Methods employed to examine which interactions were important in the grid structure developed for ALB OM in the Indian Ocean & BFT in the Eastern Atlantic Ocean

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Introduction

MSE's often use complicated grid based platforms to test alternative states of nature (e.g. CCSBT, Hillary et al. 2016). This was the case in initial development for Albacore in the Indian Ocean (Mosqueira and Sharma 2014 IOTC 2014-WPM 05) based on the Synthesis Assessment (Hoyle et. al. 2014). In that case 720 models were examined as the basis of the operating model. However, in the case of the Atlantic (Kell et. al. 2016), a much finer operating model structure was used (10 models) conditioned on the MultiFan Assessment (Anon 2012). Thus, a whole range of approaches is available in the literature (Punt et. al. 2014) and we would examine if a full grid approach is relevant, or something simpler could work.

The objective of this work is to first examine the grid structure using GLM based methods to determine which variables effect the derived parameters like B0 and current stock size. Once the main and interaction effects that are important are figured a refined grid could be examined.

In addition, the variance covariance matrix produced by the assessment and test whether we need a complex model structure for the MSE (CCSBT and IOTC) or do simpler structures perform just as well (ICCAT). We would use the Synthesis model and platform to examine this (with the Indian Ocean Albacore Assessment). Tools already developed (Mosqueira and Sharma 2014) could be further developed to examine across SS model platforms and to make it more generic for application in other assessments in the Atlantic.

The objective here is to examine whether main effects used in the grid are sufficient for robustness testing of the MP, and provide adequate contrast in the states of nature or do we need to apply all possible interactions in the grid as well, and can the variance co-variance matrix inform us of the scenarios that could be used.

Methods

GLM Based Analysis

All feasible runs from the grid were examined using the grid design to assess what drove some of the key estimable parameters (like B0). We tested linear models with interactions (eq. 1) as suggested by Green and Macdonald (1987).

$$B0 = \left(\alpha + \sum_{i=1}^{3} \beta_i ESS_i + \sum_{i=1}^{4} \beta_i M_i + \sum_{i=1}^{3} \beta_i h_i + \sum_{i=1}^{2} \beta_i llsel_i + \sum_{i=1}^{2} \beta_i q_i + \sum_{i=1}^{3} \beta_i CV_i \right) + \qquad (1)$$
$$\text{2 Way interactions (Ess, M, h, llsel, q and cv)} + \text{3way interactions} + \varepsilon$$

where B_0 is the estimated biomass at the beginning of the series the main effect design variable (ess, M, h, llsel, cv and catchability changes), and all 2 way and three way interactions. Under the null hypothesis β_i and/or *interaction coeffecients* =0. Under the alternative hypothesis βi and/or *interaction coeffecients*≠ 0.

We tested the approach on two different grids run, one for an Indian Ocean Albacore set up (Mosqueira XXXX) and another one developed for East Atlantic Bluefin based on a new assessment developed (Sharma et. al. XXXX).

Grids developed Albacore and BFT tuna are shown in Tables below which were then examined with GLMS and PCA for examining significant variables and interactions for a smaller more efficient grid to run the MP.

Table 1: Structural Uncertainty in grid examined for Albacore

Assumption	**Option**
Spatial domain	***Io****; Indian* Ocean with one area
Beverton-Holt SR Steepness (h)	h=0.7 h=0.8 **h=0.90 (Base case)**
Natural Mortality	*5 Vectors:* *M=0.2* *M=0.3* *M=0.4* *Early Ages 0.4 declining to age 5 linearly later ages 0.2 (0.2 age 5)* *Early Ages 0.4 declining to 0.3 ata ge 5later ages (0.3 at age 5)*
CPUECV σ=SD lognormal errors	***0.2,0.3,0.4,0.5***
Recruitment σ=SD(log(devs))	**σ=0.6 deviates estimated from 1951-2014** σ=0.4 deviates estimated from 1951-2014
Catch-at-Length (SS=assumed sample)	***ESS 20****,50, 100 (Base 20)*
Selectivity	***Double Normal (LL)*** *Logistic (LL)*
Catchability change	***Q change by 0.5% annually for all CPUE series used in base case***

Table 2: Structural Uncertainty examined in Eastern BFT Assessment for the OM (Total of 2280 Models).

Assumption	**Option**
Spatial domain	***ao****; Atlantic* Ocean with one area
Beverton-Holt SR Steepness (h)	h=0.5 h=0.6 h=0.7 h=0.8 **h=0.90 (Base case)**
Growth, and Maturity	*VB (Cort XXXX)****;***
Natural Mortality	*4 Vectors:* *Lorenzon (Base case, scaled to full M=0.1 at age 20)* *CCSBT old* *CCSBT new*

	Constant M (0.14)
CPUE* σ=SD lognormal errors	***Run 1 : Base (JPLL MED, JPLL NEAT, AS, LS, TRAP)*** *Run 2 : SpBB* *Run 3 : Mor TRAP* *Run 4 : JPLL MED & NE, JPLL NEAT* *Run 5 : Aerial and Larval Surveys* *Run 6 : All (other than PS)* *CV=0.2 all (JP NEAT, LS and AS (0.4))*
Recruitment σ=SD(log(devs))	**σ=0.6 deviates estimated from 1951-2014** σ=0.4 deviates estimated from 1951-2014
Catch-at-Length (SS=assumed sample)	***Lambda=0.0001 low wts to LC*** ***ESS 20****,50, 100 (Base 20)*
Selectivity	***Double Normal (LL)*** *Logistic (LL)*
Catchability change	***Q change by 1% annually for all CPUE series used in base case***

Principal Component Analysis (see Appendix 1 for results)

Principal component analysis was run on the grid results on the main diagnostics (B0, SPB_{curr}/SPB_{MSY}, F_{curr}/F_{MSY}, MSY, etc) and the grid characteristics (M, h, ESS, LLq, cpuecv, llsel). The main axis of the PCA and the clustering structure would provide information on the key elements that are important for the grid.

Results

Albacore Indian Ocean MSE

Main Effects

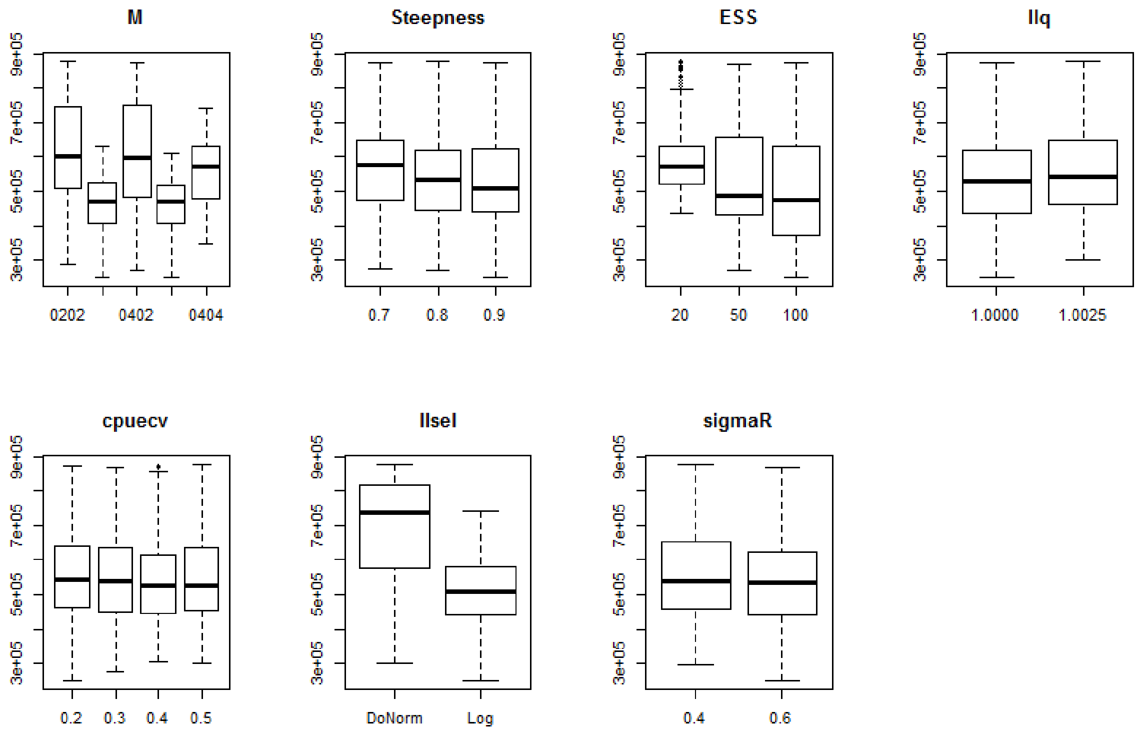

Figure 1: Main effects and B0

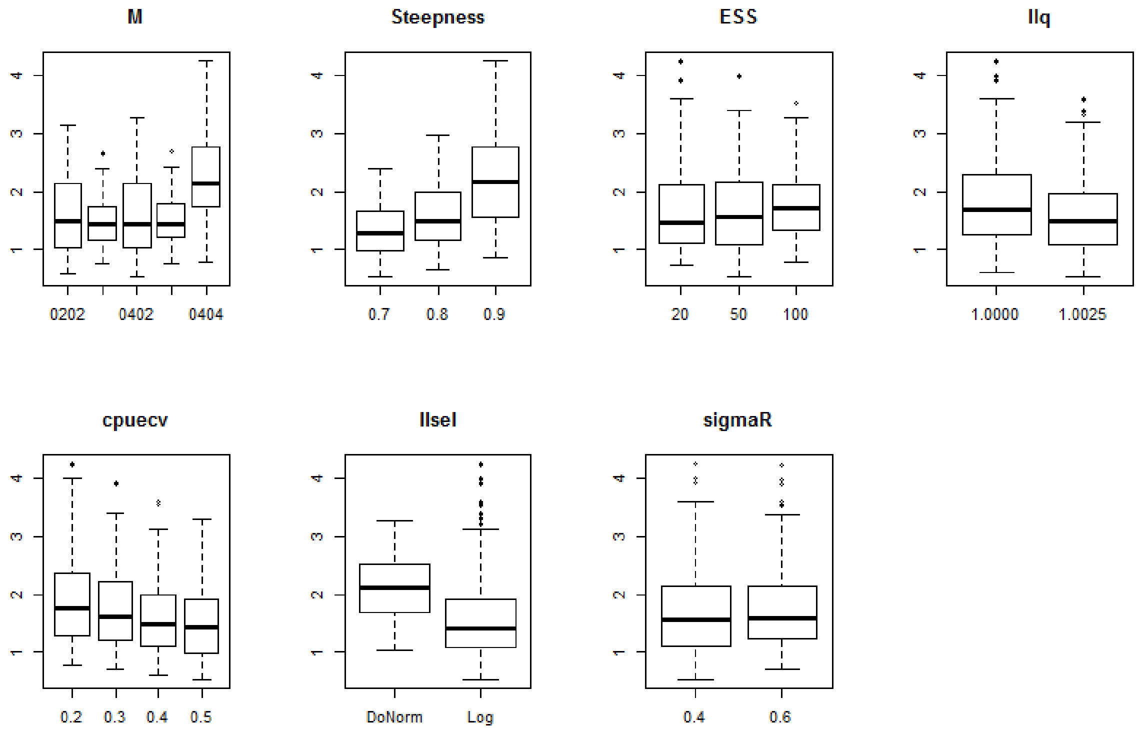

Figure 2: Main effects and B_{curr}/B_{MSY}

Table 1: ANOVA indicating variables and main effects with B0 as the dependent variable

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			654	1.2923e+13			
factor(M)	4	2.5089e+12	650	1.0414e+13	133.2578	< 2.2e-16	***
factor(steepness)	2	1.6292e+11	648	1.0251e+13	17.3062	4.789e-08	***
factor(ess)	2	1.2769e+12	646	8.9745e+12	135.6394	< 2.2e-16	***
factor(llq)	1	5.9042e+10	645	8.9155e+12	12.5437	0.0004264	***
factor(cpuecv)	3	1.0550e+11	642	8.8100e+12	7.4716	6.374e-05	***
factor(llsel)	1	5.6036e+12	641	3.2064e+12	1190.4920	< 2.2e-16	***
factor(sigmaR)	1	1.9396e+11	640	3.0124e+12	41.2083	2.666e-10	***

All variables were significant and hence we looked at all possible 2 way interactions to see what may be important to test for grid structure.

2 level interactions with main effects

The key two way interaction for some of the key variables are shown below

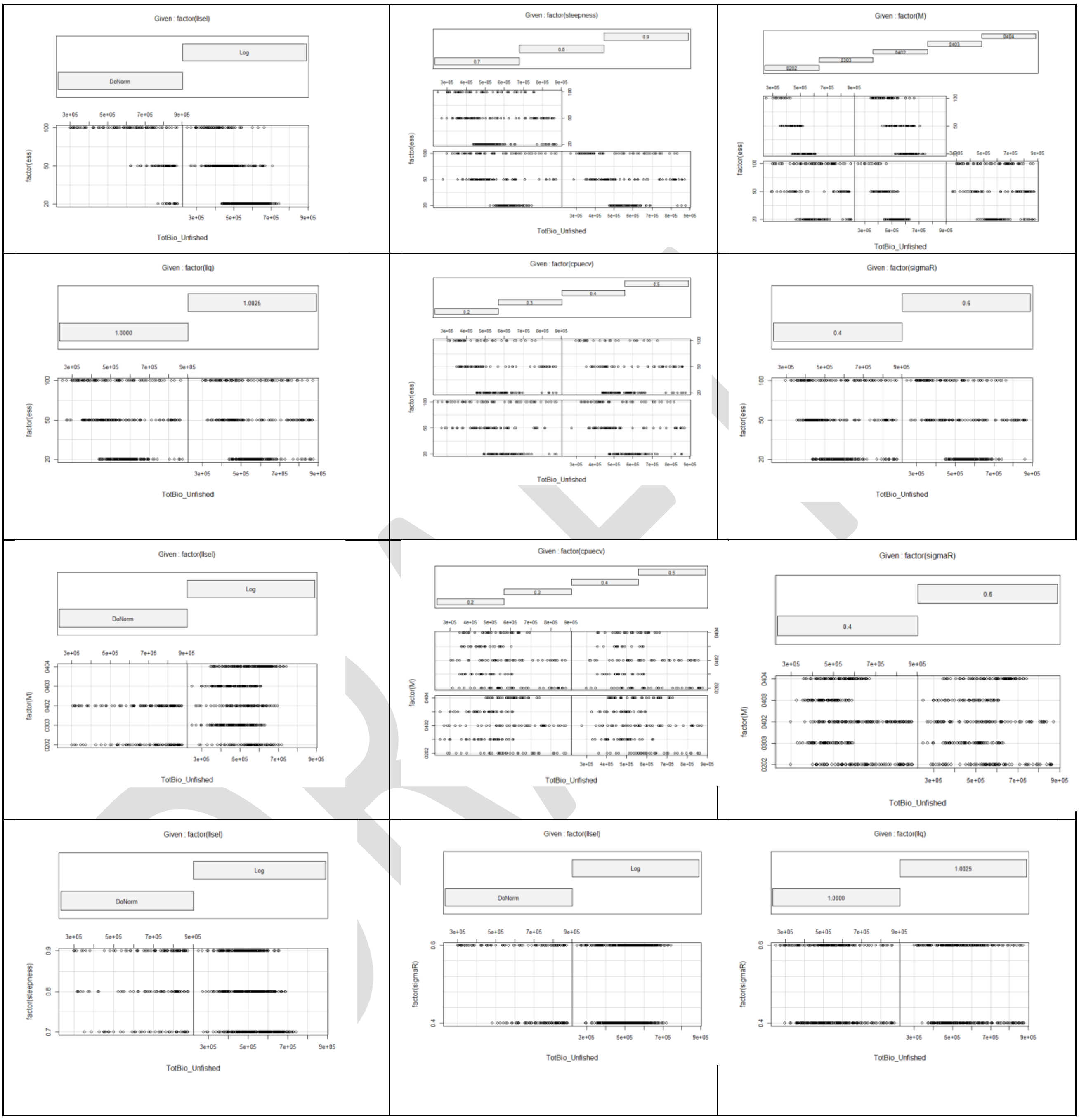

Figure 3: Main 2 way interactions between ESS and all variables (1st 2 rows), between M, cpue CV, selectivity and sigma R (row3) and between steepness and selectivity and sigmaR and selectivity and sigmaR and catchability change (row 4).

Table 2: ANOVA indicating variables and main effects and 2 way interactions with B0 as the dependent variable

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			654	1.2923e+13			
factor(M)	4	2.5089e+12	650	1.0414e+13	431.8204	< 2.2e-16	***
factor(steepness)	2	1.6292e+11	648	1.0251e+13	56.0805	< 2.2e-16	***
factor(ess)	2	1.2769e+12	646	8.9745e+12	439.5378	< 2.2e-16	***

factor(llq)	1	5.9042e+10	645	8.9155e+12	40.6476	3.801e-10	***
factor(cpuecv)	3	1.0550e+11	642	8.8100e+12	24.2115	9.501e-15	***
factor(llsel)	1	5.6036e+12	641	3.2064e+12	3857.7749	< 2.2e-16	***
factor(sigmaR)	1	1.9396e+11	640	3.0124e+12	133.5351	< 2.2e-16	***
factor(M):factor(steepness)	8	5.0697e+09	632	3.0074e+12	0.4363	0.8993488	
factor(M):factor(ess)	8	5.2134e+11	624	2.4860e+12	44.8642	< 2.2e-16	***
factor(M):factor(llq)	4	7.2289e+08	620	2.4853e+12	0.1244	0.9736628	
factor(M):factor(cpuecv)	12	5.4492e+10	608	2.4308e+12	3.1262	0.0002557	***
factor(M):factor(llsel)	1	1.0567e+10	607	2.4202e+12	7.2748	0.0072025	**
factor(steepness):factor(ess)	4	3.0613e+10	603	2.3896e+12	5.2690	0.0003586	***
factor(steepness):factor(llq)	2	3.4744e+09	601	2.3862e+12	1.1960	0.3031773	
factor(steepness):factor(cpuecv)	6	6.1161e+09	595	2.3800e+12	0.7018	0.6483010	
factor(steepness):factor(llsel)	2	1.3958e+10	593	2.3661e+12	4.8045	0.0085314	**
factor(ess):factor(llq)	2	2.5106e+10	591	2.3410e+12	8.6422	0.0002010	***
factor(ess):factor(cpuecv)	6	2.9614e+11	585	2.0448e+12	33.9800	< 2.2e-16	***
factor(ess):factor(llsel)	2	1.5833e+11	583	1.8865e+12	54.5024	< 2.2e-16	***
factor(llq):factor(cpuecv)	3	7.7295e+09	580	1.8788e+12	1.7738	0.1510317	
factor(llq):factor(llsel)	1	6.0294e+08	579	1.8782e+12	0.4151	0.5196585	
factor(cpuecv):factor(llsel)	3	3.6050e+09	576	1.8746e+12	0.8273	0.4791722	
factor(M):factor(sigmaR)	4	5.6200e+11	572	1.3126e+12	96.7276	< 2.2e-16	***
factor(steepness):factor(sigmaR)	2	7.7301e+09	570	1.3048e+12	2.6609	0.0707643	.
factor(ess):factor(sigmaR)	2	4.2664e+11	568	8.7820e+11	146.8595	< 2.2e-16	***
factor(llq):factor(sigmaR)	1	2.9271e+10	567	8.4893e+11	20.1514	8.681e-06	***
factor(cpuecv):factor(sigmaR)	3	8.9733e+09	564	8.3995e+11	2.0592	0.1045595	
factor(llsel):factor(sigmaR)	1	2.2174e+10	563	8.1778e+11	15.2654	0.0001048	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Based on Table 2, all main effects are significant, other 2 level interactions are where effective sample size interacts with everything, other factors that are significant are M:llsel, M:cpuecv, and M:sigmaR, sigmaR: llq and Sigma R: llsel.

All 3 way interactions with ESS and M were significant, other than llsel (shape of selectivity), llq(change in q) or steepness (see Table 3 below)

Table 3: Main effects with significant 2 way interactions, and remaining 3 way interactions

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			654	1.2923e+13			
factor(M)	4	2.5089e+12	650	1.0414e+13	566.9956	< 2.2e-16	***
factor(steepness)	2	1.6292e+11	648	1.0251e+13	73.6357	< 2.2e-16	***
factor(ess)	2	1.2769e+12	646	8.9745e+12	577.1288	< 2.2e-16	***
factor(llq)	1	5.9042e+10	645	8.9155e+12	53.3718	1.025e-12	***
factor(cpuecv)	3	1.0550e+11	642	8.8100e+12	31.7906	< 2.2e-16	***
factor(llsel)	1	5.6036e+12	641	3.2064e+12	5065.3962	< 2.2e-16	***
factor(sigmaR)	1	1.9396e+11	640	3.0124e+12	175.3364	< 2.2e-16	***
factor(M):factor(ess)	8	5.0314e+11	632	2.5093e+12	56.8520	< 2.2e-16	***
factor(M):factor(cpuecv)	12	5.2002e+10	620	2.4573e+12	3.9173	8.614e-06	***
factor(M):factor(llsel)	1	7.7689e+09	619	2.4495e+12	7.0228	0.0082892	**
factor(steepness):factor(ess)	4	2.9472e+10	615	2.4201e+12	6.6603	3.107e-05	***
factor(steepness):factor(llsel)	2	3.1823e+10	613	2.3882e+12	14.3835	8.271e-07	***
factor(ess):factor(llq)	2	2.5154e+10	611	2.3631e+12	11.3689	1.465e-05	***
factor(ess):factor(cpuecv)	6	3.0086e+11	605	2.0622e+12	45.3273	< 2.2e-16	***
factor(ess):factor(llsel)	2	1.5050e+11	603	1.9117e+12	68.0235	< 2.2e-16	***
factor(M):factor(sigmaR)	4	5.6696e+11	599	1.3448e+12	128.1283	< 2.2e-16	***
factor(ess):factor(sigmaR)	2	4.2988e+11	597	9.1488e+11	194.2975	< 2.2e-16	***
factor(llq):factor(sigmaR)	1	2.8619e+10	596	8.8626e+11	25.8708	5.080e-07	***
factor(llsel):factor(sigmaR)	1	1.6158e+10	595	8.7010e+11	14.6064	0.0001482	***
factor(M):factor(ess):factor(llsel)	2	3.9157e+07	593	8.7006e+11	0.0177	0.9824580	
factor(M):factor(steepness):factor(ess)	24	2.6453e+10	569	8.4361e+11	0.9964	0.4690186	
factor(M):factor(ess):factor(sigmaR)	8	1.8736e+11	561	6.5624e+11	21.1711	< 2.2e-16	***
factor(M):factor(ess):factor(cpuecv)	21	6.8145e+10	540	5.8810e+11	2.9334	1.630e-05	***
factor(M):factor(ess):factor(llq)	12	4.0002e+09	528	5.8410e+11	0.3013	0.9891227	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The final model used the main and interactions that were significant (Table 4) and Figure 14 shows all diagnostics of these model fits.

Table 4: Main effects with significant 2 way interactions

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			654	1.2923e+13			
factor(M)	4	2.5089e+12	650	1.0414e+13	573.3071	< 2.2e-16	***
factor(steepness)	2	1.6292e+11	648	1.0251e+13	74.4553	< 2.2e-16	***
factor(ess)	2	1.2769e+12	646	8.9745e+12	583.5531	< 2.2e-16	***
factor(llq)	1	5.9042e+10	645	8.9155e+12	53.9659	7.157e-13	***
factor(cpuecv)	3	1.0550e+11	642	8.8100e+12	32.1445	< 2.2e-16	***
factor(llsel)	1	5.6036e+12	641	3.2064e+12	5121.7814	< 2.2e-16	***
factor(sigmaR)	1	1.9396e+11	640	3.0124e+12	177.2882	< 2.2e-16	***
factor(M):factor(ess)	8	5.0314e+11	632	2.5093e+12	57.4848	< 2.2e-16	***
factor(M):factor(cpuecv)	12	5.2002e+10	620	2.4573e+12	3.9609	6.830e-06	***
factor(M):factor(llsel)	1	7.7689e+09	619	2.4495e+12	7.1010	0.0079240	**
factor(steepness):factor(ess)	4	2.9472e+10	615	2.4201e+12	6.7344	2.674e-05	***
factor(steepness):factor(llsel)	2	3.1823e+10	613	2.3882e+12	14.5436	6.930e-07	***
factor(ess):factor(llq)	2	2.5154e+10	611	2.3631e+12	11.4955	1.277e-05	***
factor(ess):factor(cpuecv)	6	3.0086e+11	605	2.0622e+12	45.8318	< 2.2e-16	***
factor(ess):factor(llsel)	2	1.5050e+11	603	1.9117e+12	68.7807	< 2.2e-16	***
factor(M):factor(sigmaR)	4	5.6696e+11	599	1.3448e+12	129.5545	< 2.2e-16	***
factor(ess):factor(sigmaR)	2	4.2988e+11	597	9.1488e+11	196.4603	< 2.2e-16	***
factor(llq):factor(sigmaR)	1	2.8619e+10	596	8.8626e+11	26.1588	4.311e-07	***
factor(llsel):factor(sigmaR)	1	1.6158e+10	595	8.7010e+11	14.7690	0.0001353	***
factor(M):factor(ess):factor(sigmaR)	8	1.8658e+11	587	6.8352e+11	21.3173	< 2.2e-16	***
factor(M):factor(ess):factor(cpuecv)	21	6.4276e+10	566	6.1924e+11	2.7976	3.816e-05	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

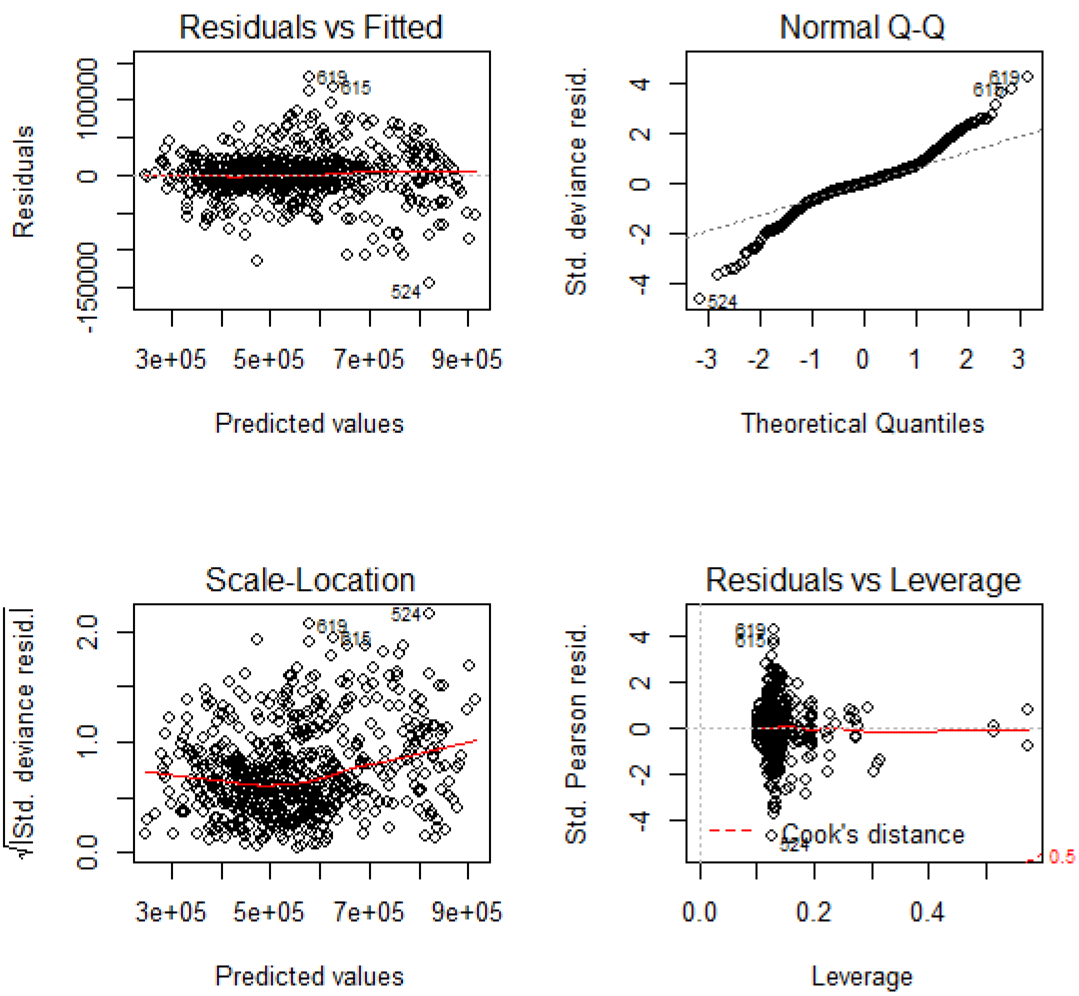

Figure 4: Diagnostic plots of final model with significant main effects and interactions.

Bluefin Tuna Eastern Atlantic

Main effects steepness and M and cpue series fits have a large influence on model dynamics (Figure 5 and 6).

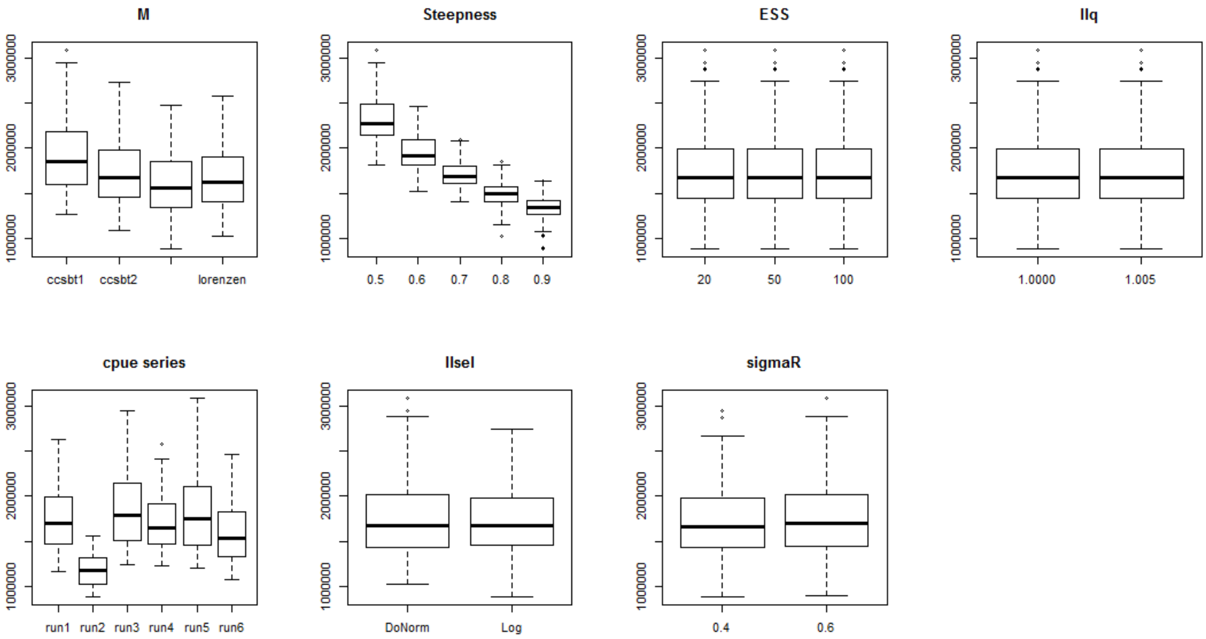

Figure 5: Main effects and B0

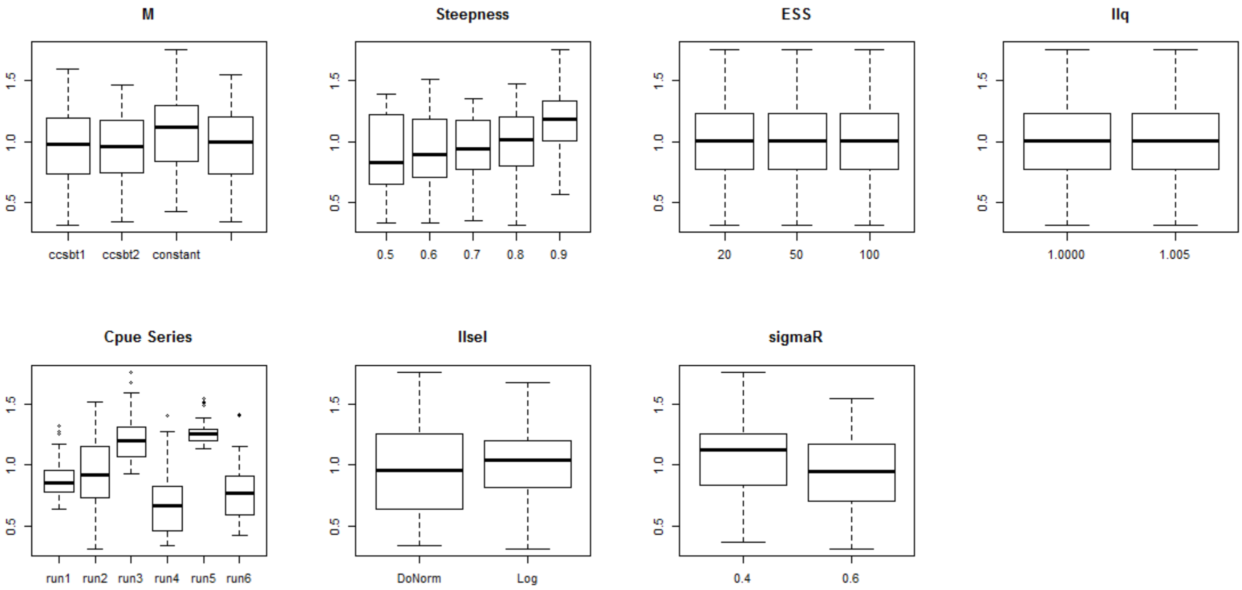

Figure 6: BFT east SSB_2015.SSBMSY against main effects

Table 5: ANOVA indicating variables and main effects with B0 as the dependent variable for EBFT

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			2195	3.4094e+14			
factor(M)	3	3.3054e+13	2192	3.0789e+14	826.1187	< 2e-16	***
factor(steepness)	4	2.6082e+14	2188	4.7072e+13	4888.9773	< 2e-16	***
factor(ess)	2	0.0000e+00	2186	4.7072e+13	0.0000	1.00000	
factor(llq)	1	0.0000e+00	2185	4.7072e+13	0.0000	1.00000	
factor(cpues)	5	1.6735e+13	2180	3.0337e+13	250.9523	< 2e-16	***
factor(llsel)	1	6.2393e+10	2179	3.0275e+13	4.6782	0.03066	*
factor(sigmaR)	1	1.2267e+12	2178	2.9048e+13	91.9762	< 2e-16	***

Based on this analysis, we assess that M, steepness, cpue series, llselectivity and sigmaR are significant main effects. We looked at main effects and 2 way interactions on these variables (Table 6) and assessed the grid structure based on that.

Table 8: ANOVA on all Main effects and 2 way interactions

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			2195	3.4094e+14			
factor(M)	3	3.3054e+13	2192	3.0789e+14	6093.809	< 2.2e-16	***
factor(steepness)	4	2.6082e+14	2188	4.7072e+13	36063.212	< 2.2e-16	***
factor(ess)	2	0.0000e+00	2186	4.7072e+13	0.000	1.000000	
factor(llq)	1	0.0000e+00	2185	4.7072e+13	0.000	1.000000	
factor(cpues)	5	1.6735e+13	2180	3.0337e+13	1851.133	< 2.2e-16	***
factor(llsel)	1	6.2393e+10	2179	3.0275e+13	34.508	4.935e-09	***
factor(sigmaR)	1	1.2267e+12	2178	2.9048e+13	678.456	< 2.2e-16	***
factor(M):factor(steepness)	12	1.3438e+12	2166	2.7704e+13	61.935	< 2.2e-16	***
factor(M):factor(ess)	6	0.0000e+00	2160	2.7704e+13	0.000	1.000000	
factor(M):factor(llq)	3	0.0000e+00	2157	2.7704e+13	0.000	1.000000	
factor(M):factor(cpues)	15	6.6232e+11	2142	2.7042e+13	24.421	< 2.2e-16	***
factor(M):factor(llsel)	3	1.7740e+11	2139	2.6865e+13	32.706	< 2.2e-16	***
factor(steepness):factor(ess)	8	0.0000e+00	2131	2.6865e+13	0.000	1.000000	
factor(steepness):factor(llq)	4	0.0000e+00	2127	2.6865e+13	0.000	1.000000	
factor(steepness):factor(cpues)	19	8.5334e+12	2108	1.8331e+13	248.402	< 2.2e-16	***
factor(steepness):factor(llsel)	4	1.4686e+11	2104	1.8184e+13	20.306	< 2.2e-16	***
factor(ess):factor(llq)	2	0.0000e+00	2102	1.8184e+13	0.000	1.000000	
factor(ess):factor(cpues)	10	0.0000e+00	2092	1.8184e+13	0.000	1.000000	
factor(ess):factor(llsel)	2	0.0000e+00	2090	1.8184e+13	0.000	1.000000	
factor(llq):factor(cpues)	5	0.0000e+00	2085	1.8184e+13	0.000	1.000000	
factor(llq):factor(llsel)	1	0.0000e+00	2084	1.8184e+13	0.000	1.000000	
factor(cpues):factor(llsel)	5	1.3210e+13	2079	4.9739e+12	1461.281	< 2.2e-16	***
factor(M):factor(sigmaR)	3	7.8338e+10	2076	4.8956e+12	14.442	2.598e-09	***
factor(steepness):factor(sigmaR)	4	2.3032e+11	2072	4.6652e+12	31.846	< 2.2e-16	***
factor(ess):factor(sigmaR)	2	0.0000e+00	2070	4.6652e+12	0.000	1.000000	
factor(llq):factor(sigmaR)	1	0.0000e+00	2069	4.6652e+12	0.000	1.000000	
factor(cpues):factor(sigmaR)	5	9.1665e+11	2064	3.7486e+12	101.396	< 2.2e-16	***
factor(llsel):factor(sigmaR)	1	1.8556e+10	2063	3.7300e+12	10.263	0.001378	**

Table 9: ANOVA on significant Main effects, 2 way interactions and remaining 3 way interactions

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			2195	3.4094e+14			
factor(M)	3	3.3054e+13	2192	3.0789e+14	14402.462	< 2.2e-16	***
factor(steepness)	4	2.6082e+14	2188	4.7072e+13	85233.891	< 2.2e-16	***
factor(cpues)	5	1.6735e+13	2183	3.0337e+13	4375.074	< 2.2e-16	***
factor(llsel)	1	6.2393e+10	2182	3.0275e+13	81.559	< 2.2e-16	***
factor(sigmaR)	1	1.2267e+12	2181	2.9048e+13	1603.503	< 2.2e-16	***
factor(M):factor(steepness)	12	1.3438e+12	2169	2.7704e+13	146.381	< 2.2e-16	***
factor(M):factor(cpues)	15	6.6232e+11	2154	2.7042e+13	57.718	< 2.2e-16	***
factor(M):factor(llsel)	3	1.7740e+11	2151	2.6865e+13	77.299	< 2.2e-16	***
factor(steepness):factor(llsel)	4	1.1704e+11	2147	2.6748e+13	38.249	< 2.2e-16	***
factor(steepness):factor(cpues)	19	8.5632e+12	2128	1.8184e+13	589.139	< 2.2e-16	***
factor(M):factor(sigmaR)	3	5.9874e+10	2125	1.8124e+13	26.089	< 2.2e-16	***
factor(llsel):factor(sigmaR)	1	6.2776e+10	2124	1.8062e+13	82.059	< 2.2e-16	***
factor(steepness):factor(sigmaR)	4	2.0257e+11	2120	1.7859e+13	66.200	< 2.2e-16	***
factor(cpues):factor(sigmaR)	5	9.1652e+11	2115	1.6943e+13	239.612	< 2.2e-16	***
factor(cpues):factor(llsel)	5	1.3213e+13	2110	3.7300e+12	3454.229	< 2.2e-16	***

```
factor(M):factor(steepness):factor(cpues)        50 1.1932e+12        2060 2.5369e+12     31.194 < 2.2e-16 ***
factor(M):factor(steepness):factor(llsel)        12 1.1530e+11        2048 2.4216e+12     12.560 < 2.2e-16 ***
factor(M):factor(steepness):factor(sigmaR)       12 2.9055e+10        2036 2.3925e+12      3.165 0.0001708 ***
factor(steepness):factor(cpues):factor(llsel)    17 6.8867e+11        2019 1.7038e+12     52.954 < 2.2e-16 ***
factor(steepness):factor(cpues):factor(sigmaR)   14 1.1928e+11        2005 1.5846e+12     11.137 < 2.2e-16 ***
factor(cpues):factor(llsel):factor(sigmaR)        5 5.4545e+10        2000 1.5300e+12     14.260 9.719e-14 ***
```

All 3 way interactions are significant, but due to complexity in examining and explaining 4 way interactions, we left the model as is with 3 way interactions. Diagnostic plots (Figure 7) indicate that the model residuals are performing well.

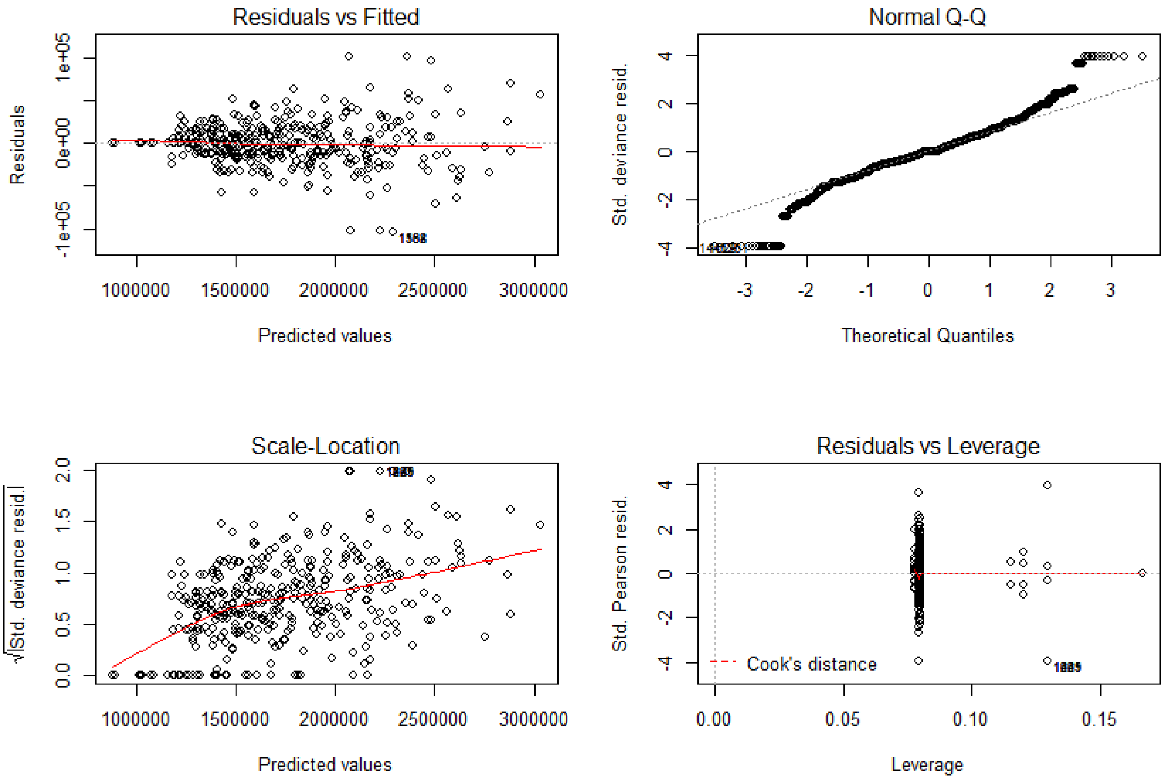

Figure 7: Diagnostic plots of final model with significant main effects and interactions.

Conclusions

ALBACORE:

Based on this analysis, we can conclude that a grid with 3 M levels, 3 steepness levels, 2 effective sample size levels, 2 llq levels, 2 cpuecv levels, 2 shape of selectivity levels, and 2 sigmaR levels (a total of 192 possible combinations should be sufficient to exhibit the uncertainty in this stock), and test the behaviour of a an empirical or model based control rule in the context of an MP.

BLUEFIN:

Based on this analysis, we can conclude that a grid with 4 M levels, 5 steepness levels, 6 cpue series assumptions, 2 shape of selectivity levels, and 2 sigmaR levels (a total of 480 possible combinations should be sufficient to exhibit the uncertainty in this stock), and test the behaviour of a an empirical or model based control rule in the context of an MP. Note, ESS is not used here primarily due to the poor quality of length composition data over the duration of the fishery. Hence, while being used to estimate selectivity, it is downweighted in the base model, and hence not a significant component (model behaviour becomes unstable when we put a strong weight on this component).

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Appendix 1: Results of PCA and Cluster Analysis to assess main components for IO Albacore Model

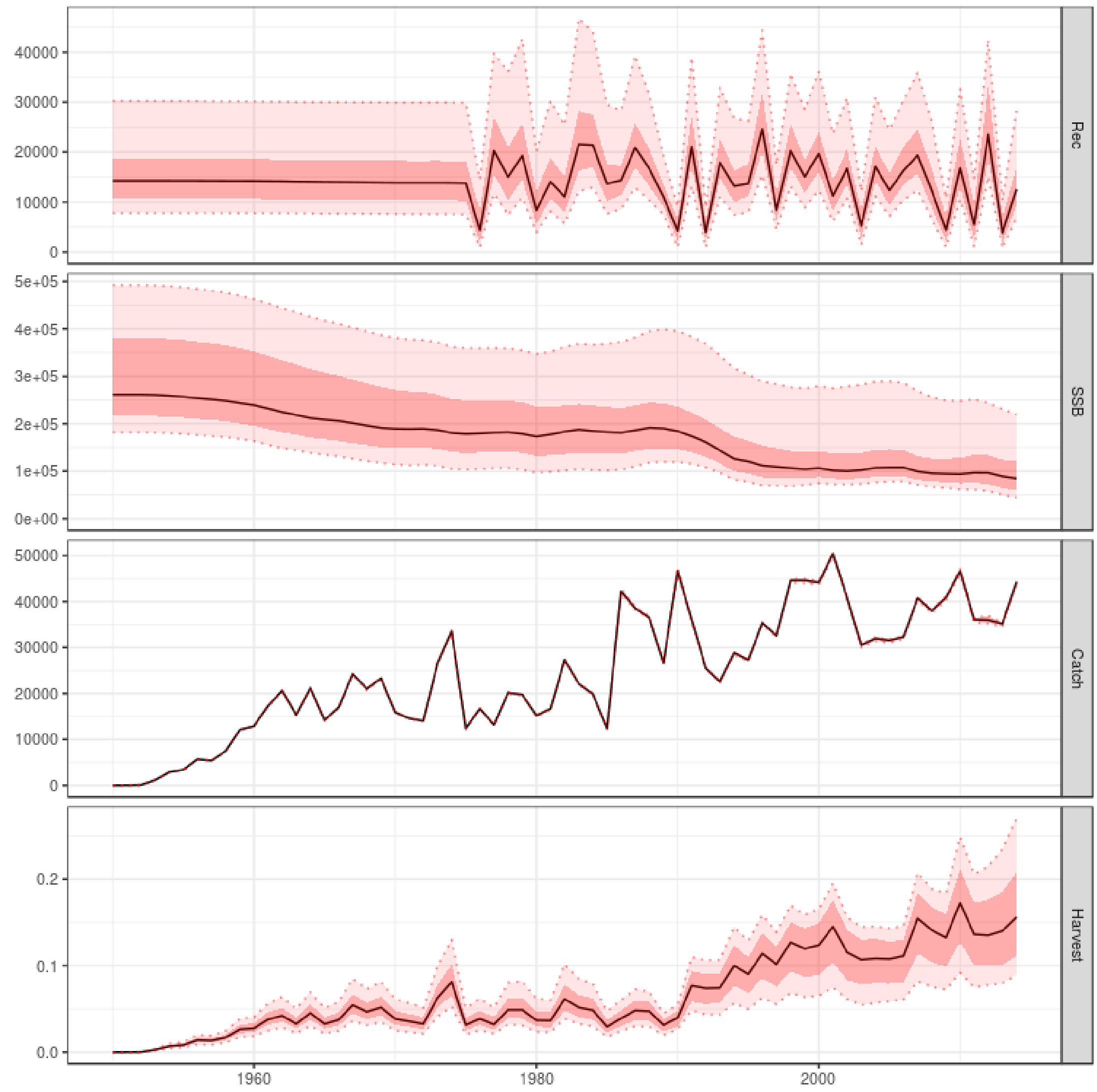


Figure 1. Time series from SS runs.

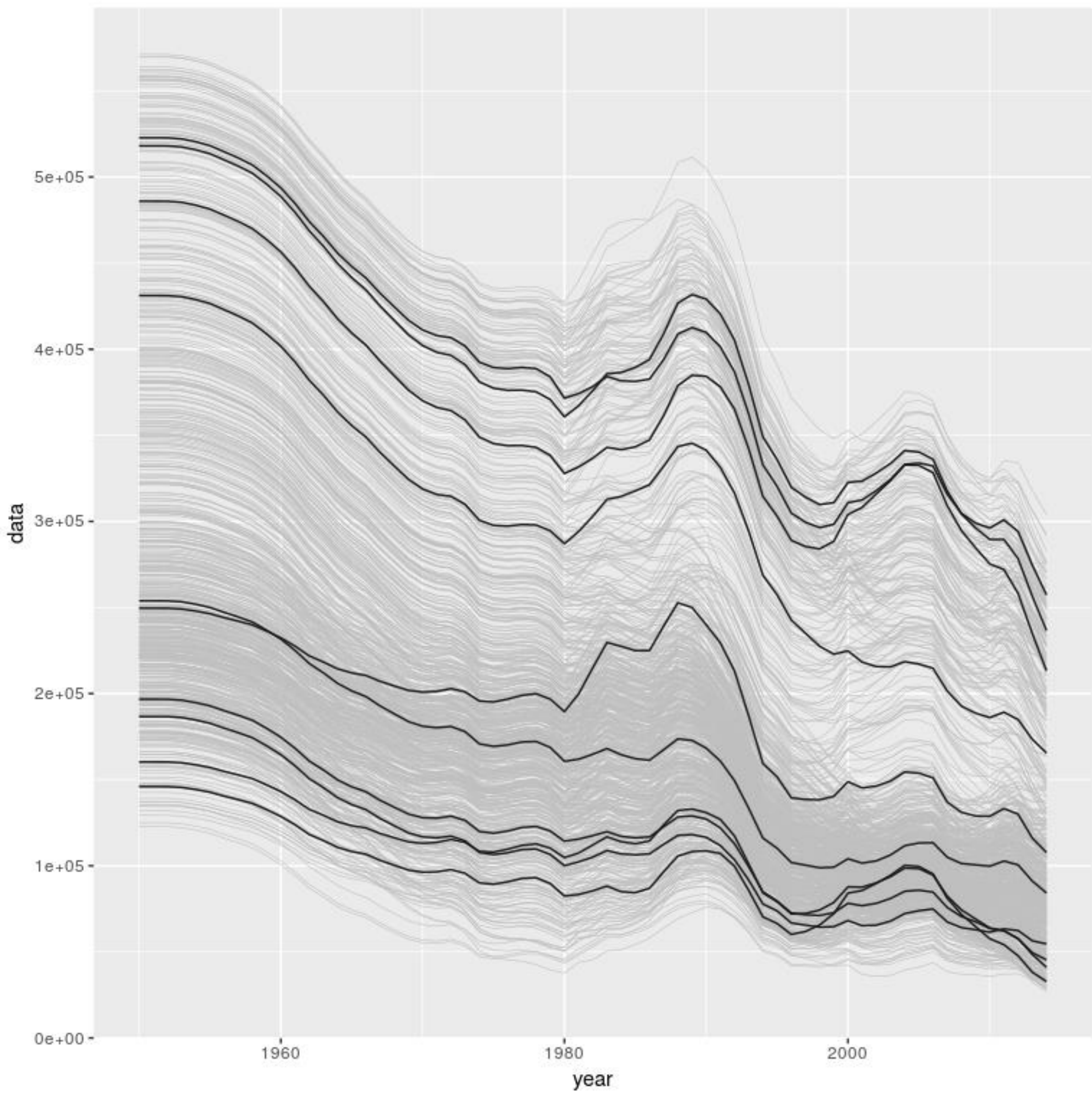


Figure 2. Time series for SSB.

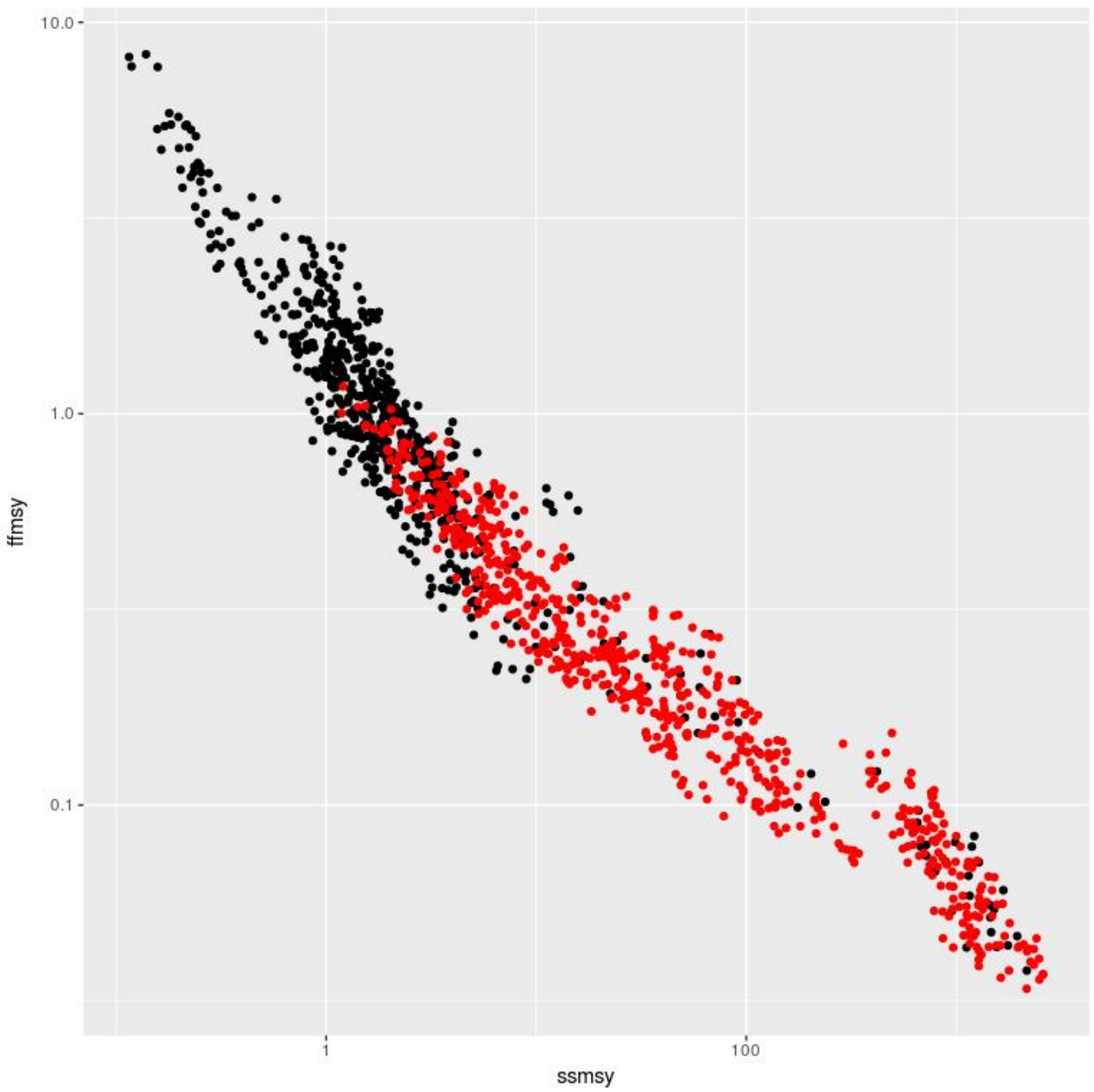


Figure 3. F/F_{MSY} against SSB/B_{MSY} for SS runs.

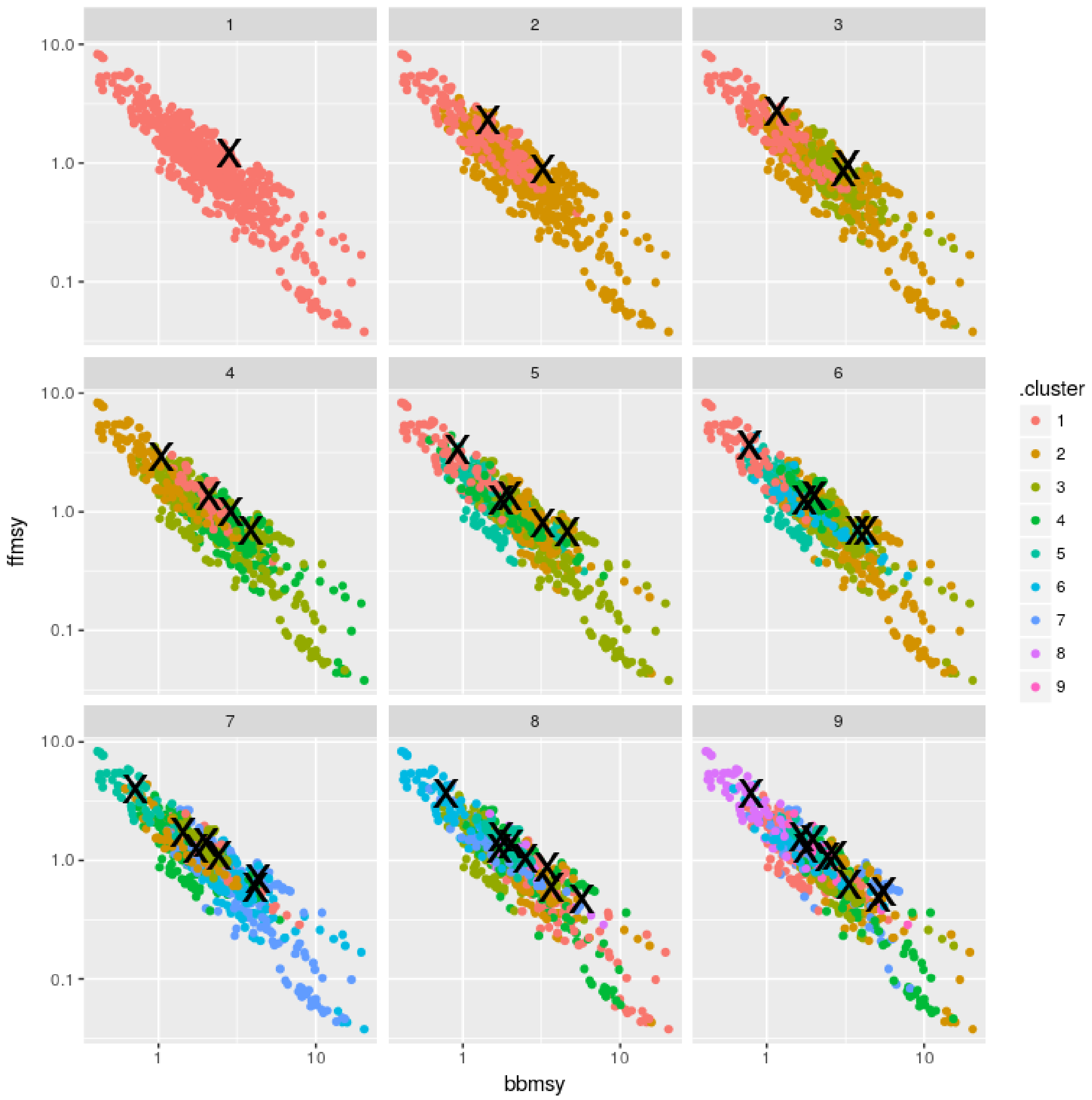


Figure 4. F/F_{MSY} against SSB/B_{MSY} for SS runs by cluster.

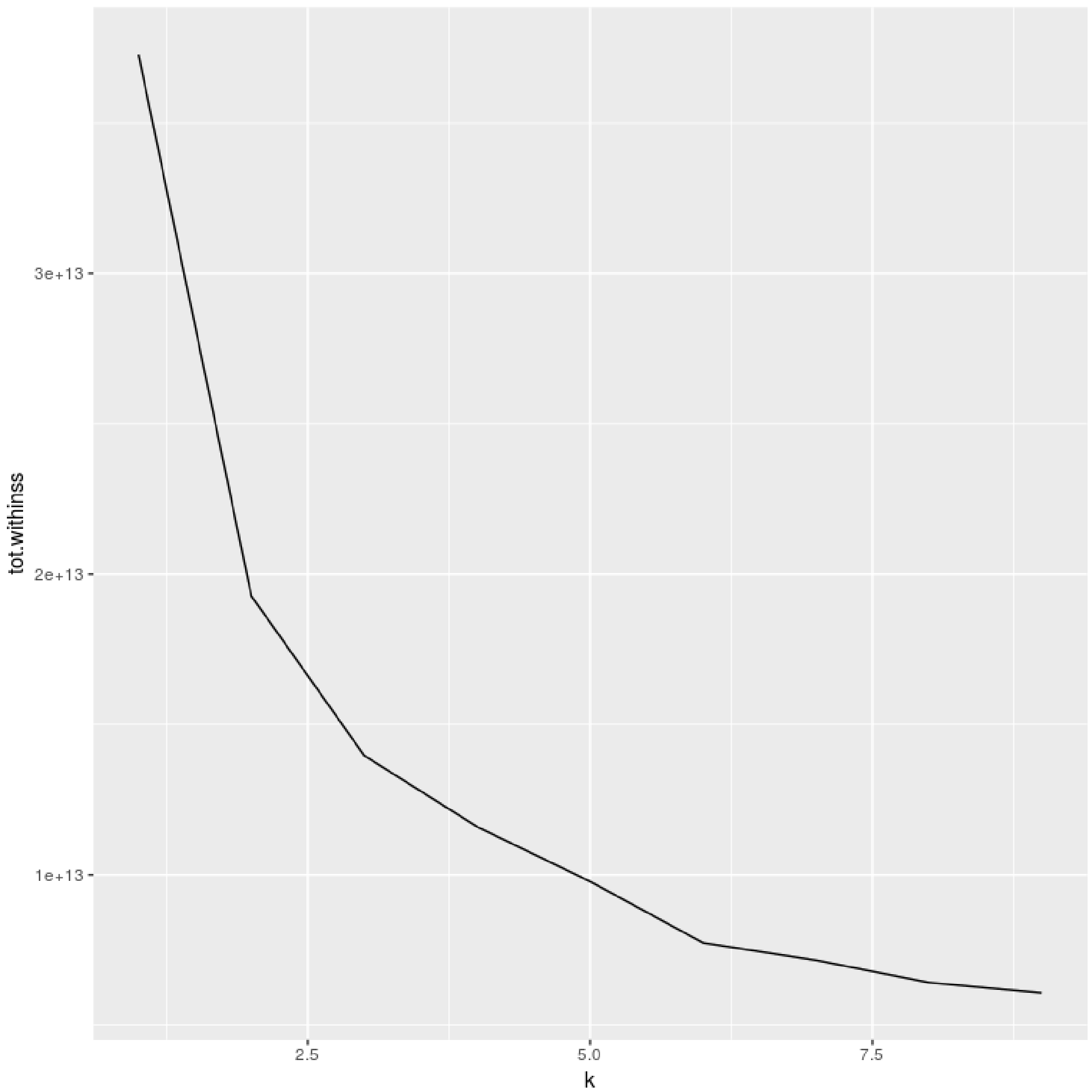


Figure 5.

PCA

i) biomass v f ref pts
ii) shape of production function
iii) current biomass v F
iv) regime

```
  s.virgin    b.fmax_      s.msy    s.fmax_         rt         rc 
-0.2614776 -0.2539173 -0.2384490 -0.2382744 -0.2352807 -0.2324472 
  b.virgin    f.fmax_     ffmsy_          r 
-0.2312375  0.2311936 -0.2253038 -0.2225971 

     shape  b.current  f.current  s.current    f.crash     bbmsy_ 
 0.3339449  0.3007661 -0.2906112  0.2886099 -0.2834624  0.2792214 
     b.msy     ffmsy_      f.msy      s.msy 
 0.2640245 -0.2630520 -0.2241542  0.1906638 

 b.current  f.current  s.current         rt      bbmsy  r.current 
-0.3712180  0.3475712 -0.2878654  0.2824470 -0.2759174 -0.2539155 
```

```
   r.fmax_    f.fmax_          r    s.fmax_
 0.2316788  0.2216983 -0.2039449 -0.2023415

     r.msy   b.virgin    r.fmax_      y.msy      ssmsy      f.msy
-0.3560004 -0.3402090 -0.3287533 -0.3207684 -0.2975443 -0.2538666
    ssmsy_   s.virgin      b.msy         rc
-0.2445313 -0.2365749 -0.2235823 -0.2001049
```

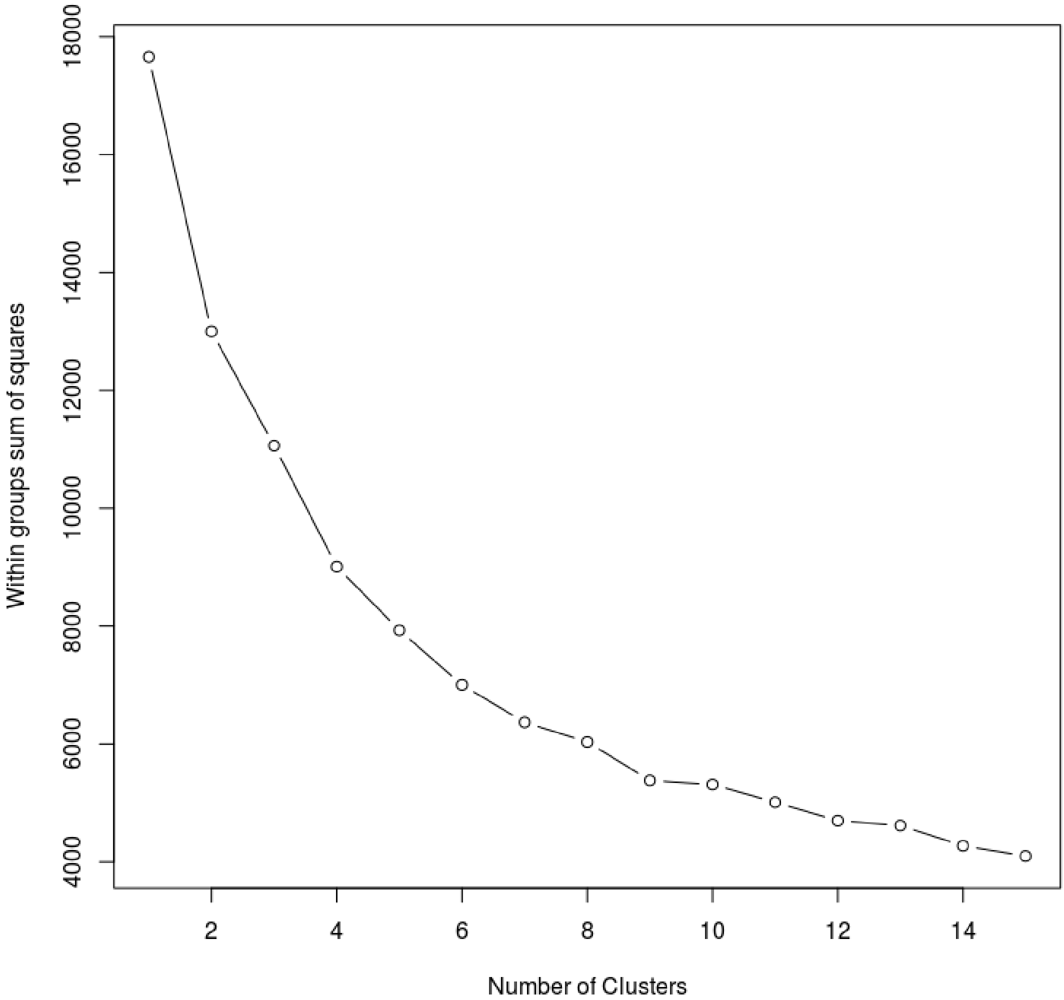


Figure 6. .

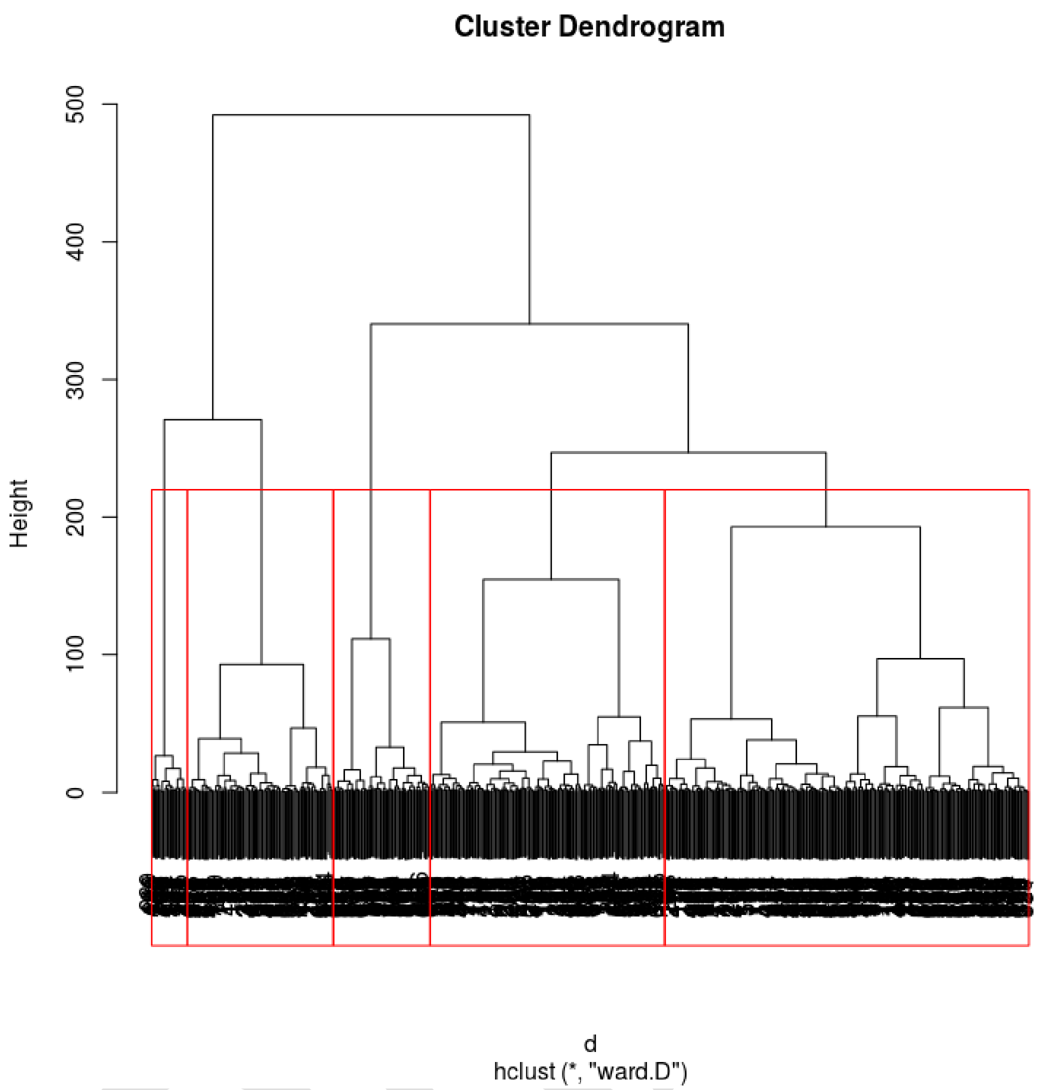

Cluster Dendrogram
Height
0
100
200
300
400
500
d
hclust (*, "ward.D")

Figure 7. .

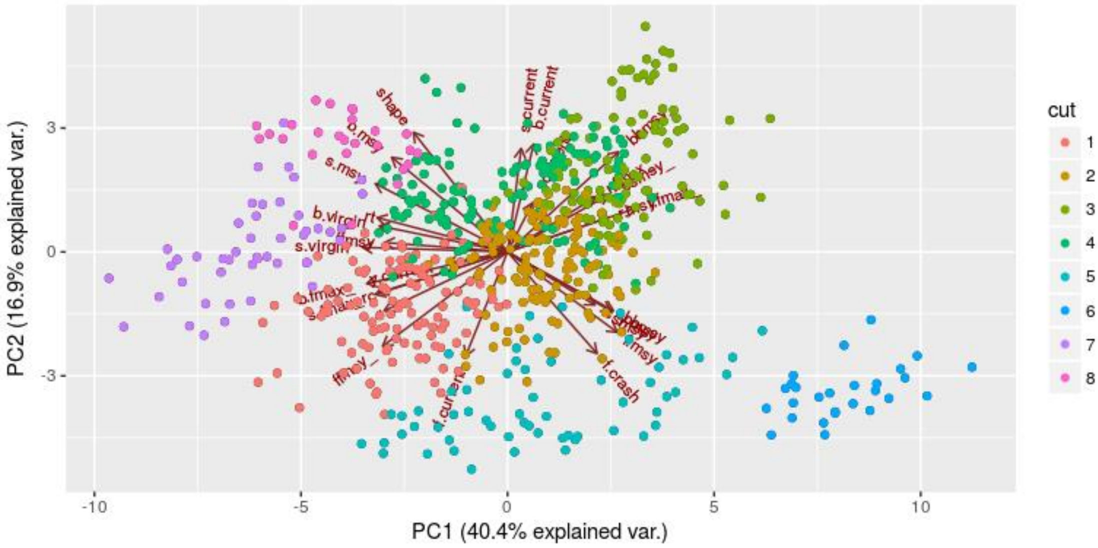


Figure 8. 1st and 2nd components by cluster.

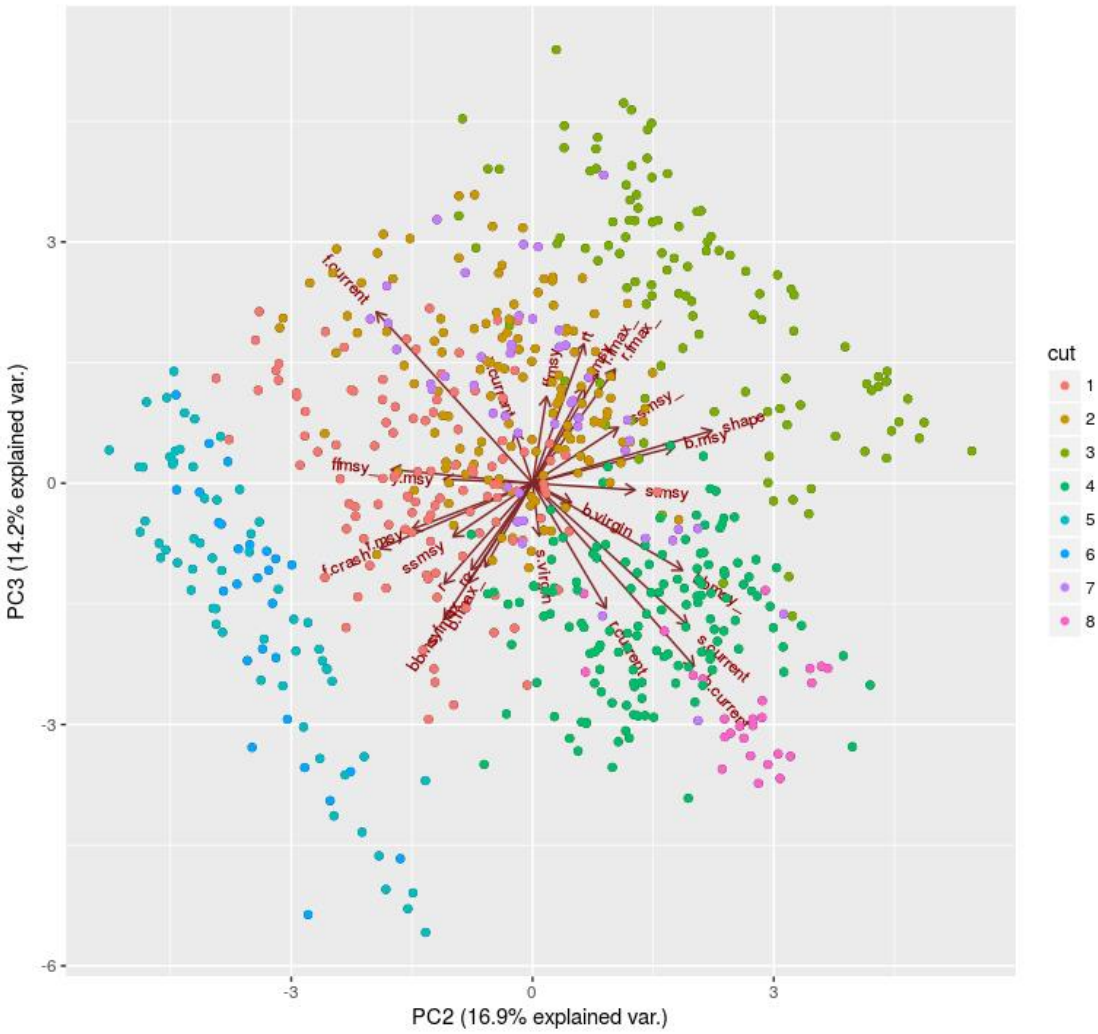


Figure 9. 2nd and 3rd components by cluster.

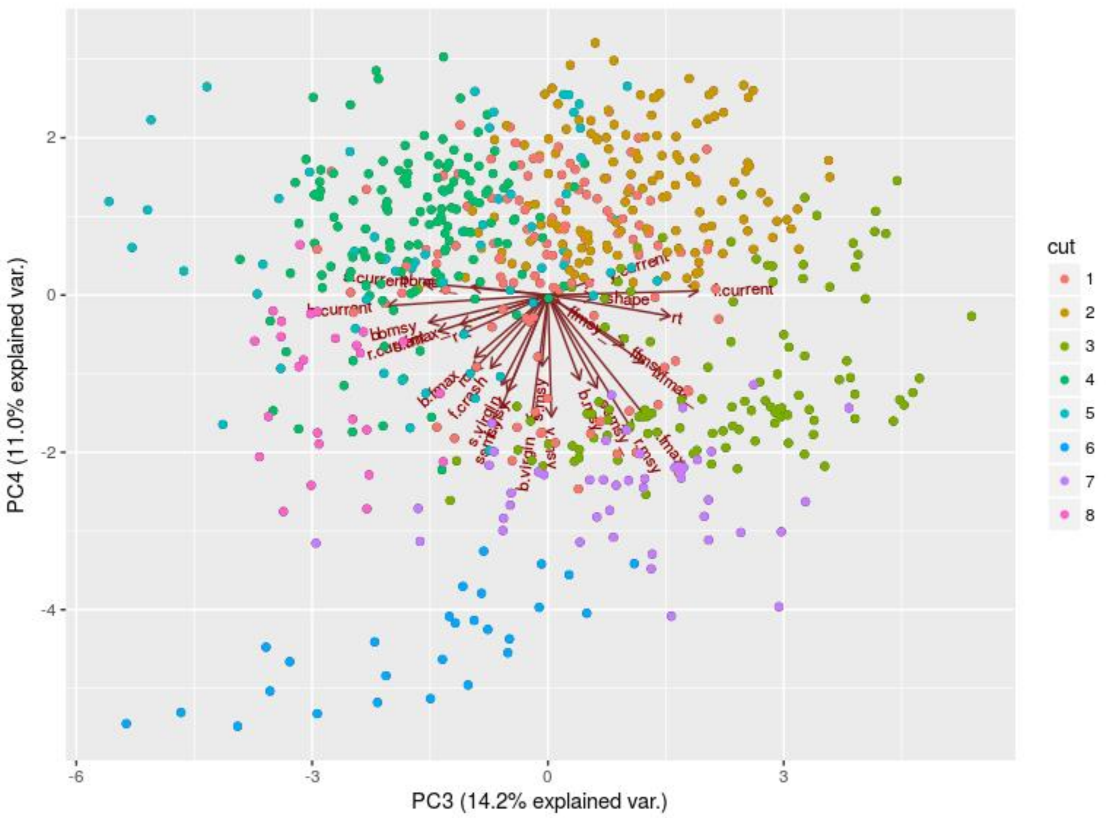
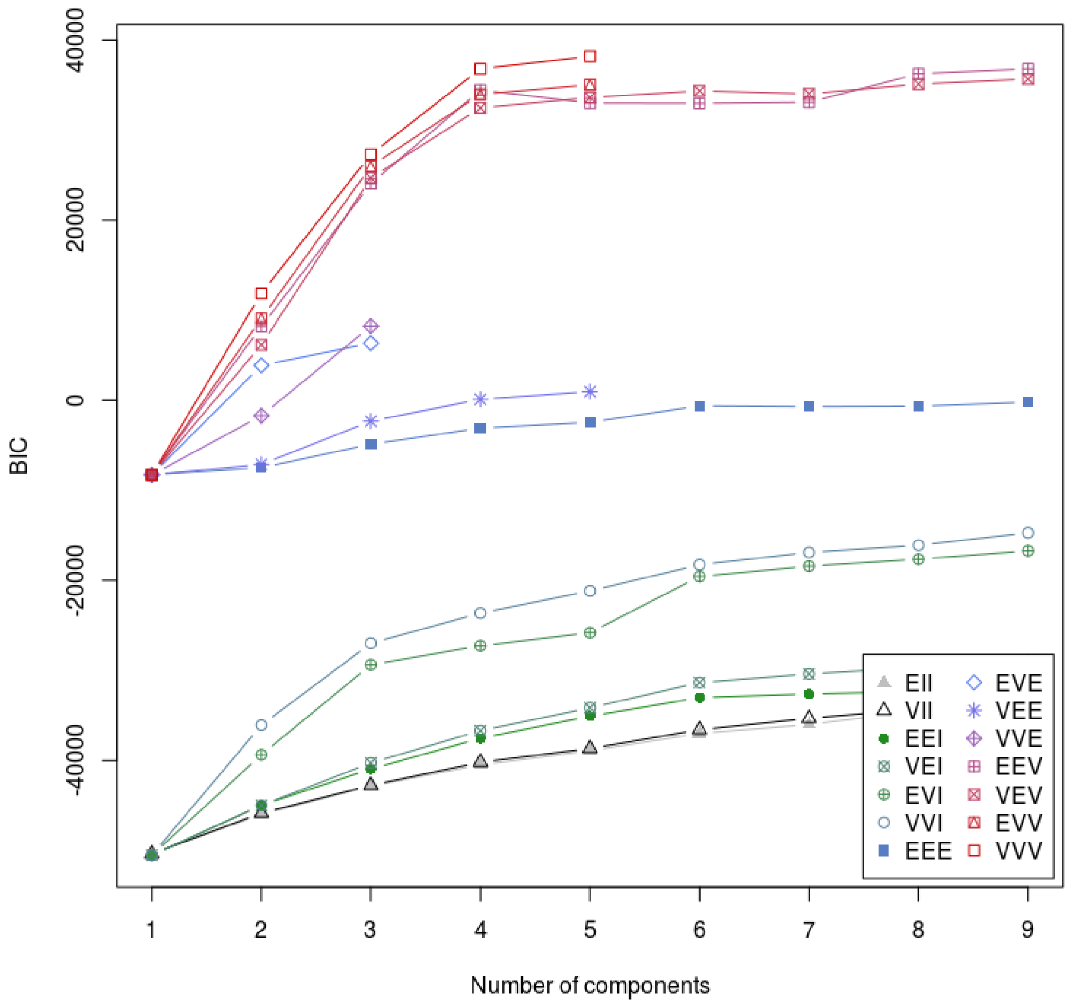


Figure 10. 3rd and 4th components by cluster.
http://www.statmethods.net/advstats/cluster.html

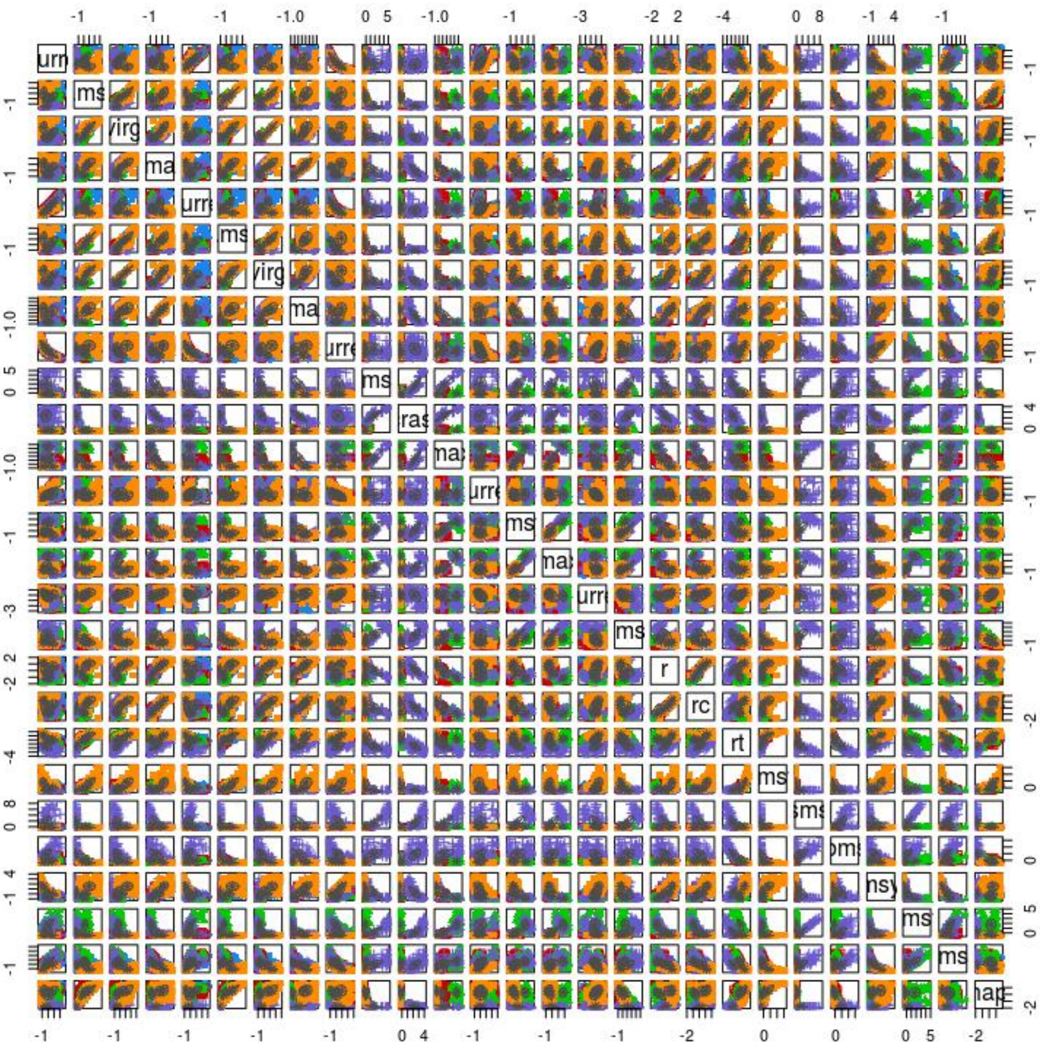
```
  Group.1   b.current      b.msy   b.virgin    b.fmax_   s.current
1       1  0.71592907 -1.5690401 -0.8901608 -1.0977655  0.12345907
2       2  0.01272145  0.2291341 -0.2732081 -0.8688372 -0.02179084
3       3 -0.78784769  1.9699310  2.0974198  1.5701209 -0.87995479
4       4  0.08605401 -0.3326236 -0.6184443 -0.5867837  0.07766019
5       5 -0.44873136 -1.5337400 -0.6862410 -0.9609914 -0.40011920
6       6 -0.70063400 -0.2913110  0.2644178  0.8272977 -0.60268482
7       7 -0.33397902 -1.4761164 -0.9132181 -0.2361593 -0.24666931
8       8  1.30396461  0.8819964  0.8640064  0.8349463  1.31337348
       s.msy   s.virgin     s.fmax_   f.current      f.msy     f.crash
1 -1.2306986 -1.1053379 -0.93517725 -0.77840199  4.5997472  3.73407942
2 -0.3392093 -0.7584059 -0.93360160 -0.08334696 -0.1569635 -0.33423431
3  2.1252681  2.0423261  1.22103711  1.04751973 -0.4988973 -0.42997333
4 -0.3557392 -0.5577819 -0.60334075 -0.18961633 -0.2033472 -0.34056538
5 -1.2304167 -0.9906566 -0.93305476  0.11476137  4.2862128  3.53605497
6 -0.1512533  0.4784329  0.94846617  0.63554997 -0.2239405 -0.09529173
7 -1.1500631 -0.6269234 -0.07369657  0.45090496  0.8483730  1.99060025
8  1.0987794  1.0021404  0.89677073 -1.02964887 -0.4515658 -0.41556189
     f.fmax_    r.current       r.msy     r.fmax_   y.current       y.msy
```

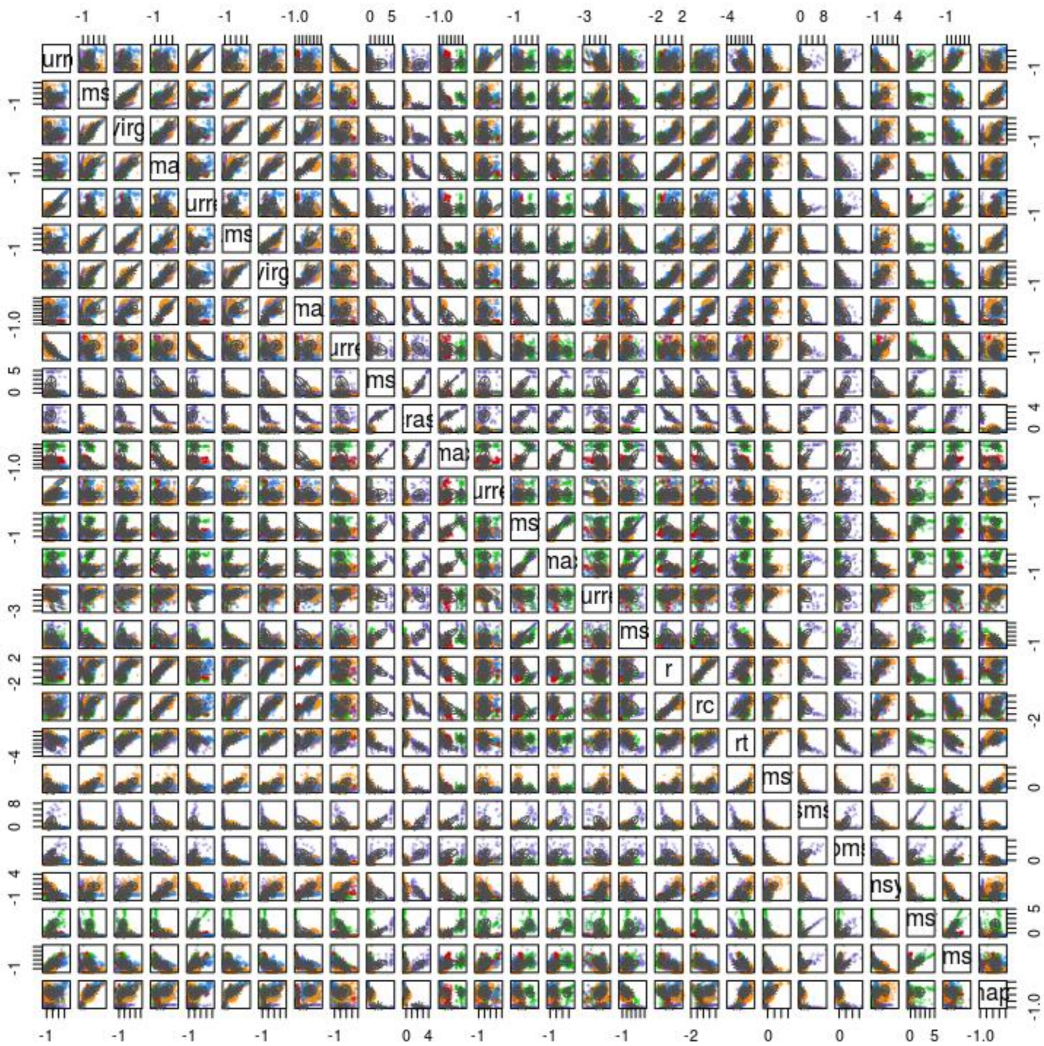
```
1  1.9140287  1.060021201  1.8082567  1.2919468 -1.37725305  2.81172802
2  1.7843742  0.037172842  1.5626373  1.7773075 -0.14725622  0.53729261
3 -0.8179367 -0.004026146 -0.3026834 -0.1863239  0.63945461 -0.59581294
4 -0.0861616  0.062842590 -0.2264686 -0.2562535 -0.19989384 -0.21488013
5  1.7198704 -0.234485600  2.1637644  1.5234576 -0.46063219  3.25641458
6 -0.7758709 -0.503055503 -0.6451788 -0.7077805  0.24607889 -0.05908225
7 -0.3971318 -0.243716915 -0.5185149 -0.6204140  0.07441002  0.20886684
8 -0.7941937  0.493455860 -0.6788802 -0.6298525  0.16536709 -0.72281014
            r         rc         rt       ffmsy       ssmsy       bbmsy
1 -0.92721322 -0.8946124 -3.0089426 -1.06966244  6.04946332  4.23238165
2 -1.17225463 -0.9034083  0.2159093 -0.28313182 -0.20155605 -0.35383086
3  1.16588921  1.4636177  1.6240135  2.54377273 -0.21155254 -0.83112724
4 -0.45799074 -0.5673221 -0.1963578 -0.26097519 -0.20150239 -0.06692727
5 -0.76582479 -0.6706680 -2.1013256 -1.04144901  3.42088573  2.04096861
6  1.03415031  0.8402640  0.4261667  0.07501089 -0.20614493 -0.32633080
7  0.04481833 -0.1313185 -1.5874302 -0.79813872 -0.03987766  1.88511698
8  0.67582342  0.7516713  0.1658413  0.05401214 -0.20625004 -0.24850000
      ffmsy_     ssmsy_     bbmsy_        shape
1 -1.0620008  2.2569972  1.7804993 -1.915974878
2 -0.9554552  1.7059570  0.6447943  0.273443082
3  1.6933879 -0.5158551 -1.2192728  1.155684788
4 -0.4522674 -0.3608053  0.3871671  0.008935341
5 -0.9221428  1.1195875  0.2342720 -1.915488661
6  1.1622452 -0.5104930 -1.0015240 -0.377295295
7  0.2667786 -0.4491874 -0.2542749 -1.742059397
8 -0.1307176 -0.4892582  0.1979360  0.844169497
```

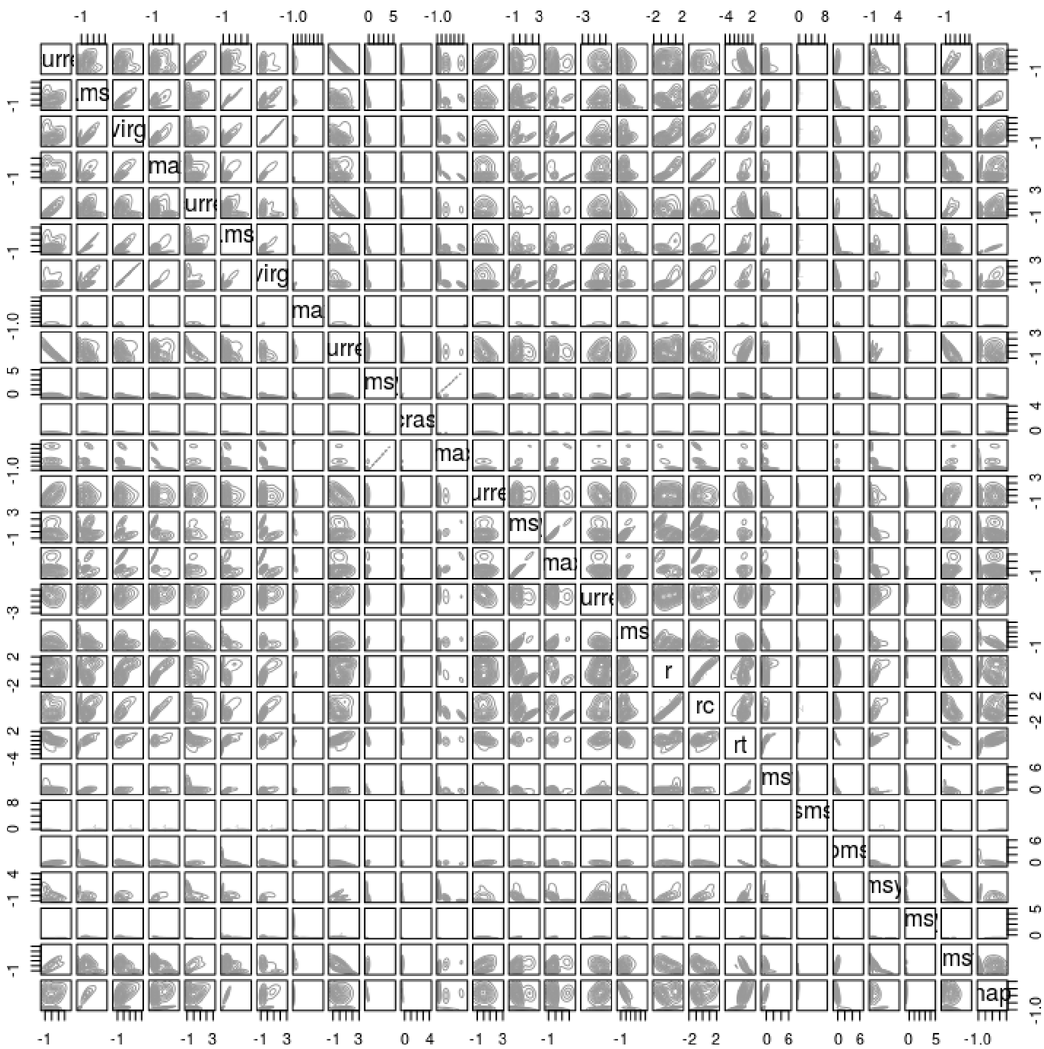
Figure 11. .



40000
20000
0
-20000
-40000
BIC
1
2
3
4
5
6
7
8
9
Number of components
EII
VII
EEI
VEI
EVI
VVI
EEE
EVE
VEE
VVE
EEV
VEV
EVV
VVV





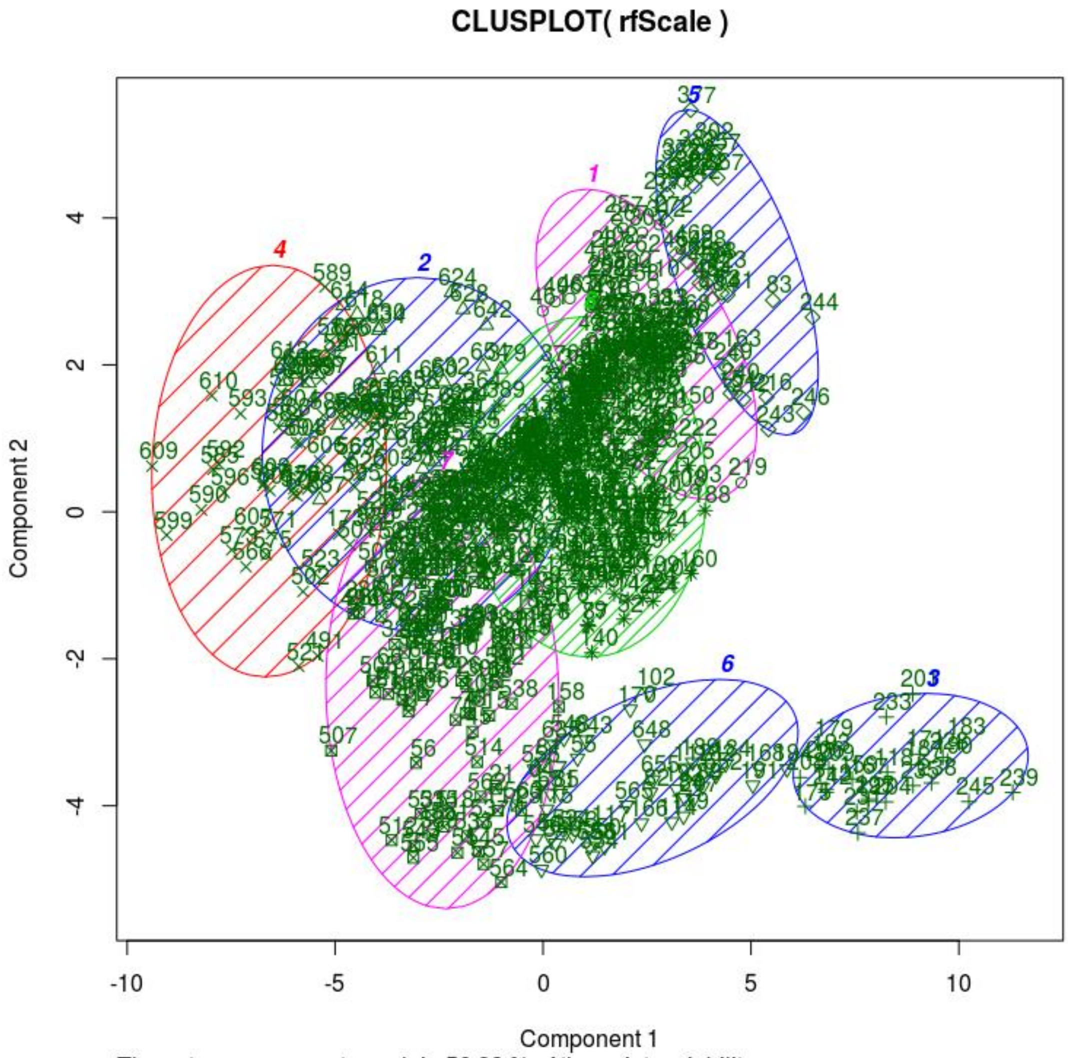


```
-----------------------------------------------------
Gaussian finite mixture model fitted by EM algorithm
-----------------------------------------------------

Mclust VVV (ellipsoidal, varying volume, shape, and orientation) model wit
h 5 components:

 log.likelihood   n   df      BIC      ICL
       25673.57 655 2029 38189.82 38188.29

Clustering table:
  1   2   3   4   5
152 197 109  88 109
```



These two components explain 56.22 % of the point variability.

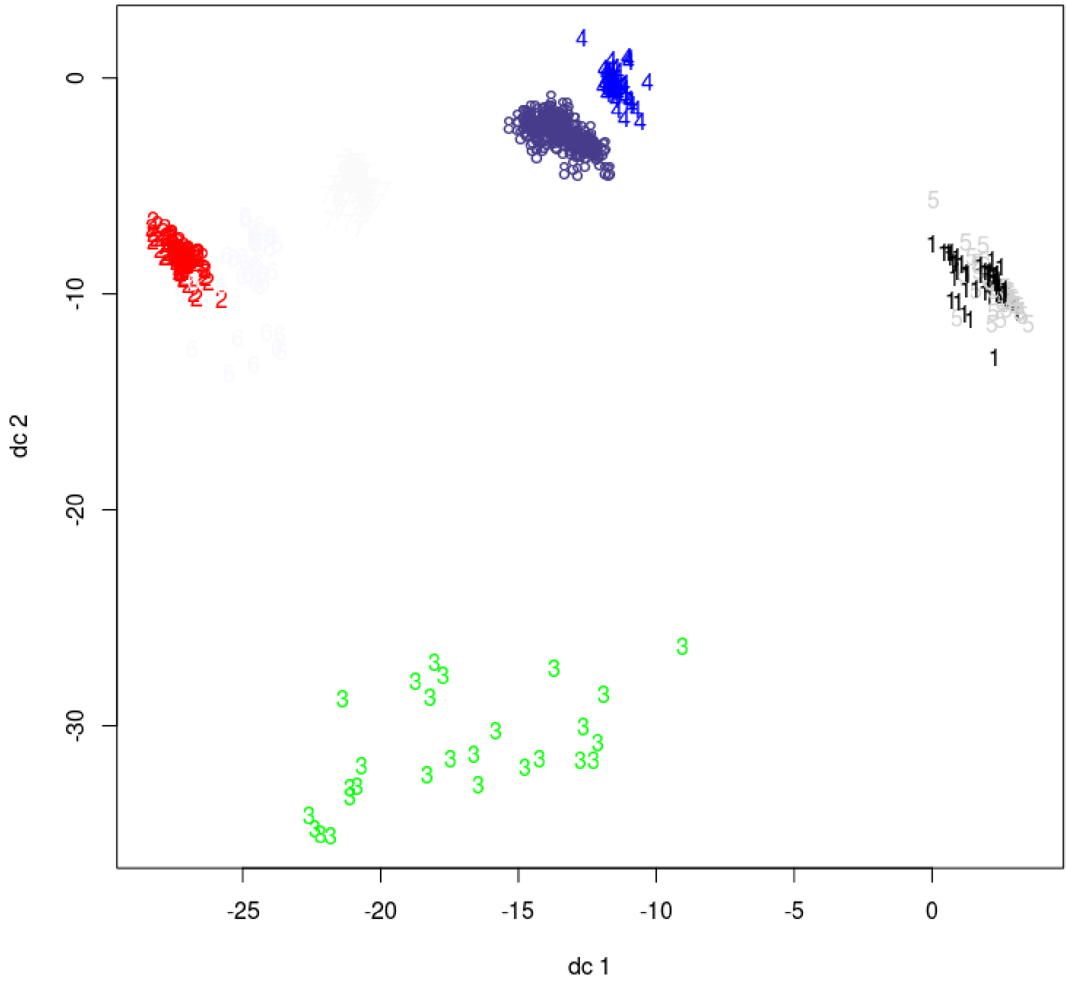


Figure 12. .

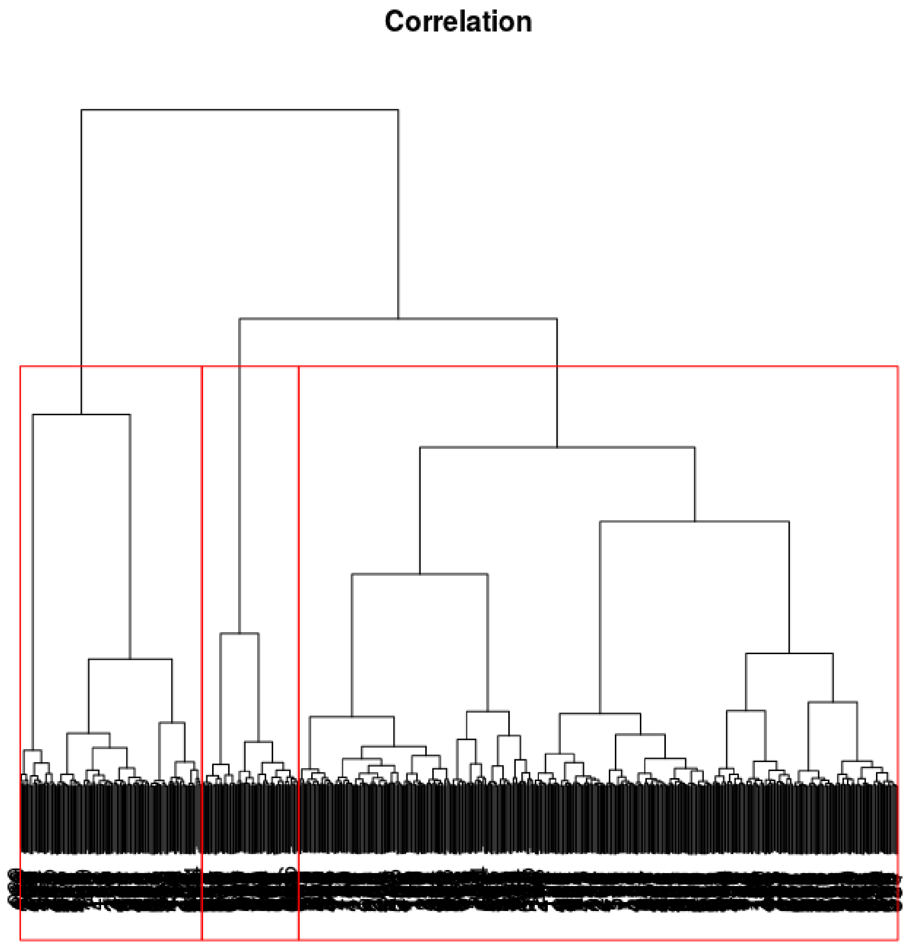


Figure 13. .