GEMFORM 2017 – Users Guide and Technical Notes

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INTRODUCTION

This report is a user's guide to the GEMFORM 2017 model for tropical mixed forest in Guyana dominated by Greenheart associations. This model is based on an earlier version of GEMFORM that has been in use for some time in Guyana as a forest planning tool (Alder, 2001, 2002, 2008). This report is not an academic or peer-reviewed document and does not fully review the science and background to either the modelling or the source data. It is primarily intended to describe how to use the model, but also includes some technical notes on the design of the model and the growth functions used. It is intended later to publish this more technical material as a peer-reviewed paper, which will at that stage include the necessary review of background material and related research.

The source data for the model are the Permanent Sample Plots (PSPs) at Pibiri, Guyana. The original design, layout and treatment of these plots, and early conclusions from the study are contained in Van der Hout (1999, 2000a, 2000b). The Pibiri experiment comprises 15 PSPs of 140 x 140 m square design, subdivided into 49 20 x 20 m sub-plots, and additional quadrats within the subplots on which smaller trees are sampled more intensively. For the present work, data was used on trees measuring 20 cm dbh[1] and above. Sub-sample data on trees from 5-20 cm, although available, was not included in the current analysis because (a) there was insufficient time, and (b) such data is often not available in field inventories needed to define baselines for model scenarios.

The original GEMFORM model incorporated data from measurements in 1993, 1995, 1997 and 2000. These were combined with data from the so-called Barama plots in North eastern Guyana (see Alder, 2001, 2002) which represented different forest types. In this earlier model, there was little concrete evidence of responses to treatment, due to the short time span, in forestry terms, of the measurements, and only average growth rate data was included. The model did not show much response to treatment and did not therefore truly allow decisions to be evaluated on the optimum intensity of harvesting and the most appropriate felling cycle.

In 2013 the Guyana Forestry Commission supported the re-measurement of the plots, which was undertaken by a team led by Anand Roopsind. This work was assisted also by Peter Van der Hout as a consultant, and the University of Florida under Prof. Francis E. Putz. It has taken some years to fully clean and evaluate the re-measurements because of the difficulties cause by the long-lapse in time between re-measurements. Also, the original experiment has been slightly affected by mining encroachments, though fortunately this has not been enough to seriously damage the experimental layout.

The GEMFORM update by the present author began in August 2015 but has proceeded slowly because of re-iterations of the data cleaning and correction process, and the limited resources available which precluded full-time work on the project.

The revised model is limited in scope to the Greenheart-dominated forest, with similar common species, to that found at Pibiri. Fortunately, in terms of timber production, this is probably the most widespread and important forest type in Guyana. However, it does not include or update data from

[1] Dbh: Tree diameter measured at 1.3 m above ground, or for large buttressed trees, above convergence of the buttress, following normal forestry standards.

the Baromalli-dominated forests of the North West, or other forest types which lack Greenheart, which were included in earlier versions of GEMFORM, and this should probably be emphasized when making general conclusions about optimal felling controls for sustained yield.

DATA ANALYSIS AND MODEL BUILDING

SQL DATABASE

The original data sets were provided as an Access database for the 1993-2000 measurements, and as Excel files for the 2013 re-measurements. To facilitate analysis, these were converted into a SQL database, called PIBIRI. A copy of this database is contained in the file set for this project (see Appendix A). Subsequently, SQL (sequel) queries were used to extract the data sets for the various analyses and tables discussed in the following sections. Most of the analysis was done in Excel, in some cases using the author's own bespoke VBA macros.

PLOT AND TREATMENT SUMMARIES

The Pibiri Experiment has 15 plots and 5 treatments, with 3 replicates of each. Statistically, it is a fully-replicated randomized block design. Van der Hout (2000b) gives details including sketch maps of the layout. As noted each plot is 140 x 140 m (1.96 ha), and trees of 20 cm and above are measured on the whole plot.

Table 1 : Pibiri plots and treatments, with Basal Areas 1993-2013

Treatments		BA 20 cm+ (m2/ha)				1993-1997	1997-2013	1993-1997	1997-2013
Plot	Tmt	1993	1997	2000	2013	ΔBA	ΔBA	ΔBA%	ΔBA%
1	B	19.7	17.1	18.7	22.3	-2.6	5.1	-13%	30%
2	C	22.7	18.3	22.3	21.4	-4.4	3.1	-19%	17%
3	A	25.3	23.7	23.5	25.8	-1.6	2.1	-6%	9%
4	D	18.9	11.9	12.3	20.2	-7.0	8.3	-37%	70%
5	E	21.7	21.6	21.7	23.2	-0.1	1.6	-1%	7%
6	E	19.5	19.6	19.4	20.3	0.0	0.7	0%	4%
7	C	19.8	13.9	13.8	17.3	-5.9	3.4	-30%	25%
8	B	21.6	18.8	18.7	20.6	-2.8	1.8	-13%	9%
9	D	20.5	11.7	13.9	18.1	-8.7	6.4	-43%	54%
10	A	18.6	17.5	17.6	19.6	-1.2	2.2	-6%	12%
11	A	21.3	19.8	19.0	20.7	-1.5	0.9	-7%	5%
12	E	23.5	23.3	23.2	25.3	-0.2	2.1	-1%	9%
13	D	24.7	12.9	13.2	19.1	-11.8	6.2	-48%	48%
14	C	20.4	16.0	16.2	23.7	-4.4	7.7	-22%	48%
15	B	24.9	22.0	22.1	25.7	-3.0	3.7	-12%	17%

The treatment codes A-E and summary statistics are shown in Table 2 below. RIL indicates Reduced Impact Logging, as discussed in Van der Hout (1999).

Table 2 : Pibiri treatments and basal area reduction and recovery 1993-2013

Tmt	Description	Δ%BA 1993-1997	Δ%BA 1997-2013	Basal Area (trees 20 cm dbh+, m2/ha)			
				1993	*1997*	*2000*	*2013*
E	Control, no treatment	0%	7%	21.57	21.47	21.44	22.94
A	RIL 4 trees/ha	-7%	9%	21.74	20.30	20.05	22.03
B	RIL 8 trees/ha	-13%	19%	22.10	19.31	19.86	22.86
C	RIL 16 trees/ha	-23%	30%	20.96	16.06	17.44	20.81
D	RIL 8 trees/ha + liberation thinning	-43%	58%	21.37	12.18	13.14	19.16

It is notable that all treatments fully recovered their original basal area over the 16-year period 1997-2013, with the most intensive treatments recovering faster. All treatments except D actually exceeded their original pre-logging basal area. The basal area loss includes the actual removals in harvesting, as per the treatment description, and the associated mortality in the period 1993-97 due to damage and/or ecological disturbance. It is also notable that this recovery occurred despite the more intensive treatments also having higher long-term mortality (probably due to non-fatal damage, fungal infection, and the ecological effects of soil disturbance), which was more than compensated for by higher growth and recruitment rates.

It was found that the original GEMFORM model, which is a simple stand projection design, could not at all accommodate this dynamism in stand behavior, and seriously underestimated recovery following logging. This was true even with updated functions using the new data. It was therefore necessary to completely re-design and re-think the model to reflect this reality.

SPECIES AND SPECIES GROUPS

In previous work, particularly for GEMFORM, the author has used a system of species groups to aggregate data for analysis from the less common species, based around the methodology described in Alder et al (2002). Initially, a similar approach was adopted here. However, the Pibiri plots do not well represent extreme pioneer types, and it was difficult to relate the groups to those of the earlier GEMFORM study on a wider range of forest types. There was also a stipulation in the author's terms of reference to consider Greenheart at least as an individual species. For this reason, it was decided after some analysis of species frequencies, to model the most common 25 species, in terms of basal area above 20 cm diameter, individually, and to group

Table 3 : Top 25 species (above 20 cm dbh) by abundance in 2013

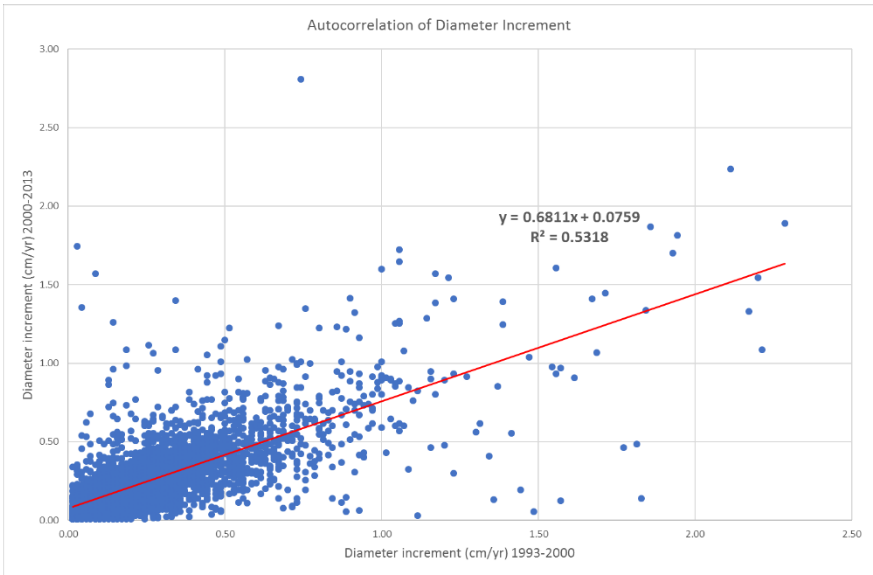
Rank	Code	Local Name	Botanical Name	Trees	% Trees	% BA	Cum% BA
1	101	Greenheart	Chlorocardium rodiei	1174	16.2%	21.8%	21.8%
2	526	Wirimiri	Lecythis confertiflora	876	12.1%	10.2%	32.0%
3	202	Wallaba, soft	Eperua falcata	253	3.5%	8.0%	40.0%
4	452	Morabukea	Mora gongrijpii	367	5.1%	6.5%	46.4%
5	503	Baromalli, sand	Catostemma fragrans	601	8.3%	5.4%	51.8%
6	326	Wamara	Swartzia leiocalycina	226	3.1%	4.2%	56.0%
7	702	Parakusan	Swartzia jenmanii	57	0.8%	3.8%	59.8%
8	307	Crabwood	Carapa guianensis	348	4.8%	3.6%	63.4%
9	317	Purpleheart	Peltogyne venosa	51	0.7%	2.4%	65.7%
10	729	Yaruru	Aspidosperma exselsum	93	1.3%	2.0%	67.8%
11	578	Kautaballi	Licania alba	252	3.5%	2.0%	69.7%
12	519	Kakaralli, black	Eschweilera sagotiana	219	3.0%	1.9%	71.6%
13	789	Sarebebeballi	Vouacapoua macropetala	171	2.4%	1.9%	73.5%
14	523	Kakaralli, smooth leaf	Eschweilera coriacea	136	1.9%	1.4%	74.9%
15	587	Marishiballi	Licania cf. canescens	245	3.4%	1.4%	76.3%
16	312	Kabukalli	Goupia glabra	47	0.6%	1.2%	77.5%
17	501	Baromalli, swamp	Catostemma commune	65	0.9%	1.1%	78.6%
18	770	Ruri	Chaetocarpus schomburgkianus	138	1.9%	1.0%	79.6%
19	511	Itikiboroballi	Swartzia benthamiana	58	0.8%	0.8%	80.4%
20	319	Silverballi, kereti	Ocotea puberula	66	0.9%	0.7%	81.1%
21	707	Trysil	Pentaclethra macroloba	100	1.4%	0.7%	81.7%
22	723	Aruadan	Sloanea guianensis	73	1.0%	0.5%	82.2%
23	584	Kudibiushi	Micropholis venulosa	68	0.9%	0.5%	82.8%
24	730	Warakosa	Inga spp.	83	1.1%	0.5%	83.2%
25	525	Kakaralli, thick skin	Eschweilera wachenheimii	58	0.8%	0.3%	83.6%
		Other species		1435	19.8%	16.4%	100.0%
		Total		7260	100%	100%	

all remaining species into a single ‘other species’ category. The cut-off of 25 species, rather than say 20 or 30, was determined on the basis of having sufficient data to reasonably estimate increment, mortality and recruitment models. These top 25 species account for 85% of basal area (and therefore approximately the same proportion for volume or crown cover), and are treated individually in the model. Table 3 lists the species with their abundances in 2013, and includes only trees over 20 cm dbh.

Diameter Increment

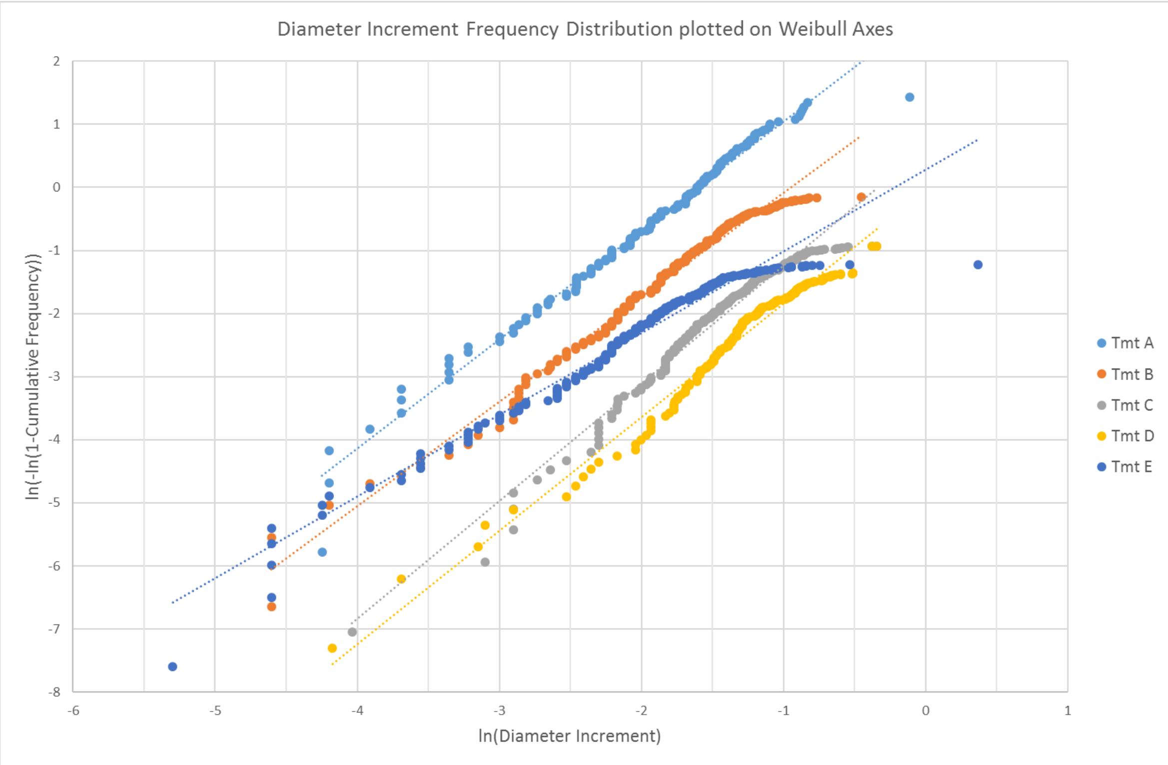
In the earlier GEMFORM, diameter increment is treated as a simple mean for a species. There is rarely a close correlation with tree size. Diameter increment is highly variable between trees of a species, and does not correlate much with plot density, sub-plot density, or local indices of competition. Increment does tend to be autocorrelated, with trees having a high increment in one period tending to have a high increment in the next.

Figure 1 : Autocorrelation of diameter increment on Pibiri Plots



Another feature of increment is that it shows a strongly left skewed frequency distribution that can be approximated by a log normal function (Mervart, 1972), or, more exactly and easily calculated, a Weibull distribution (Alder, 1995). Figure 2 shows the cumulative frequency distribution of Greenheart increments plotted on Weibull axes for the 5 treatments separately. The Weibull function (straight line) is a good approximation of the actual increment. The distributions are also clearly distinct for each of the treatments.

Figure 2 : Weibull plot of Greenheart increment frequencies for Pibiri treatments



The Weibull distribution, as used in this study, is expressed as

$$P = 1 - \exp(-\Delta d/\alpha)^{\beta}) \qquad \{eqn. 1\}$$

Where P is the probability that increment of any given tree will be less than or equal to Δd cm/yr.

The parameter α is known as the scale parameter, and β as the shape parameter. Alder (1995, pages 126-134) discusses the curve shapes, approximations for fitting the parameters and other details in the context of diameter increment and forest models. The scale parameter is closely correlated with mean increment, and corresponds to the 63rd percentile of the increment distribution.

Figure 3 : Relation between mean increment and Weibull parameters

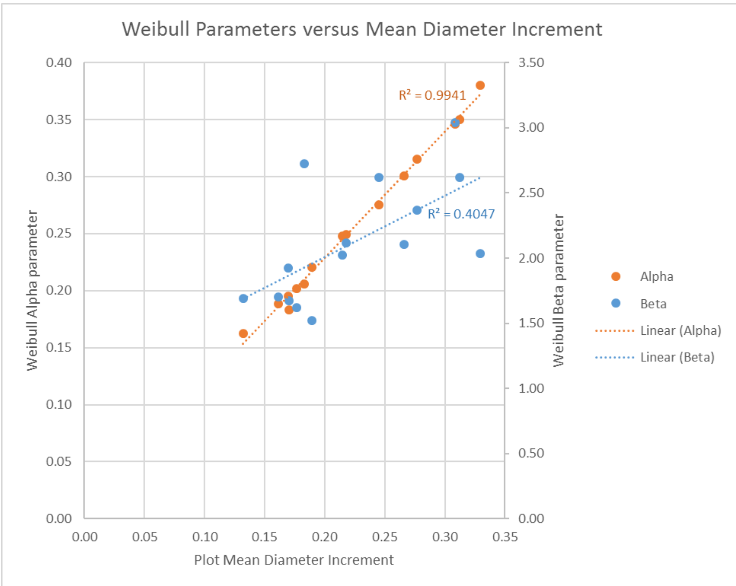


Figure 3 shows the Weibull parameters for Greenheart on each of the plots plotted against mean increment. The α parameter is very closely correlated to mean increment, with an R^2 of more than 99%, whilst the shape parameter is less so, with R^2 of 40%.

The GEMFORM 2017 model uses the probability distribution of increment to represent growth. The stand is represented by an array of 26 by 280 cells, with the rows being species (25 individual species plus one row for 'other species') and the columns being 1-cm diameter classes, from 20 to 300 cm. In each time step of the simulation, the proportions of trees for each class that grow 1 cm, 2 cm, 30 cm etc are calculated from the Weibull function for that species, as modified by stand history and other factors described below, and then added to the other classes. This method correctly accounts for the fact that there is a proportion of trees that grow much faster than the mean increment. It also maintains a realistic size-class distribution for the whole stand over time. The cells of the stand table contain tree numbers per km^2. If these fall below 1 (ie. 0.01 trees/ha), either because of the application of small transition probabilities, or due to mortality, then cell value is treated as zero.

It was found that the increment distribution, and hence mean increment, depended on indicators of treatment including the %BA Loss (% of BA reduction with treatment, including, harvest, damage and mortality), BA after treatment, and BA removed. This dependence varied between species, and was significant only for 6 out of the top 25 species, including Greenheart. Table 4 shows the mean Weibull parameters for all species and the regression coefficients and significance levels of the

Table 4 : Weibull coefficients of species increment and their dependence on stand basal area after treatment.
*Data from workbook Increment_Models_24Nov2016.xlsm, sheet SpModels. Columns from left to right are Species code (SpecNr), number of plots where found (Np), number of trees found (nt), intercept (a) and slope (b) of regression between Weibull α and plot BA after treatment, R^2, and Student's-t for slope, Probability (P) of null hypothesis being true, significance level (sig, levels *** P≤0.1%, ** P≤1%, * P≤5%) of the regression, and species common and botanical names.*

Species			*Weibull alpha from BA after treatment/felling*						Mean Weibull parameters			
SpecNr	Np	Nt	a	b	R^2	t	P	sig.	Wa	Wb	*Common Name*	Botanical Name
101	15	853	0.51231	-0.01441	74%	3.974	0.08%	***	0.2495	1.8662	*Greenheart*	*Chlorocardium rodiei*
526	15	555	0.44066	-0.01312	71%	3.654	0.15%	**	0.1946	1.7750	*Wirimiri*	*Lecythis confertiflora*
503	15	323	0.50171	-0.01321	37%	1.455	8.46%		0.2585	1.4029	*Baromalli, sand*	*Catostemma fragrans*
452	5	199	1.22520	-0.04420	95%	5.020	0.76%	**	0.4008	1.3797	*Morabukea*	*Mora gongrijpii*
202	11	163	0.37370	-0.00345	3%	0.080	46.90%		0.3022	1.9960	*Wallaba, soft*	*Eperua falcata*
307	9	158	1.09178	-0.03176	77%	3.220	0.73%	**	0.5334	1.8130	*Crabwood*	*Carapa guianensis*
326	10	128	0.47048	-0.01078	23%	0.657	26.49%		0.2563	1.2731	*Wamara*	*Swartzia leiocalycina*
519	6	140	0.65021	-0.01851	30%	0.627	28.22%		0.2330	1.7026	*Kakaralli, black*	*Eschweilera sagotiana*
578	11	143	0.32987	-0.01032	63%	2.422	1.93%	*	0.1498	1.4038	*Kautaballi*	*Licania alba*
587	10	120	0.37766	-0.01183	70%	2.765	1.22%	*	0.1695	1.7195	*Marishiballi*	*Licania cf. canescens*
789	3	96	0.61610	-0.02101	84%	1.520	18.53%		0.2074	1.5428	*Sarebebeballi*	*Vouacapoua macropetala*
523	9	89	0.46041	-0.01355	48%	1.436	9.71%		0.2216	1.6541	*Kakaralli, smooth leaf*	*Eschweilera coriacea*
729	10	58	0.67219	-0.00971	5%	0.130	44.97%		0.4627	1.4356	*Yaruru*	*Aspidosperma exselsum*
770	14	93	0.40345	-0.01397	68%	3.180	0.40%	**	0.1424	1.5118	*Ruri*	*Chaetocarpus schomburgkianus*
702	6	33	-0.38644	0.06532	48%	1.092	16.81%		1.0279	1.5062	*Parakusan*	*Swartzia jenmanii*
317	11	29	1.53738	-0.03646	28%	0.882	20.04%		0.9411	2.2575	*Purpleheart*	*Peltogyne venosa subsp. densiflora*
501	12	44	0.81706	-0.01752	9%	0.296	38.68%		0.5572	1.3597	*Baromalli, swamp*	*Catostemma commune*
511	9	38	0.31721	-0.00293	1%	0.016	49.40%		0.2325	1.6483	*Itikiboroballi*	*Swartzia benthamiana var. benthamiana*
723	9	43	0.00616	0.00825	17%	0.459	33.01%		0.1592	1.6499	*Aruadan*	*Sloanea guianensis*
707	5	48	0.74668	-0.02351	40%	0.761	25.10%		0.2588	2.0534	*Trysil*	*Pentaclethra macroloba*
312	8	22	0.63202	-0.01461	12%	0.294	38.94%		0.3952	1.2965	*Kabukalli*	*Goupia glabra*
319	6	22	1.21096	-0.03748	84%	3.104	1.80%	*	0.5254	2.4354	*Silverballi, kereti*	*Ocotea puberula*
730	7	27	0.76850	-0.02636	34%	0.799	23.02%		0.2964	1.3163	*Warakosa*	*Inga spp.*
584	7	25	0.12747	0.00905	10%	0.223	41.63%		0.3124	1.2157	*Kudibiushi*	*Micropholis venulosa*
525	7	37	0.16677	-0.00253	11%	0.251	40.61%		0.1221	1.5343	*Kakaralli, thick skin*	*Eschweilera wachenheimii*
									0.2703	1.4402		

dependence of Weibull α on stand basal area after treatment. All statistics refer only to trees of 20 cm dbh and greater.

However, the effect at the stand level, of BA change on subsequent BA growth, was very highly significant (P≥99%), as shown in Figure 4 below. Both the individual and stand response effects are incorporated in the model. Individual growth effects are applied in a preliminary calculation, and the overall stand BA response determined, which we may call ΔBA^* (first estimate of BA increment). The stand BA increment ΔBA from the regression model in Figure 4 is then determined, and a proportional adjustment factor $k = \Delta BA^*/\Delta BA$ is computed, which is then reapplied to the individual species Weibull α coefficients to derive a new tree increment function that produces a result totalling to ΔBA from the whole stand function.

Figure 4 : Effect of treatment intensity on subsequent growth response

The x-axis shows the percent of basal area reduction between the 1993 and 1997 measurements (with treatment in 1994 and subsequent mortality). The y-axis shows the % Basal Area growth (trees ≥20 cm dbh) between 1997 and 2013. Letter codes refer to treatments in table 2. The blue line with square markers shows treatment means, and the red line the fitted regression to the individual data points (plots). R^2 is 74%. (Source: BA_Increment_27Jan2017.xlsx, sheet Fig1)

It was found after some modelling and validation trials with variable time steps from 5-20 years that the best and most unbiased predictive effect for stand increment needed to include both the initial basal area and basal area loss effect. The final regression equation adopted in the GEMFORM model is calculated in the workbook *BA_Increment_27Jan2017.xlsx*, sheet plots, cells P2:R7 as:

$$\Delta G = (0.2907 - 0.00899 * G_o - 0.7798 * \Delta L_{t-1}) * \Delta t \qquad \{eqn. 2\}$$

Where ΔG is the estimated basal area increment, G_o is basal area at the start of the time step, ΔL_{t-1} is the percentage basal area reduction (expressed as a positive value) in the previous time step, and Δt is the time period in years. Validation tests showed Δt could vary from 5-20 years whilst still giving adequate results. The regression was fitted with the observed value of Δt of 16 years (1997-2013 plot measurements).

Tree mortality

Tree mortality is conventionally calculated as an Annual Mortality Rate (AMR, Sheil *et al*, 1995; Alder, 1995), expressed as the percentage of trees of an initial population which die per year. Table 5 shows AMR calculations with confidence limits for the 25 most common species, individually modelled with GEMFORM 2017. Species codes are the same as in Table 4, which gives corresponding names.

In Table 5, the blue area show the raw species counts over the period 1993-2013 (20 years), with numbers initially, logged, thinned, died, and final count. Recruits are not counted among the died or final trees. To calculate AMR, logged and thinned trees are excluded from the initial count, giving a value N_o. The final stock (excluding recruits) is N_t. The relationship with AMR and period of observation *t* years is:

$$N_t = N_o.(1 - AMR)^t \qquad \text{\{eqn. 3\}}$$

Confidence limits for the estimated AMR can be determined from the binomial distribution by the Clopper-Pearson method[2], using the formulae given on page 141 of Alder, 1995, which is that used in columns P_L and P_u (lower and upper limits) in Table 5. Using the confidence limits, the species were grouped into 5 groups with significantly different AMRs. The lowest AMRs were Greenheart

Table 5 : Calculation of average Annual Mortality Rates for 25 most common species

Data from workbook Mortality_11Oct2016.xlsx, sheet BySpp

Species Survival Data						**Mean Annual Mortality**			**Confidence Limits (95%) for mortality rates**							**Species Groups**		
specnr	initial	logged	thinned	died	final	N_o	N_t	AMR	p	pL	pU	NtL	NtU	AMRL	AMRU	No	Nt	AMR
317	39	8	0	0	31	31	31	0.00%	0.0%		9.2%		28		0.5%	950	881	0.38%
101	1051	119	13	69	850	919	850	0.39%	7.5%	6.1%	9.1%	863	835	0.3%	0.5%			
723	54	0	1	6	47	53	47	0.60%	11.3%	5.0%	21.1%	50	42	0.3%	1.2%	507	438	0.73%
519	159	1	1	18	139	157	139	0.61%	11.5%	7.5%	16.5%	145	131	0.4%	0.9%			
511	51	0	0	7	44	51	44	0.74%	13.7%	6.6%	24.2%	48	39	0.3%	1.4%			
202	207	11	6	28	162	190	162	0.79%	14.7%	10.7%	19.6%	170	153	0.6%	1.1%			
501	61	5	0	10	46	56	46	0.98%	17.9%	10.0%	28.4%	50	40	0.5%	1.7%			
452	282	13	24	45	200	245	200	1.01%	18.4%	14.4%	22.9%	210	189	0.8%	1.3%	1638	1284	1.21%
326	182	10	16	29	127	156	127	1.02%	18.6%	13.6%	24.5%	135	118	0.7%	1.4%			
770	118	0	6	21	91	112	91	1.03%	18.8%	12.9%	25.9%	98	83	0.7%	1.5%			
729	79	0	4	15	60	75	60	1.11%	20.0%	12.8%	29.1%	65	53	0.7%	1.7%			
523	116	0	1	25	90	115	90	1.22%	21.7%	15.6%	29.0%	97	82	0.8%	1.7%			
789	133	4	1	28	100	128	100	1.23%	21.9%	16.0%	28.7%	107	91	0.9%	1.7%			
525	48	0	0	11	37	48	37	1.29%	22.9%	13.4%	35.1%	42	31	0.7%	2.1%			
526	782	1	57	171	553	724	553	1.34%	23.6%	21.0%	26.4%	572	533	1.2%	1.5%			
312	41	6	0	9	26	35	26	1.48%	25.7%	14.1%	40.6%	30	21	0.8%	2.6%			
578	195	0	4	52	139	191	139	1.58%	27.2%	22.0%	33.0%	149	128	1.2%	2.0%	830	592	1.68%
587	168	2	13	44	109	153	109	1.68%	28.8%	22.8%	35.4%	118	99	1.3%	2.2%			
503	455	13	5	127	310	437	310	1.70%	29.1%	25.5%	32.8%	326	293	1.5%	2.0%			
702	51	0	2	15	34	49	34	1.81%	30.6%	19.9%	43.2%	39	28	1.1%	2.8%			
307	234	10	0	77	147	224	147	2.08%	34.4%	29.1%	40.0%	159	135	1.7%	2.5%	420	268	2.22%
319	36	4	0	12	20	32	20	2.32%	37.5%	23.3%	53.6%	25	15	1.3%	3.8%			
707	72	0	0	27	45	72	45	2.32%	37.5%	28.0%	47.8%	52	38	1.6%	3.2%			
730	47	1	2	17	27	44	27	2.41%	38.6%	26.3%	52.1%	32	21	1.5%	3.6%			
584	51	0	3	19	29	48	29	2.49%	39.6%	27.7%	52.5%	35	23	1.6%	3.7%			
			overall average			4345	3463	1.13%										

(101) and Purpleheart (317). In the GEMFORM 2017 model, the group average AMR shown in the right-hand column of Table 5 is used for each species in the group.

The rates shown in Table 5 are average AMRs on all plots over 20 years. When the average plot AMRs, for all species and for trees 20 cm dbh or more, are compared with logging treatment, then it is found that mortality on the control plots is substantially lower than on the most heavily treated plots, and there is a strong correlation (R^2 of 80%) between the net basal area reduction during the treatment period (1993-1997) and subsequent mortality.

Figure 5 shows a representation of this data, with the net basal area reduction due to treatment in the period 1993-1997 being plotted against the ratio of plot average AMR 1997-2013 versus overall average AMR for the period 1993-2013. The basal area reduction % (x-axis of Figure 5) includes logged trees, thinned trees and mortality during the period 1993-1997, which is treated as direct

[2] https://en.wikipedia.org/wiki/Binomial_proportion_confidence_interval

logging mortality. A separate function, discussed later, relates direct logging mortality to numbers of trees removed or thinned.

Figure 5: Mortality rate adjustment for felling intensity

Average AMR per species is higher on plots with higher felling intensity (net BA reduction % 1993-1997) then on control and less intensively logged plots. These are persistent effects over 16 years (1997-2013). (Source: Mortality_11Oct2016.xlsx, sheet Fig1)

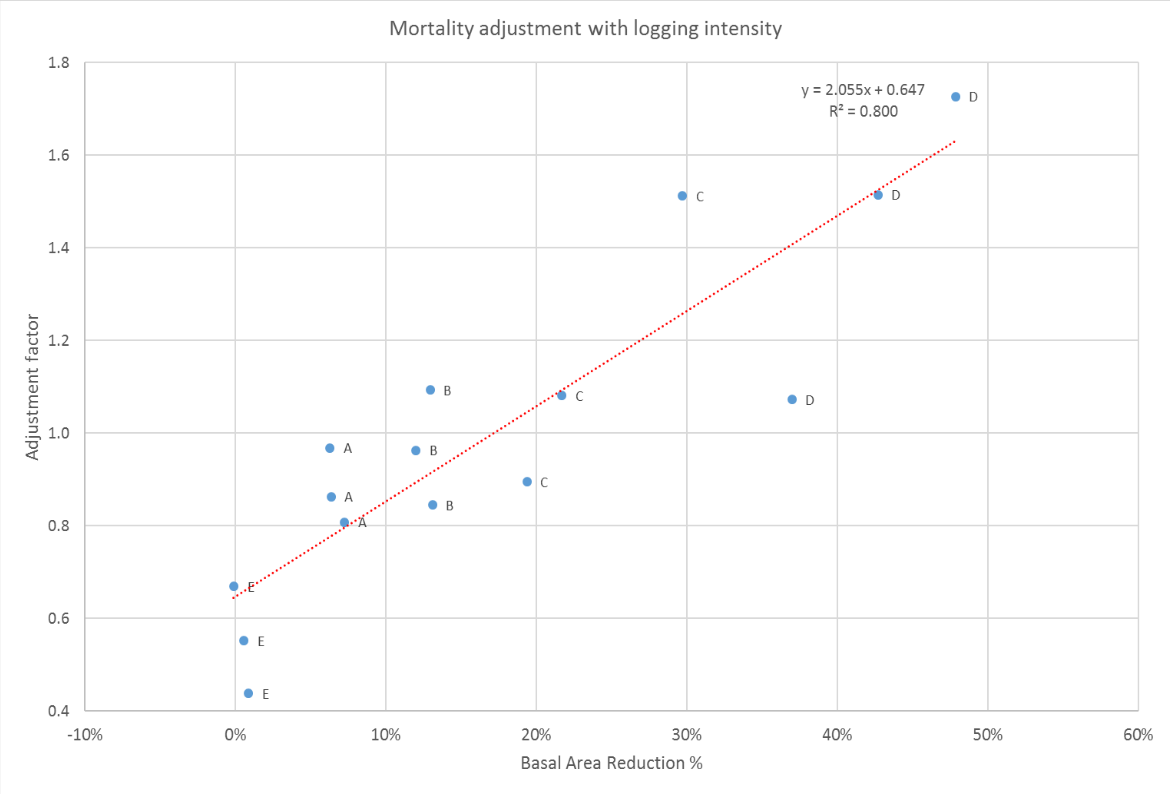


Figure 5 shows that there is an elevated mortality continuing over the entire measurement period on the more heavily logged or treated plots. Within the GEMFORM 2017 model, the function shown on Figure 5 is used to adjust the average mortality rates from Table 5 according to stand history. Although this elevated mortality will diminish over time, the Pibiri experiment is not yet old enough to show this effect, and an assumed relation is built into the model, in which the basal area reduction during the previous time step, whether due to logging or mortality, is used as the input factor for the next time step. The model allows for time steps of 5, 10 or 20 years to be used in simulations. Those of 10-20 years approximate best the period of measurement, but with this progressive reduction, the 5 year time step also performs reasonably well in validation trials.

Logging Damage

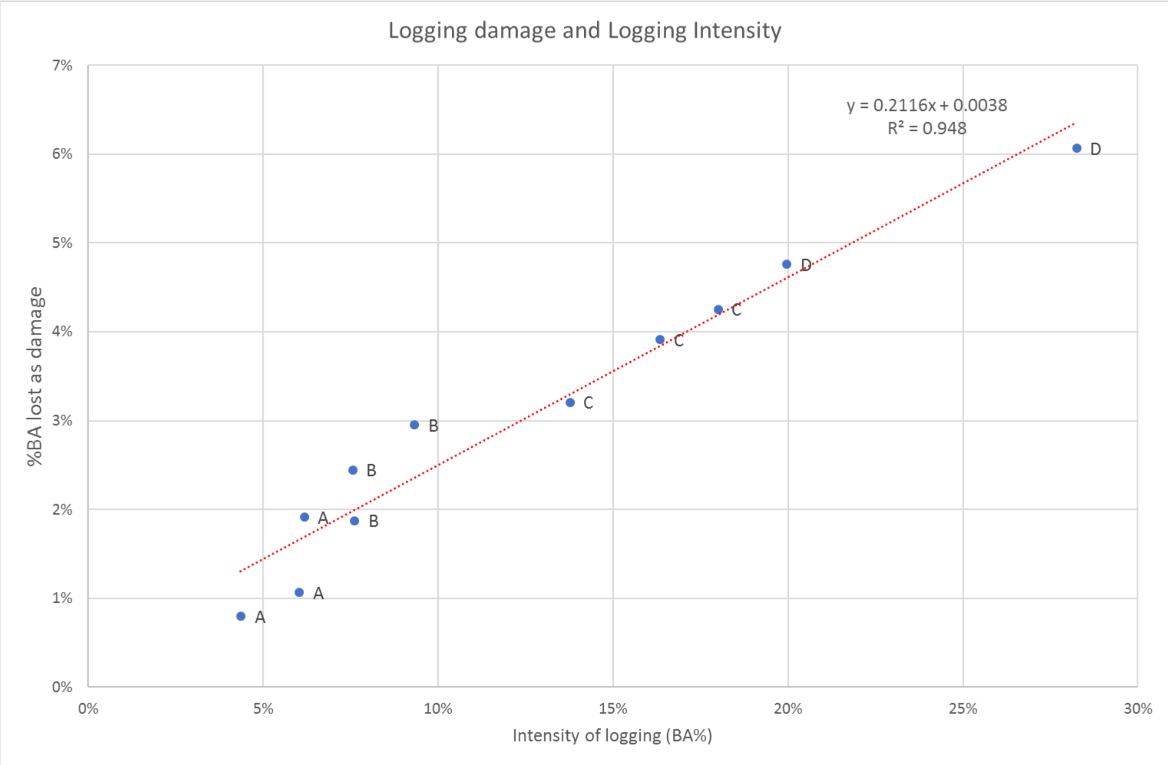
Mortality rates, as discussed above, include an element of logging damage in the form of elevated mortality for a period of years, proportional to logging and treatment intensity. However, there is also direct logging damage, in the form of trees killed, broken or destroyed during the operation, which is not included in the above estimates.

To analyze this direct destruction of trees as a side effect of logging or treatment, the measurement period 1993-1997 was used. Trees which died during this period and also were recorded as damaged during the 1995 assessment (immediately after treatment) were adjudged to be direct logging damage. Figure 6 shows the result. In this case, the treatment intensity (x-axis) is from the trees actually recorded as logged or thinned, and does not include mortality of undamaged trees. There is a strong linear relationship (R^2 of 95%) between basal area lost from damage during logging and the intensity of treatment.

In this chart, plot 13 (treatment D) has been omitted as an outlier. In the dataset, no damage-related mortality was recorded in the period 1995-97, but as this was the most heavily logged and thinned treatment, this certainly does not reflect the actuality, and is likely a data management problem. The consultant did not have time to investigate the issue, and decided to omit the plot from the regression.

Figure 6: Logging or treatment intensity and direct losses due to damage

See workbook Logging_Damage_20Dec2016.xlsx. Plot 13 (Treatment D, see Table 2) has been omitted as an outlier, and the control plots (Treatment E) are also not shown. The x-axis is the % of Basal Area (BA) of trees 20 cm dbh or more removed in logging or treatment. The y-axis is mortality of trees recorded in 1997 marked as damaged in the 1995 assessment, as a % of initial BA.



Recruitment

As with both growth and mortality, there is a strong correlation (R^2 of 78%) of recruitment with intensity of logging. For the purposes of the GEMFORM 2017 model, recruitment is defined as trees reaching the 20 cm dbh during the period 1997-2013, following the stand treatment in 1994 and the first full post-treatment assessment in 1997.

Figure 7 shows 20-year recruitment relative to basal area reduction as a result of stand treatment or logging. Plot 11 (Treatment A, Table 2) was omitted as recruitment data for 2013 were not available for this plot. The function for total stems recruited is used in the model to add stock to the initial diameter class (20-21 cm) in each time step. The 20-year function is adjusted linearly for shorter time steps (5, 10 or 20 years) proportionately using factors of 0.25, 0.5 or 1 respectively.

Once total recruitment has been apportioned, then it is allocated to species based on a table of recruitment percentage from the Pibiri experiment. This is shown in Table 6, and appears in the GEMFORM 2017 model as column H on the Parameters sheet.

Figure 7 Recruitment over 20 years and prior logging or treatment intensity

See workbook Recruitment_20Jun2016.xlsx. The x-axis is the total BA reduction in 1997 as a % of 1993 BA. The y-axis is the total recruitment recorded, in trees per ha reaching 20 cm + by 2013. This includes recruits recorded in 1997, 2001 and 2013 measurements. Treatment labels A-E are as per Table 2. Plot 11 (treatment A) is omitted as an outlier as 2013 recruitment data was unavailable.

Table 6 : Proportion of recruits by species

(see Recruitment_20Jun2016.xlsx)

Code	Local Name	Botanical Name	Nr.Recr.	%
503	Baromalli, sand	*Catostemma fragrans*	64.29	9.8%
101	Greenheart	*Chlorocardium rodiei*	52.55	8.0%
307	Crabwood	*Carapa guianensis*	50.51	7.7%
526	Wirimiri	*Lecythis confertiflora*	42.86	6.6%
452	Morabukea	*Mora gongrijpii*	38.78	5.9%
519	Kakaralli, black	*Eschweilera sagotiana*	27.55	4.2%
587	Marishiballi	*Licania cf. canescens*	27.55	4.2%
578	Kautaballi	*Licania alba*	21.43	3.3%
789	Sarebebeballi	*Vouacapoua macropetala*	20.84	3.2%
202	Wallaba, soft	*Eperua falcata*	20.41	3.1%
730	Warakosa	*Inga spp.*	16.24	2.5%
326	Wamara	*Swartzia leiocalycina*	15.82	2.4%
319	Silverballi, kereti	*Ocotea puberula*	12.75	2.0%
707	Trysil	*Pentaclethra macroloba*	11.22	1.7%
523	Kakaralli, smooth leaf	*Eschweilera coriacea*	9.18	1.4%
723	Aruadan	*Sloanea guianensis*	8.67	1.3%
770	Ruri	*Chaetocarpus schomburgkianus*	8.67	1.3%
584	Kudibiushi	*Micropholis venulosa*	7.14	1.1%
317	Purpleheart	*Peltogyne venosa subsp. densiflora*	5.1	0.8%
729	Yaruru	*Aspidosperma exselsum*	5.1	0.8%
525	Kakaralli, thick skin	*Eschweilera wachenheimii*	4.08	0.6%
511	Itikiboroballi	*Swartzia benthamiana var. benthamiana*	3.57	0.5%
312	Kabukalli	*Goupia glabra*	3.06	0.5%
702	Parakusan	*Swartzia jenmanii*	2.04	0.3%
501	Baromalli, swamp	*Catostemma commune*	1.53	0.2%
	Other species		172.88	26.4%
		Total observed	653.82	100.0%

SUMMARY OF GROWTH FUNCTIONS

Table 7 below summarizes the various functions and parameters in the model as detailed in the preceding sections.

Table 7 : Summary of growth functions and parameters in GEMFORM 2017

The Location column refers to either a sheet name and cell reference in Excel notation eg *Parameters, cells H6:H31* refers to the *Parameters* sheet, cells H6 to H31, or to a procedure (Sub in VBA) or function in the macro sheet *Module1*, which can be accessed in the Workbook by pressing Alt-F11. These latter references give a line number in Module1. So, for example, *DoHarvest, line 742* refers to the *DoHarvest* procedure, at line 742 in Module1. All references are to the workbook GEMFORM_2017_v101.xlsm. Symbols used in the equations are listed below the table.

§	Growth function or parameter	Equation or method	Text Reference	Model Location
1	**Diameter Increment** Proportion of trees moving DC 1-cm diameter classes in a time step	$P_D = \exp([(D-½)/\alpha]^\beta) - \exp([(D+½)/\alpha]^\beta)$	Eqn. 1 Table 4, cols. Wa, Wb	*Parameters*, cells B6:C31, *growTab*, line 546
2	**Increment Distribution Modifier** Modifies Weibull parameters in §1 based on stand density	α = a + b.IBA	Table 4, cols a, b	*DoGrowth*, line 391
3	**Stand Basal Area Increment** Species α adjusted to conform to estimated stand BAI	BAI = 0.2907 - 0.00899 * IBA- 0.7798 * BAL	Eqn. 2	*DoGrowth*, line 414
4	**Tree Mortality** Average tree mortality rate by species	$N_t = N_o.(1 - AMR)^t$	Eqn. 3	*Parameters*, cells I6:I31, *DoMortality*, line 481
5	**Mortality adjustment for logging** Default mortality rates are adjusted for logging history	$AMR = AMR_u.(2.055 * BAL + 0.647)$	Figure 5	*DoMortality*, line 474
6	**Mortality due to logging** Direct mortality during harvesting operations	DMGF = 0.0038 + 0.2116 * HBA / IBA	Figure 6	*DoHarvest*, line 743
7	**Recruitment rate** Stems per ha recruited over 20-year period after stand disturbance	NREC = (95.552 * BAL + 29.288) * T / 20	Figure 7	*DoRecruitment, line 501*
8	**Recruitment by species** Composition of recruitment by species	Tabulated values	Table 6	*Parameters, cells J6:J31*

Symbols used in table 7

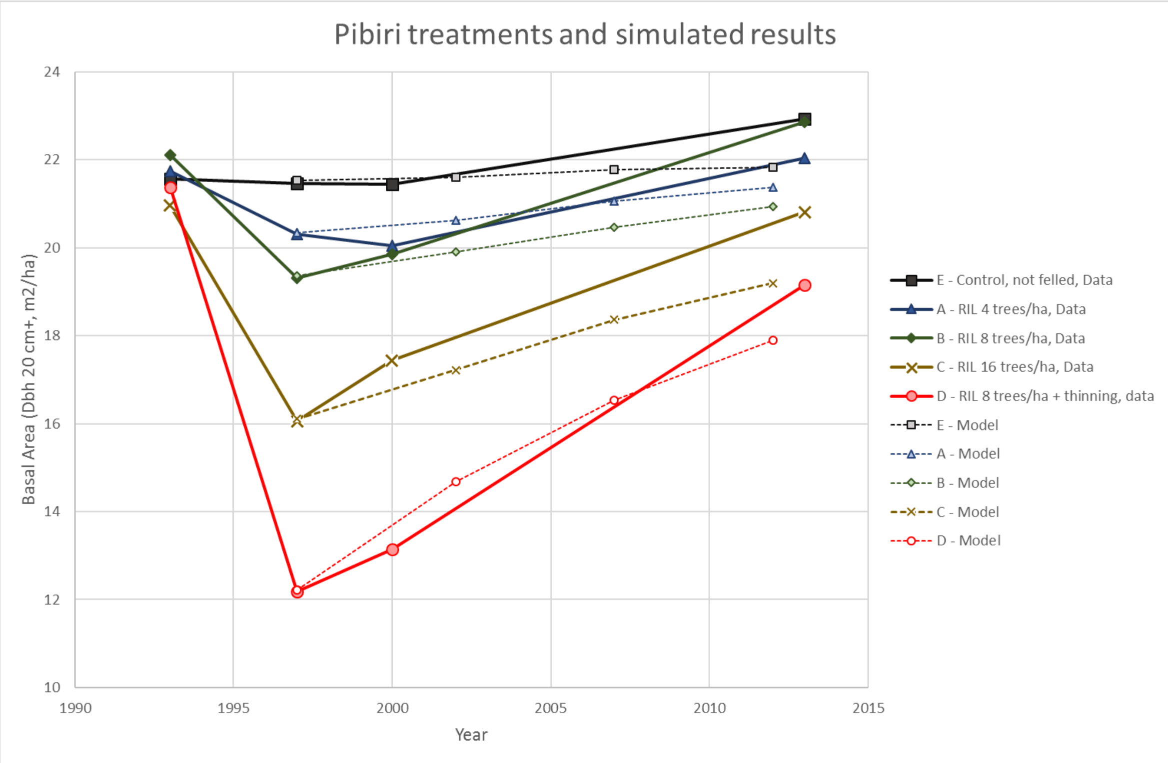
a, b .... Linear regression coefficients.
α, β .... Weibull scale and shape parameters (see eqn.1).
AMR .... Annual Mortality Rate.
AMR_u .... AMR means for species, before adjustment for logging effects.
BAI................... Basal area increment (m2/ha/yr, trees ≥ 20 cm dbh).
BAL.................. Basal Area loss due to logging and direct felling mortality, as proportion of basal area at start of time period
D...................... Lower bound of a 1-cm Diameter class.
DMGF .... Proportion of basal area destroyed by logging damage or dying within 3 years after harvest as a result of damage.
HBA .... Basal area removed as harvested trees or in a thinning treatment.
IBA................... Initial stand basal area (m2/ha, trees ≥ 20 cm dbh) at start of a time step.
NREC .... Number of recruits per ha over a time step. Recruits are trees reaching 20 cm dbh or more.
N_t, N_o............... Trees surviving after t years (N_t), Initial stock of trees (N_o).
P_D .... Proportion of trees in each diameter class moving D 1-cm diameter classes over a time step.
T .... Length of time step. Values allowed in the model are 5, 10 and 20 years.

MODEL TESTING

The model was tested by reviewing behavior with long-term projections without felling or after heavy fellings, to ensure conformance to the normal stability conditions for tropical forest in terms of stand basal area and tree size distribution after a long-period of growth. Additionally, a detailed evaluation was made to compare the model projections with the observed results from the Pibiri Experiment. The results are shown in Figure 8.

Figure 8 : Simulated and actual basal area growth of the Pibiri experimental treatments

See workbook *BA_Increment_27Jan2017.xlsx*, sheet *Fig4*. The reference copy of the GEMFORM model, *GEMFORM_2017_v101.xlsm* has the 5 treatments A-E (see table 2) summarized as sheets BASIS A to BASIS E. These were used to represent the simulated stand initial conditions, together with the prior BA loss (column 3 in Table 2). The dotted lines in the figure show simulated growth, and the solid lines the actual data.



Generally, the model gives a good estimate of the recovery trajectory of each treatment over the 16 year period 1997-2013, though it appears to slightly underestimate growth relative to the actual situation. This is probably beneficial in operational terms, as it means the model's projections will err on the conservative side.

USERS GUIDE

STARTING GEMFORM 2017

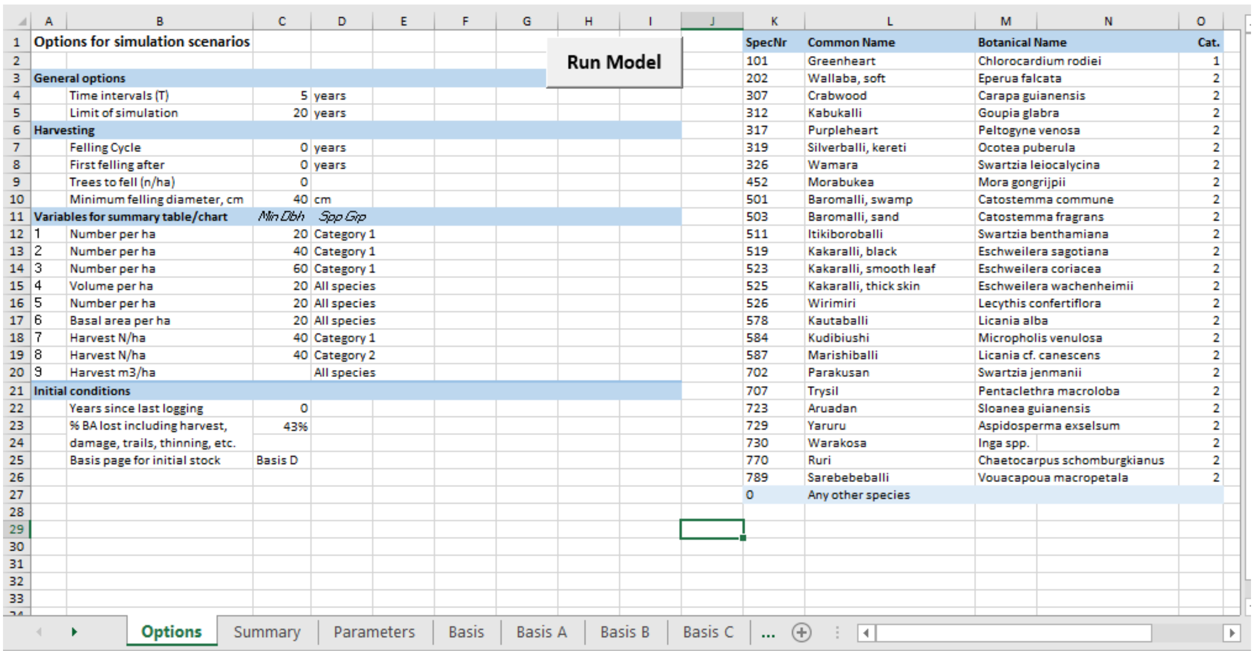
GEMFORM 2017 is distributed as a Microsoft Excel macro-enabled workbook. This can be downloaded from http://denisalder.net/proj/guyana/GEMFORM_2017_v101.xlsm. Note that for updates the version number (v101 part of name) may be revised.

Versions of Microsoft Excel later than 2010 should open this workbook without difficulty. For earlier versions of Excel, please contact the author (post@denisalder.com). If any difficulties or error messages are encountered while opening or running the model, please take a screen shot of the error message[3] and email it to the author together with a copy of the workbook you are using exactly as it was at the time the error occurred.

WORKBOOK CONTENTS

When the workbook is opened, the following pages will be seen (Figure 9):

Figure 9 : Options sheet of GEMFORM model



	A	B	C	D
1	Options for simulation scenarios			
2				
3	General options			
4		Time intervals (T)	5	years
5		Limit of simulation	20	years
6	Harvesting			
7		Felling Cycle	0	years
8		First felling after	0	years
9		Trees to fell (n/ha)	0	
10		Minimum felling diameter, cm	40	cm
11	Variables for summary table/chart		*Min Dbh*	*Spp Grp*
12	1	Number per ha	20	Category 1
13	2	Number per ha	40	Category 1
14	3	Number per ha	60	Category 1
15	4	Volume per ha	20	All species
16	5	Number per ha	20	All species
17	6	Basal area per ha	20	All species
18	7	Harvest N/ha	40	Category 1
19	8	Harvest N/ha	40	Category 2
20	9	Harvest m3/ha		All species
21	Initial conditions			
22		Years since last logging	0	
23		% BA lost including harvest,	43%	
24		damage, trails, thinning, etc.		
25		Basis page for initial stock	Basis D	

Run Model

SpecNr	Common Name	Botanical Name	Cat.
101	Greenheart	Chlorocardium rodiei	1
202	Wallaba, soft	Eperua falcata	2
307	Crabwood	Carapa guianensis	2
312	Kabukalli	Goupia glabra	2
317	Purpleheart	Peltogyne venosa	2
319	Silverballi, kereti	Ocotea puberula	2
326	Wamara	Swartzia leiocalycina	2
452	Morabukea	Mora gongrijpii	2
501	Baromalli, swamp	Catostemma commune	2
503	Baromalli, sand	Catostemma fragrans	2
511	Itikiboroballi	Swartzia benthamiana	2
519	Kakaralli, black	Eschweilera sagotiana	2
523	Kakaralli, smooth leaf	Eschweilera coriacea	2
525	Kakaralli, thick skin	Eschweilera wachenheimii	2
526	Wirimiri	Lecythis confertiflora	2
578	Kautaballi	Licania alba	2
584	Kudibiushi	Micropholis venulosa	2
587	Marishiballi	Licania cf. canescens	2
702	Parakusan	Swartzia jenmanii	2
707	Trysil	Pentaclethra macroloba	2
723	Aruadan	Sloanea guianensis	2
729	Yaruru	Aspidosperma exselsum	2
730	Warakosa	Inga spp.	2
770	Ruri	Chaetocarpus schomburgkianus	2
789	Sarebebeballi	Vouacapoua macropetala	2
0	Any other species		

Options | Summary | Parameters | Basis | Basis A | Basis B | Basis C | ...

Three sheets have fixed names which must not be altered. These are Options, Summary, and Parameters. The remaining sheets are provided by the user and can have any name. In the standard version downloaded, they are *Basis, Basis A, Basis B, Basis C, Basis D, Basis E* and include summaries from the Pibiri plots for the various treatments.

[3] On most systems, the keyboard PrintScreen button will copy the entire screen to the clipboard. This image can then be pasted into an email message. Windows 10 also provides a Snipping Tool (under the Start Menu/Windows Accessories group) which will copy selected areas of the screen to the clipboard.

In all areas of the model, the layout should not be changed, by inserting or deleting rows or columns. If this is done, the model will no longer run correctly.

Only the Options sheet contains data that can normally be amended by the user. The Summary sheet is an output, written by the model, and contains the simulation results. The Parameters sheet contains growth model parameters and should not be altered in any way.

OPTIONS FOR RUNNING THE MODEL

On the Options sheet are the various parameters that can be set by the user to simulate different scenarios. These are described below, with the sheet cells being indicated as A1, C2 etc.

The Time Interval for simulations is limited to values of 5, 10 or 20 years (cell C5). A 10 year time step is the closest to the data analysis interval, recommended as the most accurate, but for some example (short term or very long term simulations), 5 or 20 years may be preferred. With different time steps the figures will change slightly as the growth functions interact in a non-linear way, but the differences are small and not practically important from a forest management perspective. *The felling cycle must always be an integer multiple of the time step*, so if examining cycles of 35, 65 etc years, a 5-year time step must be used, but practically speaking this should not be necessary, and a 10-year time step should be preferred.

The Limit of Simulation, cell C5, can be any period, but will typically be a multiple of 2 or 3 felling cycles. The model does not incorporate climate change or other long-term ecological processes, so simulations beyond 200 years are not likely to be meaningful.

The harvesting options allowed in the model are:

- Felling Cycle (C7), being the interval at which felling is repeated. This must be an exact multiple of the Time Step (C4). If zero, no felling will be performed.
- First Felling after (C8) can adjust when the first felling is performed after the start of the simulation. If the past history of the stand is known, and it was previously felled, for example, 20 years ago, and a 60 year felling cycle is to operate, then the first felling should occur 40 years after the start of the simulation. If left as zero, the first felling will be after one felling cycle.
- Felling Control options (B9, C9). In cell B9, values of Trees to Fell (n/ha) or Volume to Fell (m3/ha) can be selected from the drop-down lists. In cell C9 is given the respective value. For example, if Trees to Fell is specified as 10, then the model will attempt to fell 10 trees per ha at each felling cycle. If left as zero in C9, no felling will be performed.
- Minimum felling diameter is given in cell C10. If a value of less than 20 is given, it will be treated as 20. Only trees above the minimum diameter will be felled, up to the limit specified by the felling control specified in B9 and C9.

The species list (columns K-O) should not be altered in terms of species codes or the order of the species, but names can be amended if required. However, the Species Category is important and can be specified by the user. It influences harvesting and reporting of results.

If the Species Category is blank or zero, the species will not be harvested at all. For example, if it is desired to protect Crabwood from felling, then cell O4 should be set to blank or zero. If the Category is 1, then those species will be felled first, before category 2 species. This reflects the normal behavior of logging companies of prioritizing highly commercial species such as Greenheart. If the specified felling limit is reached before exhausting all available Category 1 species, then no Category 2 species will be felled.

Variables displayed on the output summary are stipulated by cells A12:D20. Upto 9 lines can be given, although fewer may be specified by leaving unwanted lines blank. The variables that can be displayed are Number per ha, Basal area per ha, Volume per ha, of the standing crop, and Harvested Number or volume per ha. These are selectable from the drop down lists in cells B12:B20. In cells C12:C20 are given the corresponding diameter limit. The value is calculated for all trees above that diameter limit. Values below 20 cm will be treated as if they were 20 cm, and for harvested numbers or volume, the diameter figure is ignored, the volume or number reported is always all those harvested above the specified minimum harvesting diameter (C10).

In column D12:D20 are given the species categories to be reported. These may be Category 1 species, Category 2 species, Other species (not category 1 or 2), and All species. The categories are, as noted above, those listed in cells O2:O26, and can be set by the user (although only values 0, 1 or 2 are allowed).

The Initial conditions for the stand are given in cells C22 and C23. C22 gives the estimated time since the stand was last logged. This influences the growth functions, so if the stand is known to have been previously logged, an estimate should be given here. Likewise the % Basal Area reduction needs to be estimated. It is suggested figures should be between 10 and 40% for lightly or heavily logged stands.

The Basis for the simulation gives the name of the sheet containing stand table data for the initial condition of the stand. 6 sheets are pre-supplied here, as shown in Table 8 below. This must contain the name of a valid data sheet at the time the model is run, or an error will result. The format of the Basis sheets is discussed in the next section.

Table 8 : Pre-supplied Basis sheets in GEMFORM 2017

Sheet Name	Treatment Code and Description		BA Loss%	Pibiri Plots
Basis A	A	RIL 4 trees/ha (1997)	-7%	3, 10, 11
Basis B	B	RIL 8 trees/ha (1997)	-13%	1, 8, 15
Basis C	C	RIL 16 trees/ha (1997)	-23%	2, 7, 14
Basis D	D	RIL 8 trees/ha + liberation thinning (1997)	-43%	4, 9, 13
Basis E	E	Control, not logged or thinned (1993)	0%	5, 6, 12
Basis		All plots combined (1993)	-17%	1-15

Basis sheets for simulation

The basis sheets give the initial stand table for the forest to be simulated, and can be compiled from inventory plots, stock surveys or other sources. The examples included with the model are from the Pibiri PSP measurements of 1997 (2 years after treatment) except for the control plots, measured in 1993, and the 'All plots' summary, also made before treatment in 1993 (see Table 8).

Figure 10 : Basis sheet layout

	A	B	C
1	**Basis for stand projection**		
2	Note:	Summarised from all Pibiri plots (1-15) in 1993 (before treatment) as a basis for generic projections	
3			
4	SpCode	Dbh (cm)	N km^{-2}
5	101	20	68
6	101	21	133
7	101	22	75
8	101	23	88
9	101	24	119
10	101	25	119
11	101	26	75
12	101	27	88
13	101	28	119
14	101	29	92
15	101	30	78
16	101	31	95
17	101	32	92
18	101	33	71
19	101	34	78
1492	942	28	3
1493	942	30	7
1494	942	32	3
1495	942	33	3
1496	942	34	3
1497	942	35	3
1498	942	38	3
1499	951	23	3

Figure 10 shows the Basis sheet. Rows 1-4 can contain any text, but it is suggest they describe the data source.

From row 5 on are tree numbers summaries by species and 1 cm diameter classes. Tree numbers must be given as trees/km2 (trees/ha x 100), as a whole number (decimal places are ignored). Column A gives the species codes, which should correspond to the list on the Options sheet, columns K:M. Codes which are not in the list of 25 recognized by this version of the model are treated as 'other species' and coded internally as zero.

Note however, that all trees of whatever species above 20 cm must be measured, otherwise Basal Area, which is a key model variable, cannot be calculated correctly. If data is from partial measurements, such as only Greenheart, or only commercial species, or does not include trees below 40 cm, for example, then it cannot be used unless augmented by some assumed or estimated data for the unmeasured component of the stand.

Column B contains the 1-cm diameter class value. Here, 20 for example, denotes a class from 20.0 to 20.9 cm. When compiling data, tree measurements to the nearest mm should be truncated to the next lowest cm, not rounded to the nearest cm. Any data for trees below 20 cm or above 300 cm dbh is ignored.

There is no limit to the number of data lines (except that imposed by Excel for a datasheet), but reading of data will stop at the first blank entry in column A.

Outputs : The Summary sheet

The Summary sheet (Figure 11) is generated when the model is run. Any pre-existing data on the sheet will be deleted.

In Cell E1 will be the name of the basis sheet used for the simulation.

Rows 4 to 12, columns A-C will contain the selected variables to be output, as per the Options sheet A12:D20 specifications. One column will be output for the calculated values for each time step. The year from the start of the simulation is shown in row 3.

The stand dynamics summary in rows 16-26 gives basal area values which are designed mainly for model testing, but may also be insightful with respect to stand responses. The data given for each time step are the initial BA, recruitment BA, mortality BA, BA increment (excluding mortality and recruitment), BA harvested and lost as damage during harvest. Also given are numbers per ha for recruitment and mortality. All these figures are for trees 20 cm and above.

Also given is the current value of the BA Loss%, or basal area reduction due to harvesting (including damage, and thinning treatment if applicable). This is adjusted for each time step as a residual effect used in the growth functions, and does not indicate actual BA% loss during that period.

If it is desired to save the data to make charts or compare scenarios, then the data should be copied to another sheet before the next run, otherwise it will be overwritten. Do not rename the Summary sheet, or the model will fail, but the sheet as a whole can be copied using the normal Excel methods, and the copy then renamed.

Figure 11 : Example of outputs – The Summary sheet

	A	B	C	D	E	F	G	H
1	Stand Projection Summmary		Basis page:	Basis D				
2				Year of projection				
3	Variable	MinDbh	Species	0	5	10	15	20
4	Number per ha	20	Category 1	25.50	26.31	26.86	27.38	27.83
5	Number per ha	40	Category 1	9.52	12.07	13.42	14.24	14.79
6	Number per ha	60	Category 1	2.21	2.62	3.21	3.67	4.02
7	Volume per ha	20	All species	174.24	209.31	235.61	255.10	269.43
8	Number per ha	20	All species	133.62	139.78	145.38	150.12	153.96
9	Basal area per ha	20	All species	12.22	14.68	16.53	17.90	18.90
10	Harvest N/ha	40	Category 1					
11	Harvest N/ha	40	Category 2					
12	Harvest m3/ha	40	All species					
13								
14								
15	**Stand dynamics summary**							
16	Initial BA (m2/ha)				12.22	14.68	16.53	17.9
17	Harvest (m2/ha)				0.00	0	0	0
18	Damage (m2/ha)				0.00	0	0	0
19	Recruitment (m2/ha)				0.58	0.49	0.42	0.37
20	Recruitment (N/ha)				18	15	13	11
21	Mortality (m2/ha)				-0.88	-0.76	-0.72	-0.67
22	Mortality (N/ha)				11	10	9	8
23	Growth (m2/ha)				2.76	2.12	1.66	1.3
24	Final BA (m2/ha)				14.68	16.53	17.9	18.9
25								
26	BA% Loss Effect			0.43	0.43	0.31	0.23	0.16

RUNNING THE MODEL

On the Options sheet is a button labelled Run Model (see Figure 9). Clicking this will run the model, which normally takes 1-2 seconds. Focus will switch to the Summary sheet, which will be updated with the results based on current options.

TROUBLESHOOTING

As version 1.01 of GEMFORM 2017 is an early version, problems with different versions of Excel and Windows are quite likely to occur. Problems can also be expected as a result of accidental or inappropriate alterations to the datasheets, wrongly compiled Basis sheets, etc.

In all cases, please send the author a copy of the workbook being used at the time the error occurred, as an email attachment, a screenshot of the error message, and details of the version of Excel and Windows being used. Information should be sent to post@denisalder.com.

CONCLUSIONS

FELLING CYCLE AND PRODUCTION

The model can be used to examine questions of optimum felling cycle and production. Figure 12 shows the option settings for a model run that uses the Pibiri plots as a basis for projection, in their initial condition prior to logging in 1993. In this setup, the Category 1 species includes only Greenheart, and the category 2 all other commercial species except *Carapa guianensis*, which is assumed to be protected. Felling is assumed to take place after 5 years and thereafter be repeated at 60 year intervals.

Figure 12: Options for trials with a 60-year felling cycle and 30 m3/ha harvest

	A	B	C	D
1	**Options for simulation scenarios**			
2				
3	**General options**			
4		Time intervals (T)	20	years
5		Limit of simulation	200	years
6	**Harvesting**			
7		Felling Cycle	60	years
8		First felling after	5	years
9		Volume to fell (m3/ha)	30	
10		Minimum felling diameter, cm	40	cm
11	**Variables for summary table/chart**		*Min Dbh*	*Spp Grp*
12	1	Number per ha	20	Category 1
13	2	Number per ha	40	Category 1
14	3	Number per ha	60	Category 1
15	4	Volume per ha	20	All species
16	5	Number per ha	20	All species
17	6	Basal area per ha	20	All species
18	7	Harvest N/ha	40	Category 1
19	8	Harvest N/ha	40	Category 2
20	9	Harvest m3/ha		All species
21	**Initial conditions**			
22		Years since last logging	0	
23		% BA lost including harvest,	0%	
24		damage, trails, thinning, etc.		
25		Basis page for initial stock	Basis	

Figure 13 shows the results, projected over 200 years. Yield of Greenheart is maintained over the first 2 cycles (felling in year 20 and 80) but declines thereafter although the stock of small trees (20 cm dbh) appears adequate.

Similar trials can be made with various felling cycles and intensities of felling. The initial condition assumed here is of an unlogged stand. For a logged over stand, to simulate recovery time, one of the other Basis sheets can be used. Basis C is the average of the Treatment C plots on Pibiri (plots 2, 7 and 14), with 16 trees per ha felled and a 23% reduction in basal area after felling. This can be used to evaluate the likely recovery trajectory for a stand that has been heavily exploited in the past.

Figure 13: 200 year projection based on 60 year felling cycle, with 30 m3/ha felled per cycle

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Stand Projection Summmary		Basis page:	Basis										
2				Year of projection										
3	Variable	MinDbh	Species	0	20	40	60	80	100	120	140	160	180	200
4	Number per ha	20	Category 1	35.70	27.76	28.96	29.95	22.79	24.29	25.53	20.59	22.08	23.38	21.96
5	Number per ha	40	Category 1	17.01	10.51	11.57	12.05	4.90	5.94	6.49	1.36	2.19	2.74	0.89
6	Number per ha	60	Category 1	4.65	2.69	3.03	3.24	1.04	1.19	1.27				
7	Volume per ha	20	All species	299.87	289.98	307.00	314.90	303.72	318.86	324.22	318.59	331.05	337.83	339.78
8	Number per ha	20	All species	192.79	186.77	191.71	195.41	190.47	195.13	198.32	194.00	198.24	201.51	199.91
9	Basal area per ha	20	All species	21.10	20.38	21.55	22.09	21.25	22.28	22.62	22.16	22.99	23.42	23.52
10	Harvest N/ha	40	Category 1		8.71			8.86			6.49			2.74
11	Harvest N/ha	40	Category 2					0.00			2.18			4.29
12	Harvest m3/ha	40	All species		30.00			30.00			30.00			30.00

THE NEED FOR MANAGEMENT INVENTORY

GEMFORM requires complete measurements on all species down to 20 cm dbh in the form of a management inventory, according to GFC specifications. It cannot make projections only on stock survey data for a limited number of commercial species. This was true both for the original GEMFORM model, and for the current update.

Some work has been done on integrating GEMFORM 2017 with the original GEMFORM database system, to allow rapid projections from management-level inventories. However, this work could not be completed within the time frame of this update, and was also found to be possibly misdirected, given that GFC no longer seems to be requiring MLI within the forest management process. Under this circumstance, the best use of the model is to support general forest management recommendations that can be incorporated into a system of area control (*i.e.* Strict application and regulation of the felling cycle).

BUFFER ZONES AND PROXIMITY LIMITS

Another topic concerns the effect of buffer zones and proximity limits. GEMFORM is a non-spatial model that cannot account for these directly. Indirectly, the area being managed can be adjusted to exclude buffer zones, and likewise, the intensity of felling can be adjusted to allow for proximity limits, but in both cases the use of some independent spatial analysis with a GIS system is needed to estimate the proportional effects.

GENERAL CONCLUSION

The original GEMFORM model, developed in 2002 and refined in 2007, was based on PSP data including the Pibiri experiment available up to 2000. The new 2013 measurements show a considerably more complex behavior in stand dynamics than could be seen on the shorter-term measurements. Growth, mortality and recruitment all depend strongly on the intensity of disturbance, and these factors had to be added to the model, making analysis considerably more complex than originally envisaged.

There is a very strong case for GFC making every effort to protect and maintain the Pibiri experiment in the longer term, as well as developing a network of PSPs in other forest zones. Alder and Kujik (2009) made proposals for a national biomass monitoring system as part of the REDD program. This included such PSPs, which would be now have been providing very useful information. Unfortunately, different technical opinions prevailed and this opportunity fell by the wayside. But sooner or later, if Guyana is to rely on its natural forests as a sustainable wood resource, it must invest in a national network of permanently maintained PSPs, as without this information, the forest cannot be sustainably managed.

The present model however provides a useful tool for exploring general regulations regarding forest management, with a stronger base than has been technically possible prior to the availability of the latest re-measurement data, and it will hopefully inform and support forest management policies accordingly.

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APPENDIX A: DOWNLOAD MATERIALS

The following files are available to download from http://denisalder.net/proj/guyana/. Note that file names are case-sensitive, and must be typed exactly as shown.

GEMFORM_2017_v101.xlsm	The version 1.01 of the GEMFORM 2017 model, as described in this report
GEMFORM_2017_report.pdf	Contains this report
Workbooks.zip	Contains the reference workbooks for the analysis of increment, mortality, and recruitment, as described in the report
Pibiri_database.zip	A MySQL dump of the Pibiri database. Where tables in the above workbooks are derived from this database, there are in-cell comments giving the SQL queries used.