Lathyrus ms2: Selection on reaction norms - multivariate modeling for phenotypic selection on plasticity 2b (Arnold et al. 2019 Phil. Trans. R. Soc. B)

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Code based on Arnold et al. 2019 Phil. Trans. R. Soc. B. Using plant individuals with at least 3/5 years of data.

Using plant individuals with at least 3 years of data.

Stack data

```
# Create a single data-set "data.stack3", with single column at start to index observations
data.stack3 <- c()
data.stack3$Obs <- 1:(359 + 1803)
data.stack3$id <- c(data_3yrs_total$id, data_3yrs$id)

# Add first_yr to total data +
# Year column is only relevant for FFD, but is set to first_yr for fitness values

data_3yrs_total_wfirstyr<-data_3yrs_total%>%
  right_join(data_3yrs[c(3,10)]%>%
             group_by(id)%>%
             summarise(first_yr=mean(first_yr)),by="id")

data.stack3$year <- c(data_3yrs_total_wfirstyr$first_yr,
                      data_3yrs$year)
# Temperature column is only relevant for FFD, but is set to 0 for fitness values
data.stack3$temp <- c(rep(0, 359), data_3yrs$cmean_4)

# Create single column with first fitness values, then FFD values:
data.stack3$fitness.FFD.stack <- c(data_3yrs_total$mean_fitness_rel, data_3yrs$FFD)

# Create 3 index columns needed for MCMCglmm
data.stack3$traits <- c(rep("fitness", 359), rep("FFD", 1803))
data.stack3$variable <- data.stack3$traits
# Both fitness and FFD will be modelled with a Gaussian distribution
# Specify this with the column 'family':
data.stack3$family <- c(rep("gaussian", 359), rep("gaussian", 1803))
```

```r
data.stack3 <- data.frame(data.stack3)

data.stack3$id <- as.factor(data.stack3$id)
data.stack3$year <- as.factor(data.stack3$year)
head(data.stack3)
```

```
##   Obs id year temp fitness.FFD.stack  traits variable   family
## 1   1  1 2006    0         5.1754021 fitness  fitness gaussian
## 2   2  2 2007    0         1.5290819 fitness  fitness gaussian
## 3   3  3 2007    0         0.8847473 fitness  fitness gaussian
## 4   4  4 2007    0         2.2064658 fitness  fitness gaussian
## 5   5  5 2007    0         1.4149314 fitness  fitness gaussian
## 6   6  6 2007    0         0.6230090 fitness  fitness gaussian
```

Bivariate models of fitness and FFD, with random regressions for individuals

```r
# Scaling factor for MCMCglmm iterations
sc <- 100#0 # Increase this parameter for longer runs

priorBiv_RR3 <- list(G = list(G1 = list(V = diag(1), nu = 1)),
                    # ^ random effect for year (fitted for FFD only)
                    R = list(R1 = list(V = diag(3), nu = 3, covu = TRUE),
                             # ^ 3-way var-cov matrix of (id + temp:id) for FFD,
                             # residual for fitness
                             R2 = list(V = diag(1), nu = 1))) # residual for FFD

modelBV_RR3 <- MCMCglmm(fitness.FFD.stack ~ variable - 1 +
                          # ^ means for each variable (and no overall mean (hence "-1"))
                          at.level(variable, "FFD"):temp, # single fixed effect of temp
                        random = ~us(at.level(variable, "FFD")):year +
                          us(at.level(variable, "FFD") +
                               at.level(variable,"FFD"):temp):id,
                        # ^ random intercepts for individual,
                        # and random slopes for temp|id
                        rcov = ~us(at.level(variable, "fitness")):id +
                          # ^ variance between indivduals in fitness
                          # (which is residual variance)
                          us(at.level(variable, "FFD")):Obs,
                          # ^ residual variance within indivduals between years
                        # (labelled by 'Obs')
                        data = data.stack3,
                        prior = priorBiv_RR3,
                        family = NULL, # specified already in the data-set
                        nitt = 1100 * sc, thin = sc, burnin = 100 * sc, verbose = F)
```

```r
kable(summary(modelBV_RR3)$solutions,digits=c(3,3,3,0,3),caption="Fixed effects")
```

Table 1: Fixed effects

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC
variableFFD	58.508	56.518	60.620	1000	0.001
variablefitness	1.001	0.891	1.114	1116	0.001
at.level(variable, “FFD”):temp	-2.334	-3.950	-0.825	1000	0.006

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC

```r
kable(summary(modelBV_RR3)$Gcovariances,digits=c(3,3,3,0),caption="Random effects")
```

Table 2: Random effects

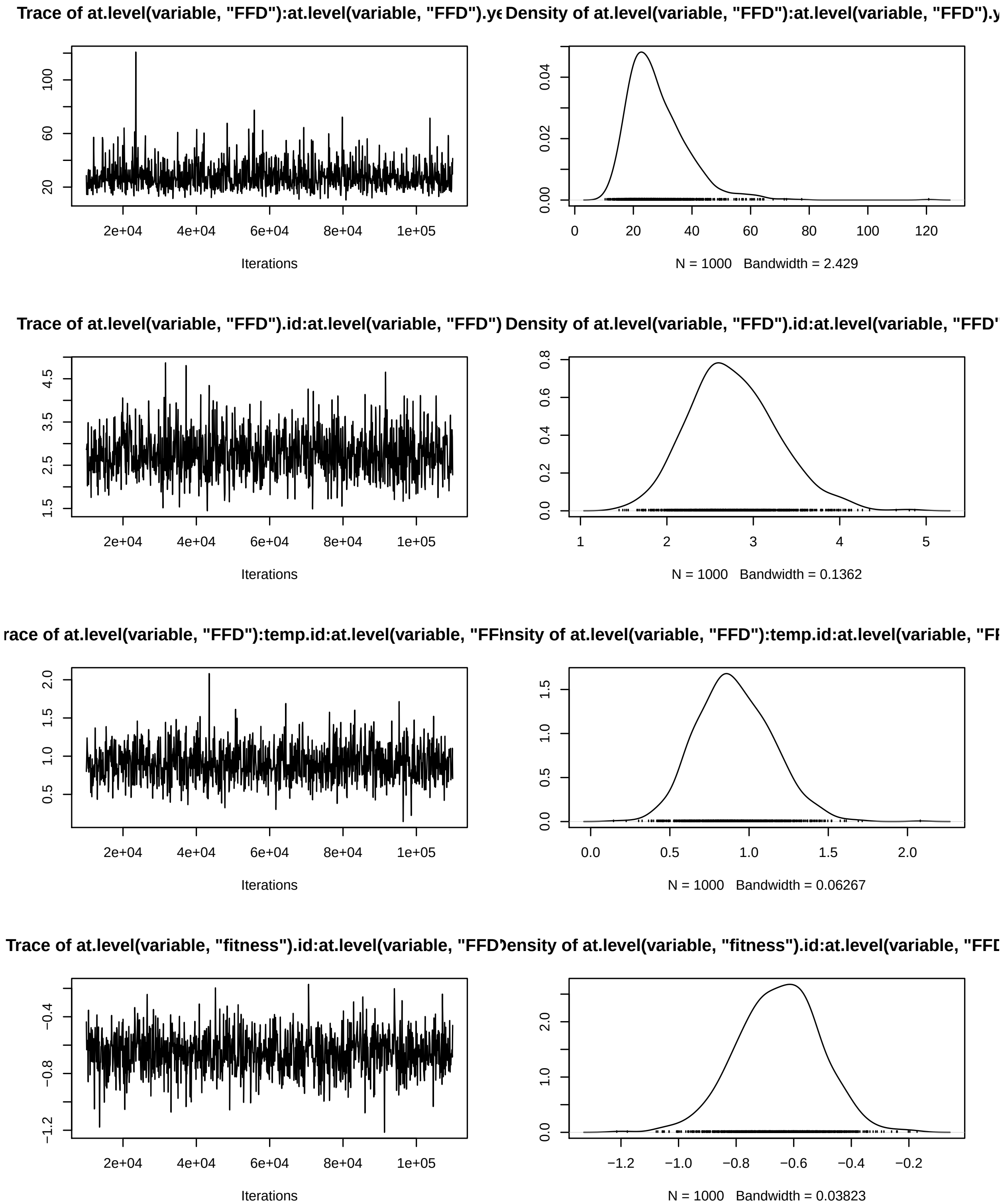
	post.mean	l-95% CI	u-95% CI	eff.samp
at.level(variable, "FFD"):at.level(variable, "FFD").year	28.17	11.828	46.451	1228

```r
kable(summary(modelBV_RR3)$Rcovariances,digits=c(3,3,3,0),caption="Random effects")
```

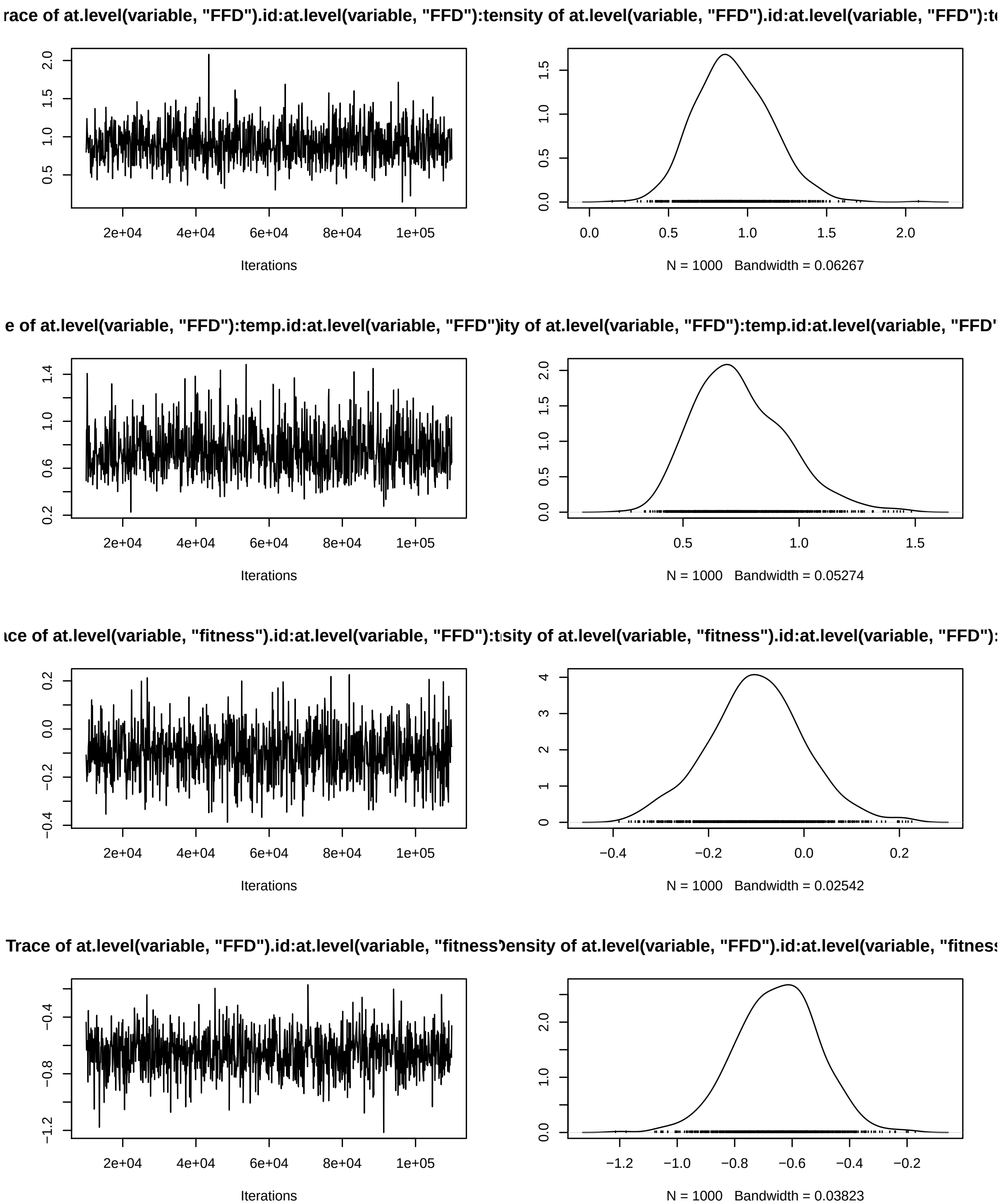
Table 3: Random effects

	post.mean	l-95% CI	u-95% CI	eff.samp
at.level(variable, "FFD").id:at.level(variable, "FFD").id	2.770	1.718	3.733	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD").id	0.910	0.426	1.333	1000
at.level(variable, "fitness").id:at.level(variable, "FFD").id	-0.652	-0.919	-0.370	1000
at.level(variable, "FFD").id:at.level(variable, "FFD"):temp.id	0.910	0.426	1.333	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD"):temp.id	0.747	0.421	1.165	1000
at.level(variable, "fitness").id:at.level(variable, "FFD"):temp.id	-0.100	-0.307	0.097	1000
at.level(variable, "FFD").id:at.level(variable, "fitness").id	-0.652	-0.919	-0.370	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "fitness").id	-0.100	-0.307	0.097	1000
at.level(variable, "fitness").id:at.level(variable, "fitness").id	1.204	1.015	1.371	921
at.level(variable, "FFD"):at.level(variable, "FFD").Obs	18.762	17.385	20.096	1098

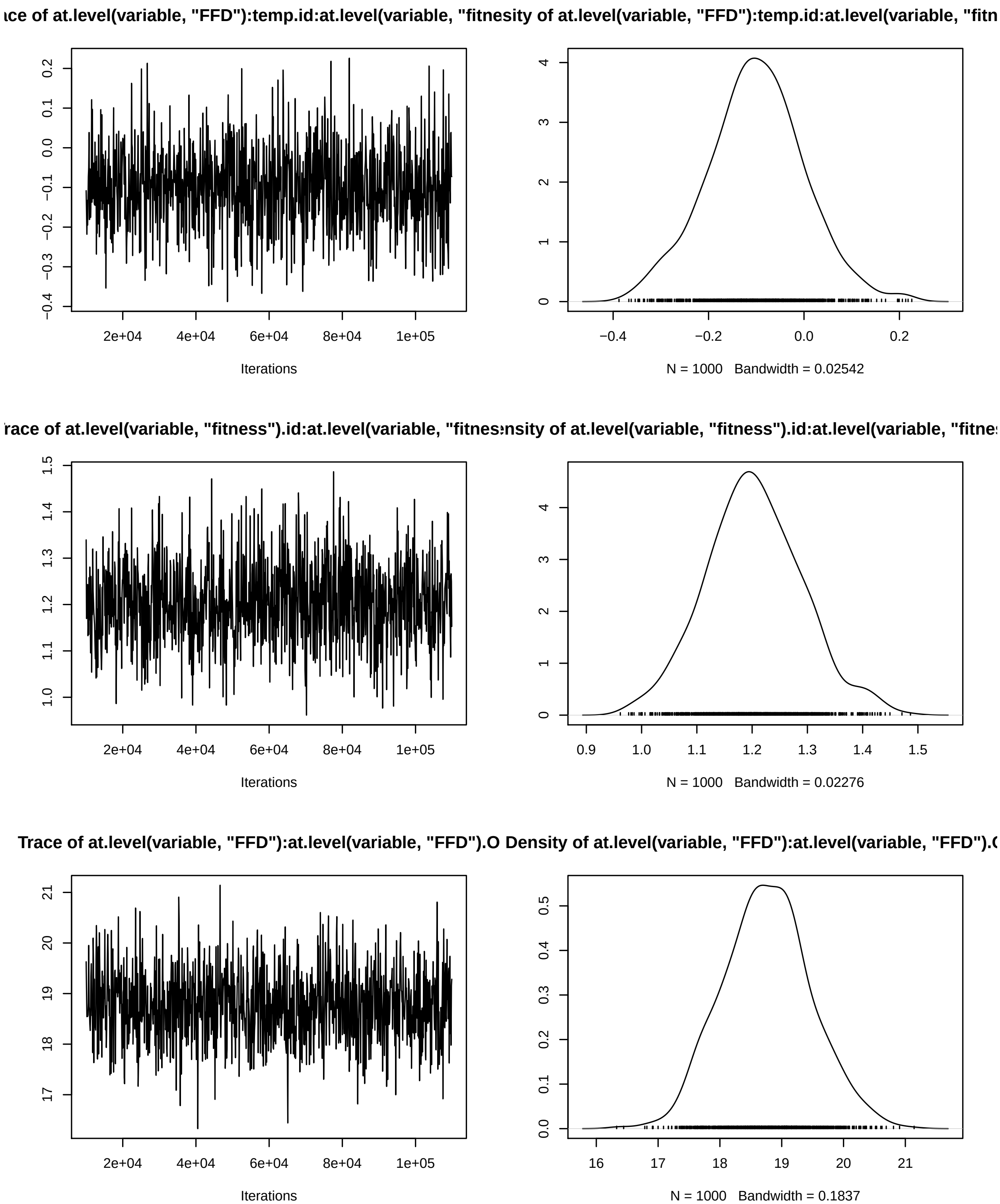
```r
plot(modelBV_RR3$VCV[,1:4])
```




```
plot(modelBV_RR3$VCV[,5:8])
```




```
plot(modelBV_RR3$VCV[,9:11])
```



Check for autocorrelation between successive stored iterations (suggested to be less than 0.1):

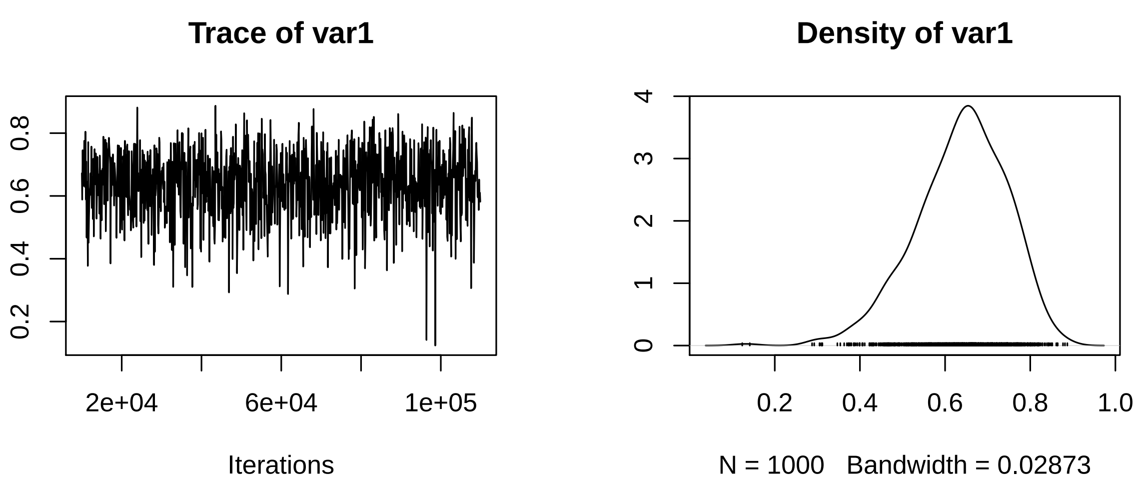
```
kable(diag(autocorr(modelBV_RR3$VCV)[2, , ]),caption="Autocorrelation")
```

Table 4: Autocorrelation

	x
at.level(variable, “FFD”):at.level(variable, “FFD”).year	-0.0287245
at.level(variable, “FFD”).id:at.level(variable, “FFD”).id	-0.0246556
at.level(variable, “FFD”):temp.id:at.level(variable, “FFD”).id	-0.0135211
at.level(variable, “fitness”).id:at.level(variable, “FFD”).id	-0.0205143
at.level(variable, “FFD”).id:at.level(variable, “FFD”):temp.id	-0.0135211
at.level(variable, “FFD”):temp.id:at.level(variable, “FFD”):temp.id	0.0105971
at.level(variable, “fitness”).id:at.level(variable, “FFD”):temp.id	-0.0071625
at.level(variable, “FFD”).id:at.level(variable, “fitness”).id	-0.0205143
at.level(variable, “FFD”):temp.id:at.level(variable, “fitness”).id	-0.0071625
at.level(variable, “fitness”).id:at.level(variable, “fitness”).id	-0.0256359
at.level(variable, “FFD”):at.level(variable, “FFD”).Obs	0.0268231

Ensure that the among-individual correlation between intercepts and slopes for FFD is (approximately) the same as we estimated in our earlier univariate random regression model.

```
cor_BV_RR_intslope3 <-
  modelBV_RR3$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\").id"]/
(sqrt(modelBV_RR3$VCV[,"at.level(variable, \"FFD\").id:at.level(variable, \"FFD\").id"])*
sqrt(modelBV_RR3$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\"):temp.id"]))
plot(cor_BV_RR_intslope3)
```




```
posterior.mode(cor_BV_RR_intslope3)
```

```
##      var1
## 0.6630133
```

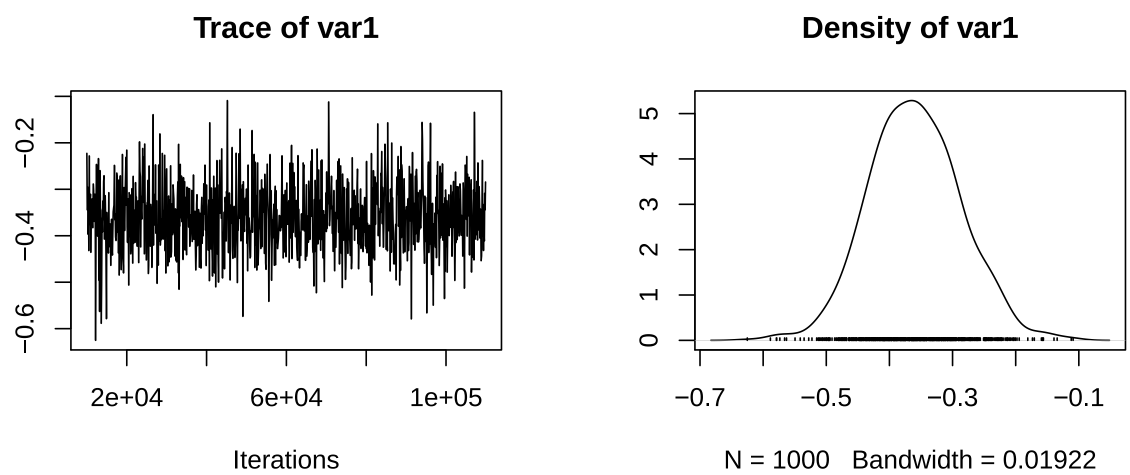
```
HPDinterval(cor_BV_RR_intslope3)
```

```
##        lower     upper
## var1 0.42205 0.8207443
## attr(,"Probability")
## [1] 0.95
```

We find a strong positive correlation between among-individual variance in intercepts and slopes, at the intercept (x = 0). Although it is a bit lower than in our earlier univariate random regression model (OK?).

Determining the among-individual correlation between FFD and fitness:

```
cor_BV_RR_intfit3 <-
  modelBV_RR3$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"FFD\").id"]/
  (sqrt(modelBV_RR3$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"fitness\").id"])*
     sqrt(modelBV_RR3$VCV[,"at.level(variable, \"FFD\").id:at.level(variable, \"FFD\").id"]))
plot(cor_BV_RR_intfit3)
```




```
posterior.mode(cor_BV_RR_intfit3)
```

```
##       var1
## -0.3624622
```

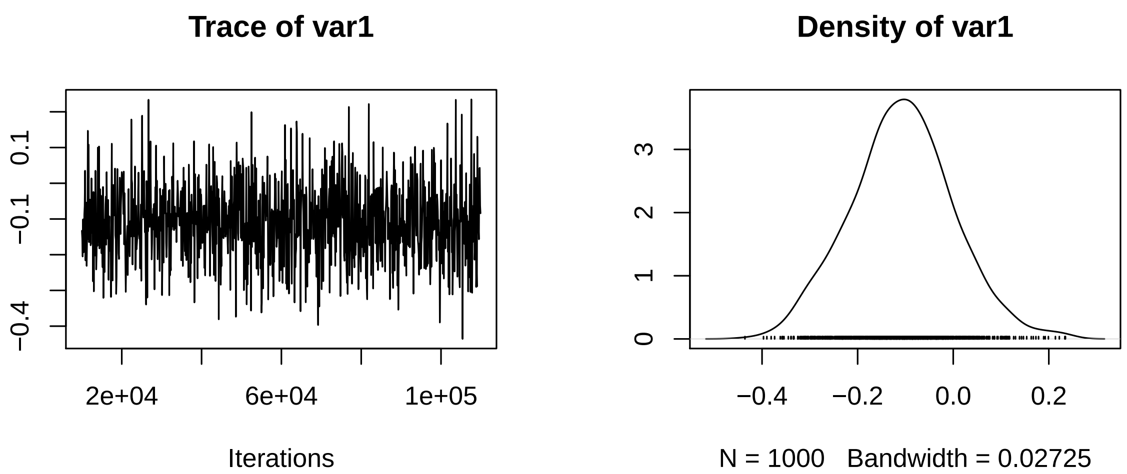
```
HPDinterval(cor_BV_RR_intfit3)
```

```
##           lower      upper
## var1 -0.5008114 -0.2224181
## attr(,"Probability")
## [1] 0.95
```

Negative correlation: Fitness increases when FFD decreases (i.e. is earlier).

Determining the among-individual correlation between fitness and variation in slopes for FFD:

```
cor_BV_RR_slopefit3 <-
  modelBV_RR3$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"FFD\"):temp.id"]/
  (sqrt(modelBV_RR3$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"fitness\").id"])*
     sqrt(modelBV_RR3$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\"):temp.id"]))
plot(cor_BV_RR_slopefit3)
```




```
posterior.mode(cor_BV_RR_slopefit3)
```

```
##        var1
## -0.08510696
```

```
HPDinterval(cor_BV_RR_slopefit3)
```

```
##           lower     upper
## var1 -0.3113769 0.1120625
## attr(,"Probability")
## [1] 0.95
```

Negative correlation: Fitness increases when the slope for FFD decreases (i.e. is more negative, and therefore plasticity increases). Fitness is higher in more plastic individuals. However, this correlation is not significant because the CIs encompass zero!!!

Using plant individuals with at least 5 years of data.

Stack data

```
# Create a single data-set "data.stack5", with single column at start to index observations
data.stack5 <- c()
data.stack5$Obs <- 1:(156 + 1107)
data.stack5$id <- c(data_5yrs_total$id, data_5yrs$id)

# Add first_yr to total data +
# Year column is only relevant for FFD, but is set to first_yr for fitness values

data_5yrs_total_wfirstyr<-data_5yrs_total%>%
  right_join(data_5yrs[c(3,10)]%>%
               group_by(id)%>%
               summarise(first_yr=mean(first_yr)),by="id")

data.stack5$year <- c(data_5yrs_total_wfirstyr$first_yr,
                      data_5yrs$year)
```

```
# Temperature column is only relevant for FFD, but is set to 0 for fitness values
data.stack5$temp <- c(rep(0, 156), data_5yrs$cmean_4)

# Create single column with first fitness values, then FFD values:
data.stack5$fitness.FFD.stack <- c(data_5yrs_total$mean_fitness_rel, data_5yrs$FFD)

# Create 3 index columns needed for MCMCglmm
data.stack5$traits <- c(rep("fitness", 156), rep("FFD", 1107))
data.stack5$variable <- data.stack5$traits
# Both fitness and FFD will be modelled with a Gaussian distribution
# Specify this with the column 'family':
data.stack5$family <- c(rep("gaussian", 156), rep("gaussian", 1107))
data.stack5 <- data.frame(data.stack5)

data.stack5$id <- as.factor(data.stack5$id)
data.stack5$year <- as.factor(data.stack5$year)
head(data.stack5)
```

```
##   Obs id year temp fitness.FFD.stack  traits variable   family
## 1   1  1 2006    0         3.4130481 fitness  fitness gaussian
## 2   2  2 2007    0         1.0083912 fitness  fitness gaussian
## 3   3  3 2007    0         0.5834687 fitness  fitness gaussian
## 4   4  4 2007    0         1.4551090 fitness  fitness gaussian
## 5   5  5 2007    0         0.9331119 fitness  fitness gaussian
## 6   6  6 2007    0         0.4108589 fitness  fitness gaussian
```

Bivariate models of fitness and FFD, with random regressions for individuals

```
priorBiv_RR5 <- list(G = list(G1 = list(V = diag(1), nu = 1)),
                    # ^ random effect for year (fitted for FFD only)
                    R = list(R1 = list(V = diag(3), nu = 3, covu = TRUE),
                             # ^ 3-way var-cov matrix of (id + temp:id) for FFD,
                             # residual for fitness
                             R2 = list(V = diag(1), nu = 1))) # residual for FFD

modelBV_RR5 <- MCMCglmm(fitness.FFD.stack ~ variable - 1 +
                          # ^ means for each variable (and no overall mean (hence "-1"))
                          at.level(variable, "FFD"):temp, # single fixed effect of temp
                        random = ~us(at.level(variable, "FFD")):year +
                          us(at.level(variable, "FFD") +
                               at.level(variable,"FFD"):temp):id,
                        # ^ random intercepts for individual,
                        # and random slopes for temp|id
                        rcov = ~us(at.level(variable, "fitness")):id +
                          # ^ variance between indivduials in fitness
                          # (which is residual variance)
                          us(at.level(variable, "FFD")):Obs,
                          # ^ residual variance within indivduials between years
                        # (labelled by 'Obs')
                        data = data.stack5,
                        prior = priorBiv_RR5,
                        family = NULL, # specified already in the data-set
```

```r
                    nitt = 1100 * sc, thin = sc, burnin = 100 * sc, verbose = F)
```

```r
kable(summary(modelBV_RR5)$solutions,digits=c(3,3,3,0,3),caption="Fixed effects")
```

Table 5: Fixed effects

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC
variableFFD	57.482	55.369	59.486	1000	0.001
variablefitness	1.001	0.862	1.138	1000	0.001
at.level(variable, "FFD"):temp	-2.422	-3.933	-0.814	1000	0.001

```r
kable(summary(modelBV_RR5)$Gcovariances,digits=c(3,3,3,0),caption="Random effects")
```

Table 6: Random effects

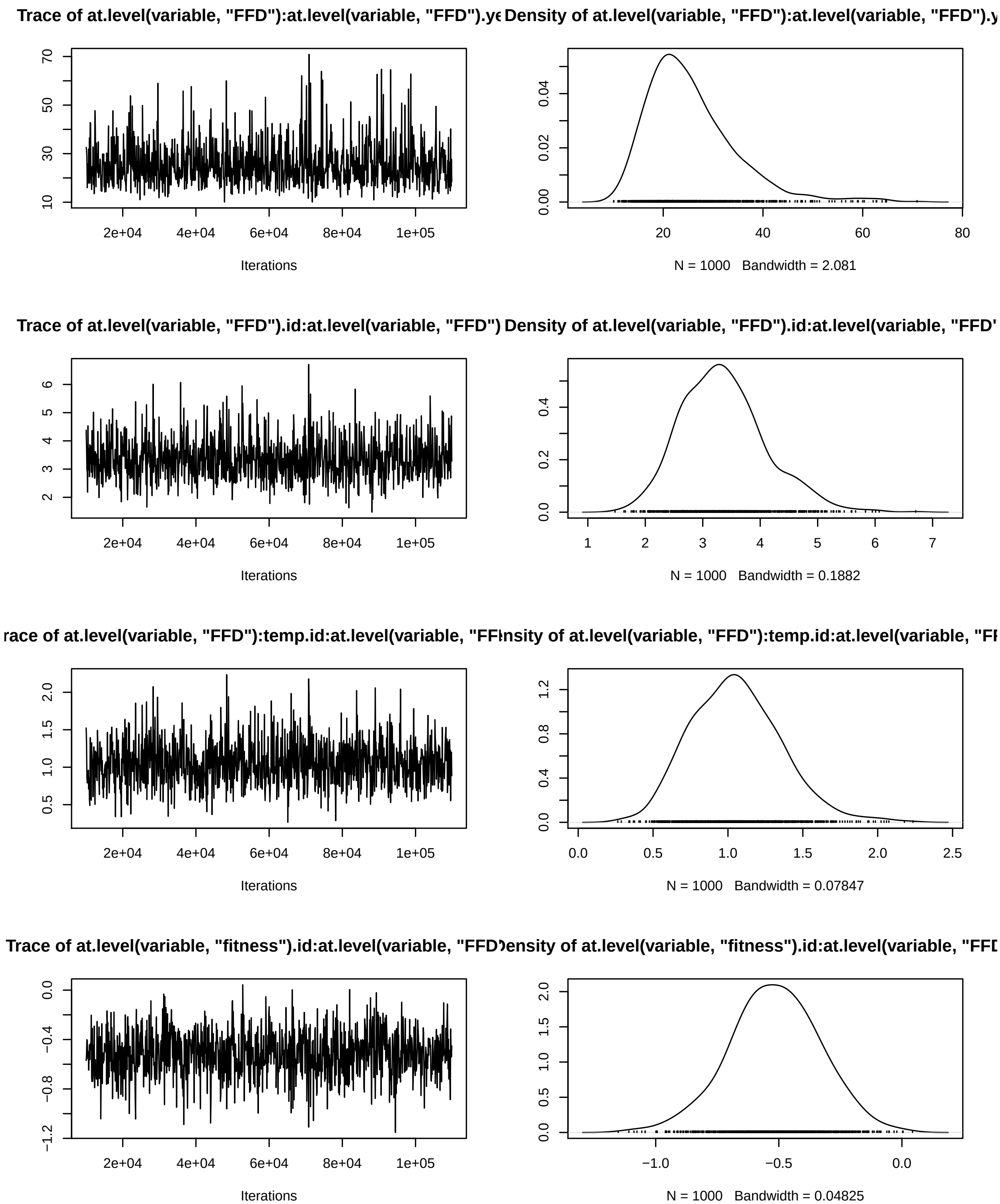
	post.mean	l-95% CI	u-95% CI	eff.samp
at.level(variable, "FFD"):at.level(variable, "FFD").year	25.586	11.971	42.785	1000

```r
kable(summary(modelBV_RR5)$Rcovariances,digits=c(3,3,3,0),caption="Random effects")
```

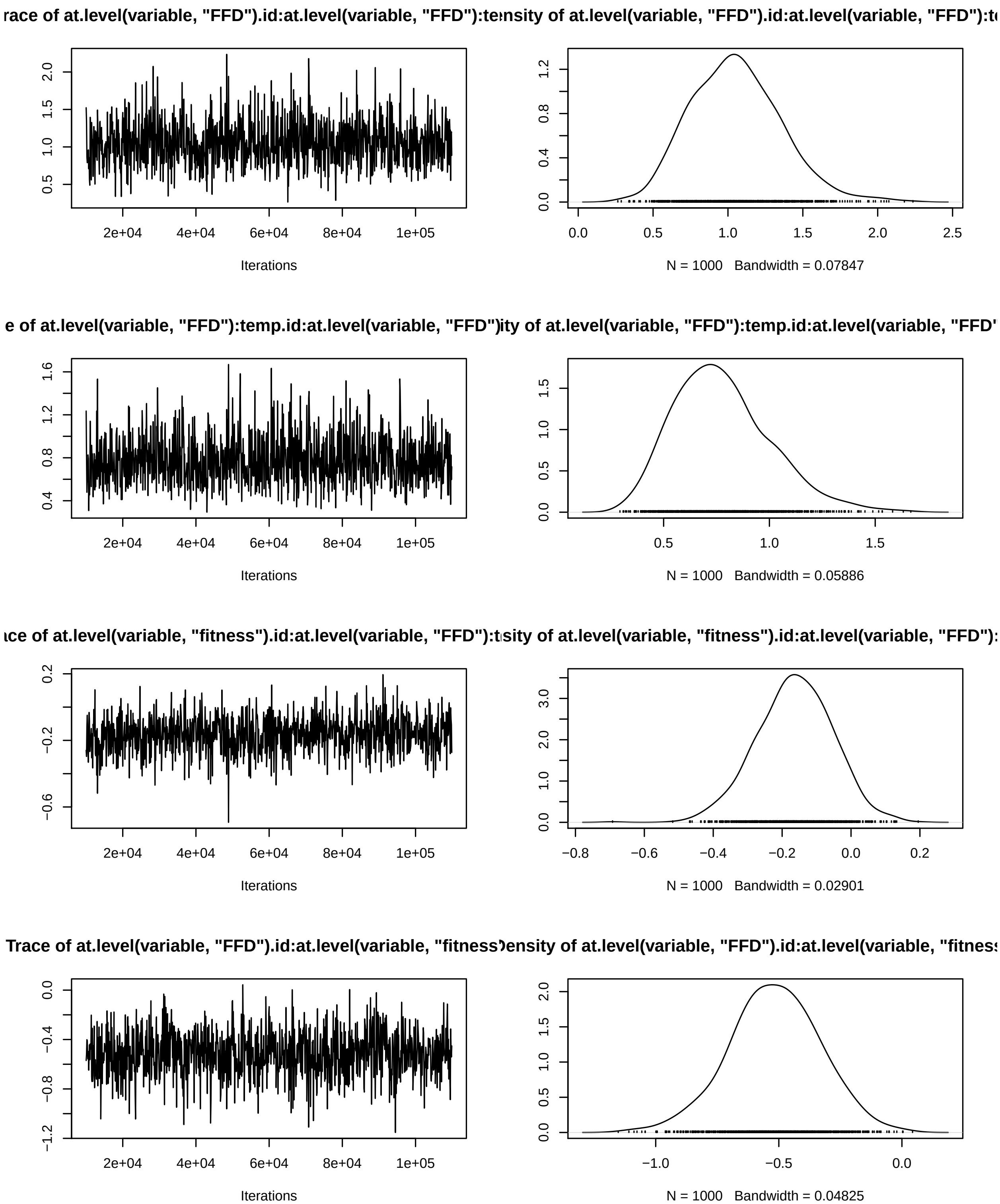
Table 7: Random effects

	post.mean	l-95% CI	u-95% CI	eff.samp
at.level(variable, "FFD").id:at.level(variable, "FFD").id	3.363	2.042	4.889	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD").id	1.055	0.504	1.634	1000
at.level(variable, "fitness").id:at.level(variable, "FFD").id	-0.517	-0.901	-0.169	1000
at.level(variable, "FFD").id:at.level(variable, "FFD"):temp.id	1.055	0.504	1.634	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD"):temp.id	0.777	0.391	1.249	900
at.level(variable, "fitness").id:at.level(variable, "FFD"):temp.id	-0.164	-0.395	0.035	1000
at.level(variable, "FFD").id:at.level(variable, "fitness").id	-0.517	-0.901	-0.169	1000
at.level(variable, "FFD"):temp.id:at.level(variable, "fitness").id	-0.164	-0.395	0.035	1000
at.level(variable, "fitness").id:at.level(variable, "fitness").id	0.808	0.638	0.994	1405
at.level(variable, "FFD"):at.level(variable, "FFD").Obs	18.820	17.178	20.756	1000

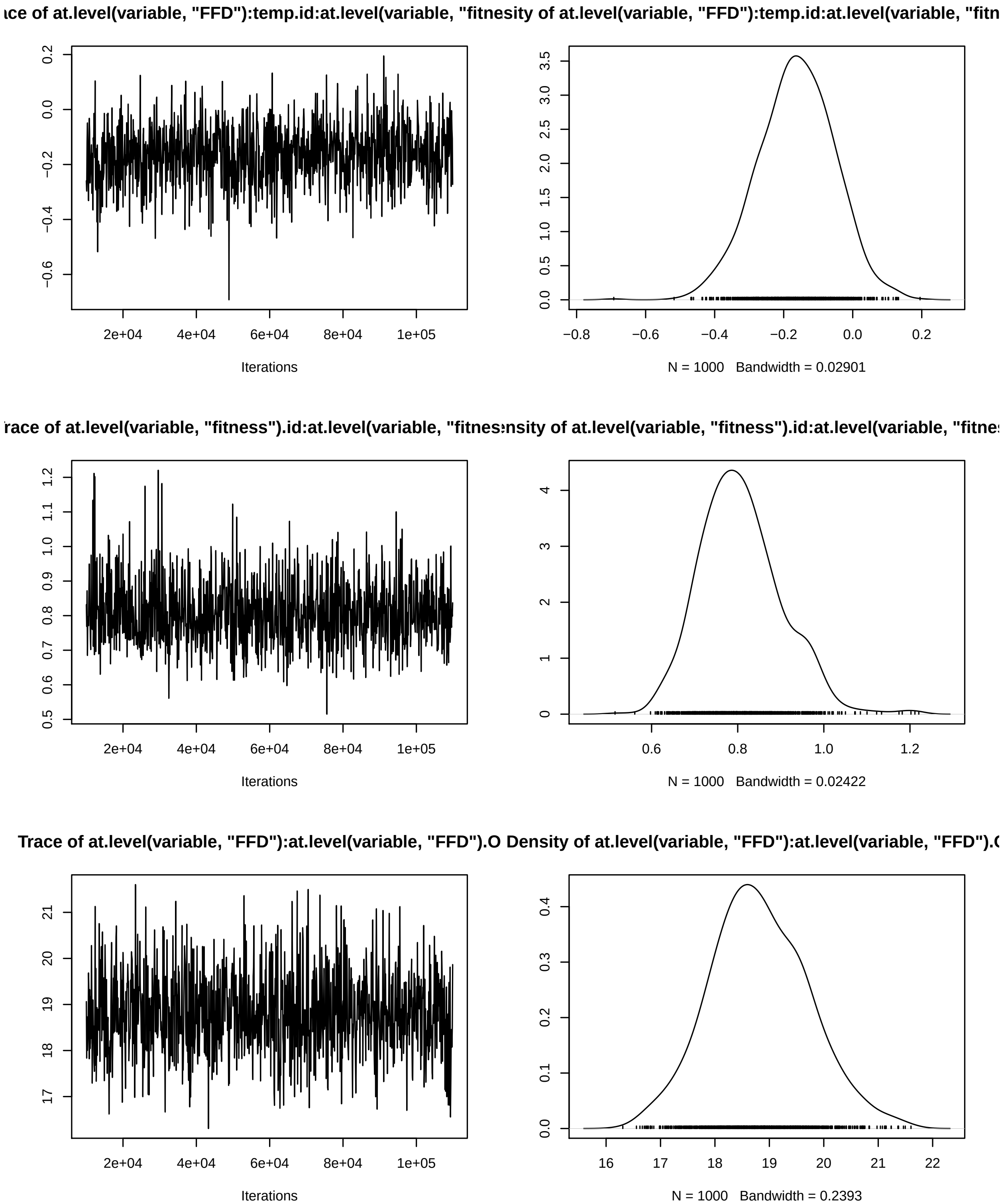
```r
plot(modelBV_RR5$VCV[,1:4])
```




```r
plot(modelBV_RR5$VCV[,5:8])
```




```
plot(modelBV_RR5$VCV[,9:11])
```



Check for autocorrelation between successive stored iterations (suggested to be less than 0.1):

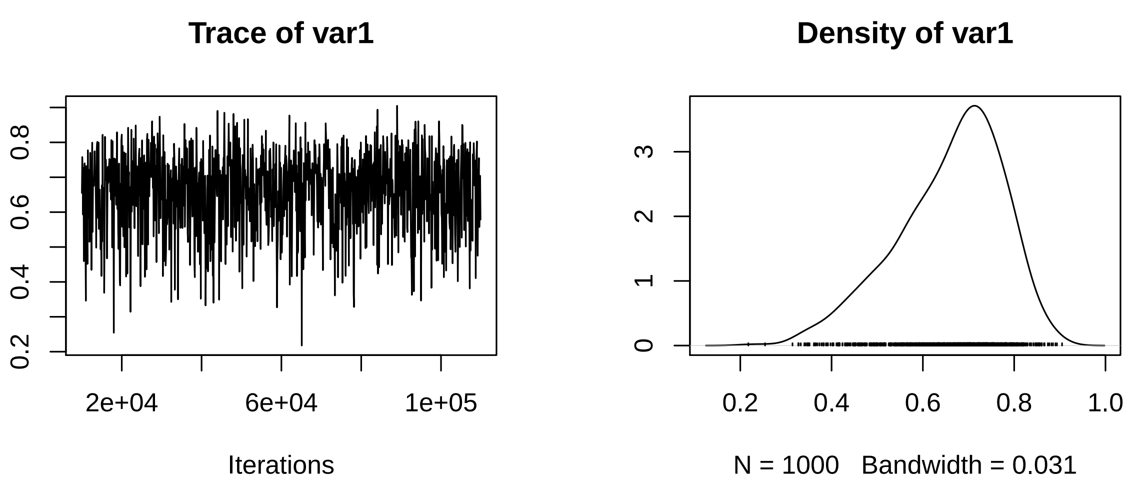
```
kable(diag(autocorr(modelBV_RR5$VCV)[2, , ]),caption="Autocorrelation")
```

Table 8: Autocorrelation

	x
at.level(variable, "FFD"):at.level(variable, "FFD").year	0.0251569
at.level(variable, "FFD").id:at.level(variable, "FFD").id	0.0292216
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD").id	-0.0054265
at.level(variable, "fitness").id:at.level(variable, "FFD").id	-0.0150576
at.level(variable, "FFD").id:at.level(variable, "FFD"):temp.id	-0.0054265
at.level(variable, "FFD"):temp.id:at.level(variable, "FFD"):temp.id	0.0518957
at.level(variable, "fitness").id:at.level(variable, "FFD"):temp.id	0.0197337
at.level(variable, "FFD").id:at.level(variable, "fitness").id	-0.0150576
at.level(variable, "FFD"):temp.id:at.level(variable, "fitness").id	0.0197337
at.level(variable, "fitness").id:at.level(variable, "fitness").id	-0.1155707
at.level(variable, "FFD"):at.level(variable, "FFD").Obs	0.0254621

Ensure that the among-individual correlation between intercepts and slopes for FFD is (approximately) the same as we estimated in our earlier univariate random regression model.

```
cor_BV_RR_intslope5 <-
  modelBV_RR5$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\").id"]/
(sqrt(modelBV_RR5$VCV[,"at.level(variable, \"FFD\").id:at.level(variable, \"FFD\").id"])*
sqrt(modelBV_RR5$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\"):temp.id"]))
plot(cor_BV_RR_intslope5)
```




```
posterior.mode(cor_BV_RR_intslope5)
```

```
##      var1
## 0.7022926
```

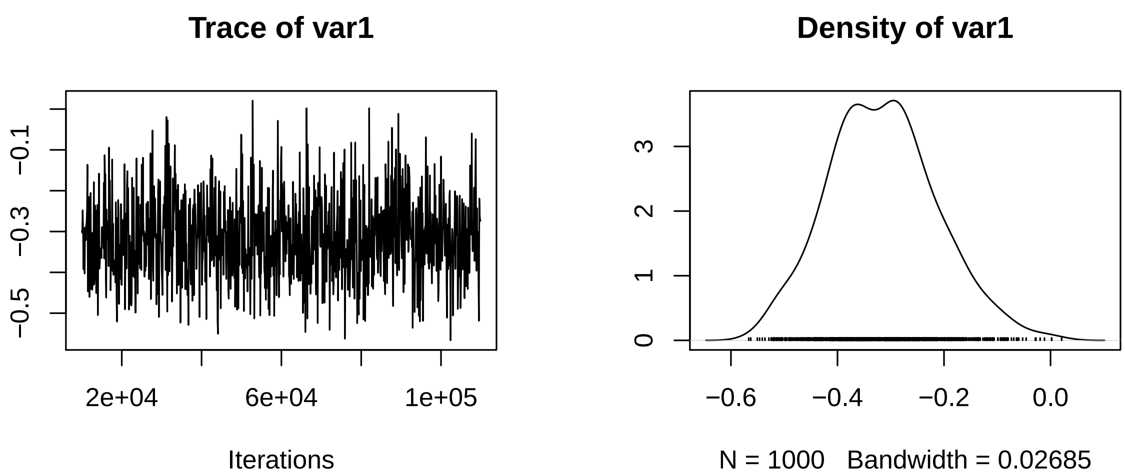
```
HPDinterval(cor_BV_RR_intslope5)
```

```
##          lower     upper
## var1 0.4130572 0.8502383
## attr(,"Probability")
## [1] 0.95
```

We find a strong positive correlation between among-individual variance in intercepts and slopes, at the intercept (x = 0). Although it is a bit lower than in our earlier univariate random regression model (OK?).

Determining the among-individual correlation between FFD and fitness:

```
cor_BV_RR_intfit5 <-
  modelBV_RR5$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"FFD\").id"]/
  (sqrt(modelBV_RR5$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"fitness\").id"])*
     sqrt(modelBV_RR5$VCV[,"at.level(variable, \"FFD\").id:at.level(variable, \"FFD\").id"]))
plot(cor_BV_RR_intfit5)
```




```
posterior.mode(cor_BV_RR_intfit5)
```

```
##       var1
## -0.2946276
```

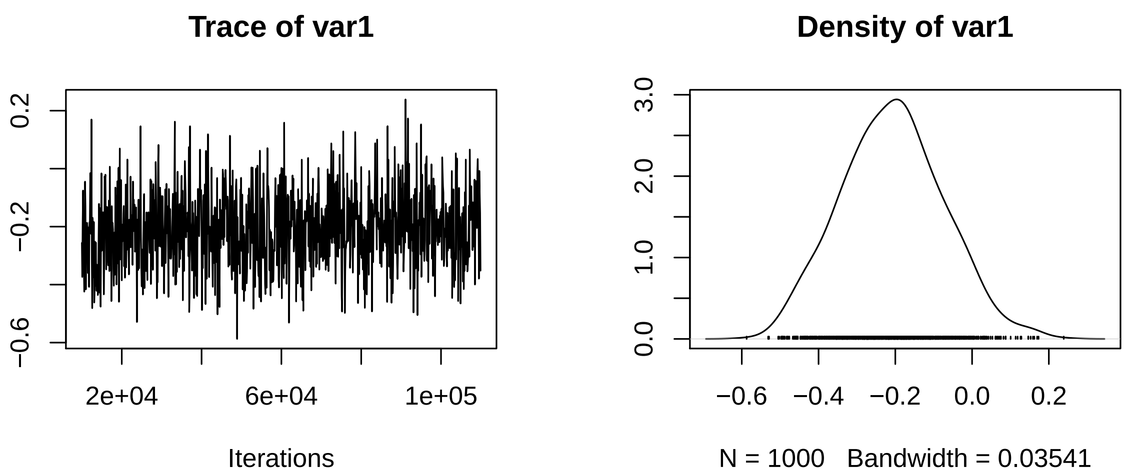
```
HPDinterval(cor_BV_RR_intfit5)
```

```
##           lower      upper
## var1 -0.5246968 -0.1319095
## attr(,"Probability")
## [1] 0.95
```

Negative correlation: Fitness increases when FFD decreases (i.e. is earlier).

Determining the among-individual correlation between fitness and variation in slopes for FFD:

```
cor_BV_RR_slopefit5 <-
  modelBV_RR5$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"FFD\"):temp.id"]/
  (sqrt(modelBV_RR5$VCV[,"at.level(variable, \"fitness\").id:at.level(variable, \"fitness\").id"])*
     sqrt(modelBV_RR5$VCV[,"at.level(variable, \"FFD\"):temp.id:at.level(variable, \"FFD\"):temp.id"]))
plot(cor_BV_RR_slopefit5)
```




```r
posterior.mode(cor_BV_RR_slopefit5)
```

```
##       var1
## -0.1783788
```

```r
HPDinterval(cor_BV_RR_slopefit5)
```

```
##           lower      upper
## var1 -0.4652263 0.03685632
## attr(,"Probability")
## [1] 0.95
```

Negative correlation: Fitness increases when the slope for FFD decreases (i.e. is more negative, and therefore plasticity increases). Fitness is higher in more plastic individuals. However, this correlation is not significant because the CIs encompass zero!!!