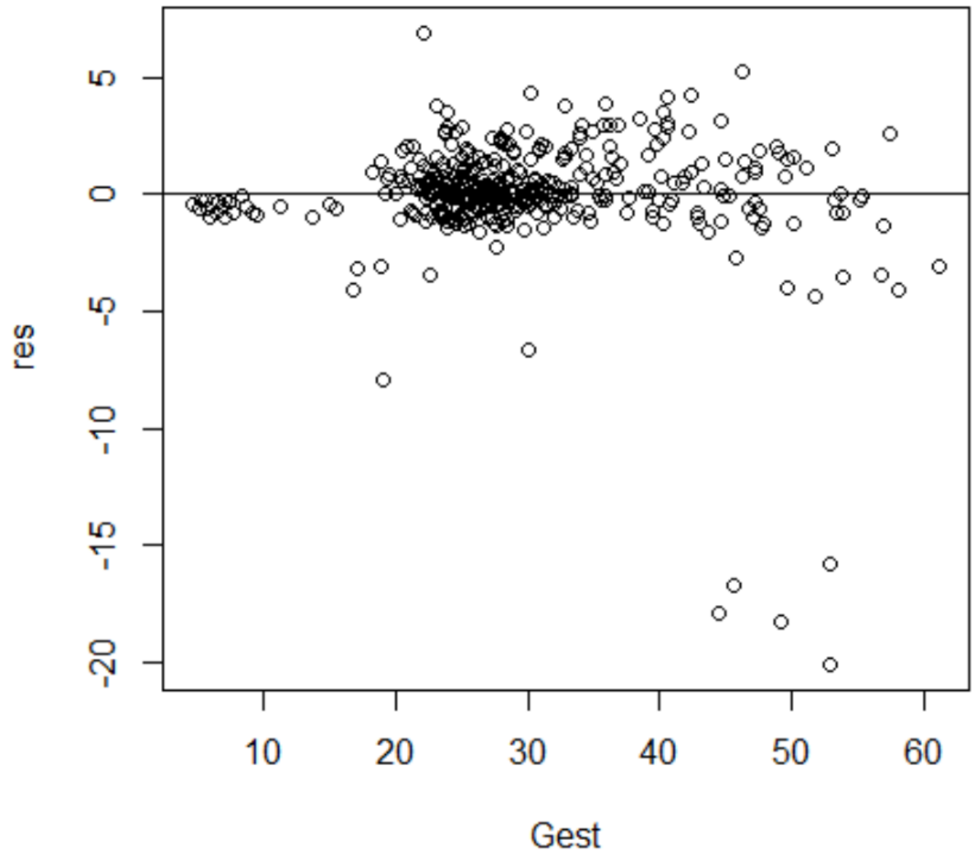
✓ Rename the file (e.g. Pine_BasalAreaGrowth.R), open it and comment (#) or delete the blocks of code we won't be using

✓ First, fit the **simplest model**

$$G_2 = A\left(\frac{G_1}{A}\right)^{\left(\frac{t_1}{t_2}\right)^m}$$

```
<- nls(G2 ~ A*(G1/A)**(t1/t2)**m,
            data=GrowthData,
             start=list(A=100,m=1))
```

Using R-Studio



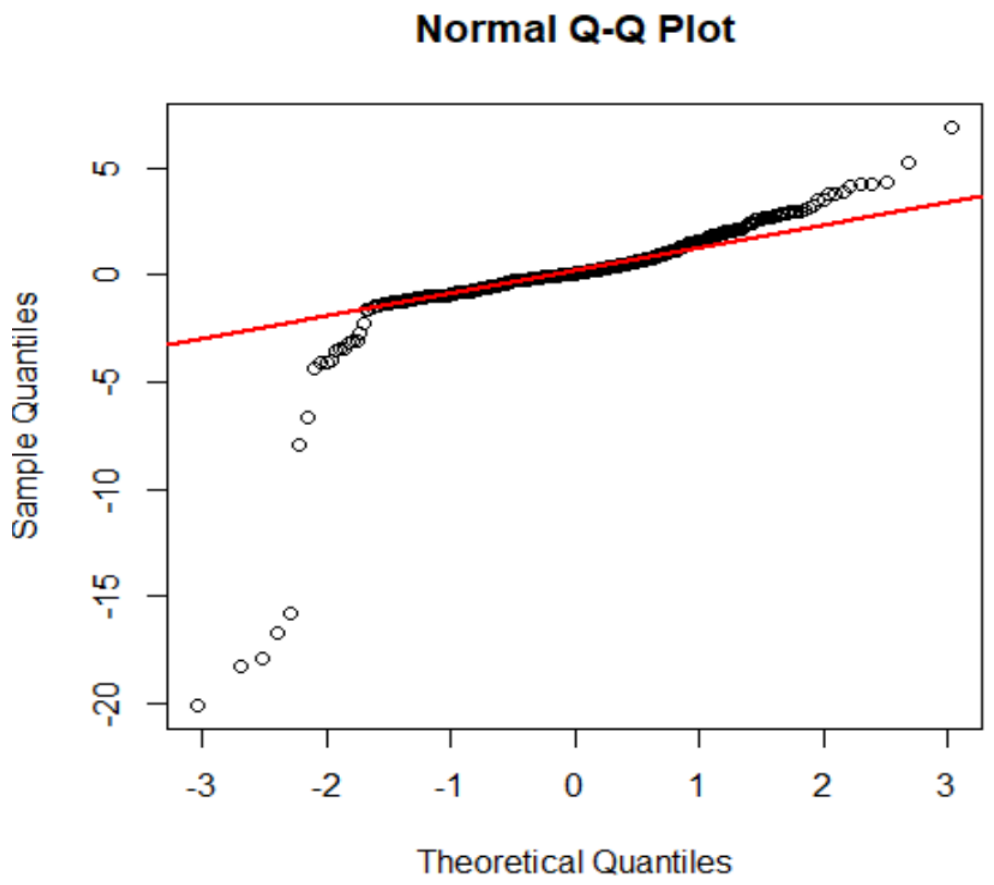
✓ res= G_2 - G_{est}

– G_2 – observed basal area in the excel file

– G_{est} – estimated basal area using the equation you tested

(the closer to zero the better the the equation you tested is)

Using R-Studio



ideally the circles would overlap the red line, when these don't it means the equation you tested requires a "correction"

Weighted regression is required (Huber)

Using R-Studio

- ✓ Test expressing the parameters as a function of any combination of stand variables you find reasonable using the parameter values obtained in the previous fit as starting values for the parameters in the current fit

```
<- nls( G2 ~ (a0+a1*S)*(G1/(a0+a1*S))**(t1/t2)**n,
              data=GrowthData,
              start=list( a0=89.11, a1=1, m=0.89))
```

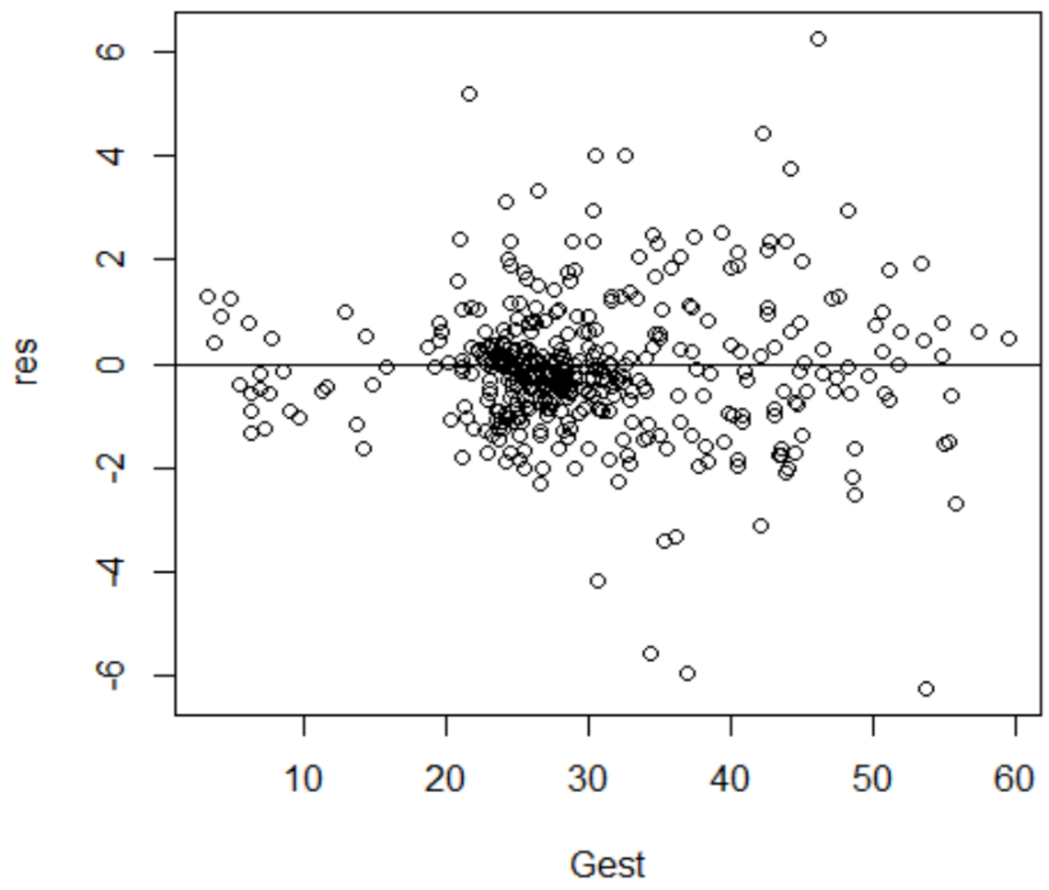
Formula: G2 ~ A * (G1/A)^(t1/t2)^n

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
A	89.10655	11.49615	7.751	6.94e-14 ***
m	0.88728	0.09138	9.710	< 2e-16 ***

- ✓ Proceed testing different combinations of variables in A and m

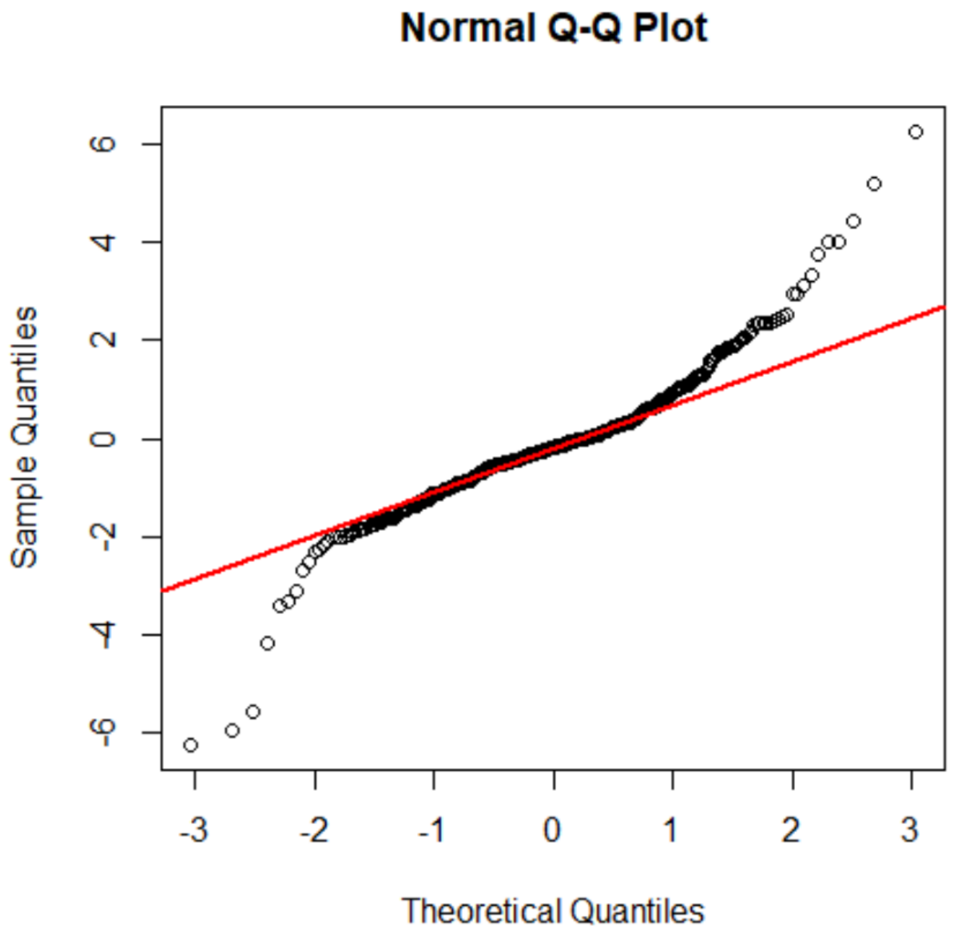
Using R-Studio



- ✓ This example, shows a smaller range of residuals (-6 , 6) opposed to the previous graph where the range was (-20 , 6)

This shows some improvement in the model

Using R-Studio



- ✓ However, the correction is still required

Using R-Studio (some examples of what I tested, but feel free to test different combinations)

```
# Load the library into R workspace.
library("xlsx")
GrowthData<-read.xlsx("SAS_paired_Pb_Class.xlsx", header= TRUE, sheetIndex = 3)
# print(GrowthData)
head(GrowthData,n=20)
Summary(GrowthData)

#BasalArea2 <- nls(G2~A*(G1/A)**(t1/t2)**m,
#               data=GrowthData,
#               start=list(A=100,m=1))
# BasalArea2 <- nls(G2~(a0+a1*S)*(G1/(a0+a1*S))**(t1/t2)**m,
#                    data=GrowthData,
#                   start=list(a0=89.11,a1=0,m=0.88728))
BasalArea2 <- nls(G2~A*(G1/A)**((t1**(m0+m1*N1/1000))/(t2**(m0+m1*N2/1000))),
              data=GrowthData,
              start=list(A=89.11,m0=0.88728, m1=0.1))
#BasalArea2 <- nls(G2~A*(G1/A)**((t1**(n0+nf1*FW1))/(t2**(n0+nf1*FW2))),
#               data=GrowthData,
#               start=list(A=100,n0=0.1, nf1=0.1))
#BasalArea2 <- nls(G2~A*(G1/A)**((t1**(n0+nf1*FW1+n2*N1/1000))/(t2**(n0+nf1*FW2+n2*N2/1000))),
#               data=GrowthData,
#               start=list(A=100,n0=0.1, nf1=0.1, n2=0.1))
#BasalArea2 <- nls(G2~A*(G1/A)**((t1**(n0+nf1*FW1+n2*N1/1000+ns*S))/(t2**(n0+nf1*FW2+n2*N2/1000+ns*S))),
#               data=GrowthData,
#               start=list(A=100,n0=0.1, nf1=0.2, n2=0.01, ns=0.1))
#BasalArea2 <- nls(G2~A*(G1/A)**((t1**(n0+nf1*FW1+n2*N1/1000+ns*S+nt*dummyT*ImpT))/(t2**(n0+nf1*FW2+n2*N2/1000+ns*S+nt*dummyT*ImpT))),
#               data=GrowthData,
#               start=list(A=89, n0=0.1, nf1=0.2, n2=0.01, ns=0.1, nt=0.1))
#BasalArea2 <- nls(G2~90*(G1/90)**((t1**(n0+nf1*FW1+n2*N1/1000+ns*S+nt*dummyT*ImpT))/(t2**(n0+nf1*FW2+n2*N2/1000+ns*S+nt*dummyT*ImpT))),
#               data=GrowthData,
#               start=list(n0=0.1, nf=0.2, n2=0.01, ns=0.1, nt=0.1))
```