Contents

Loading in packages and data.

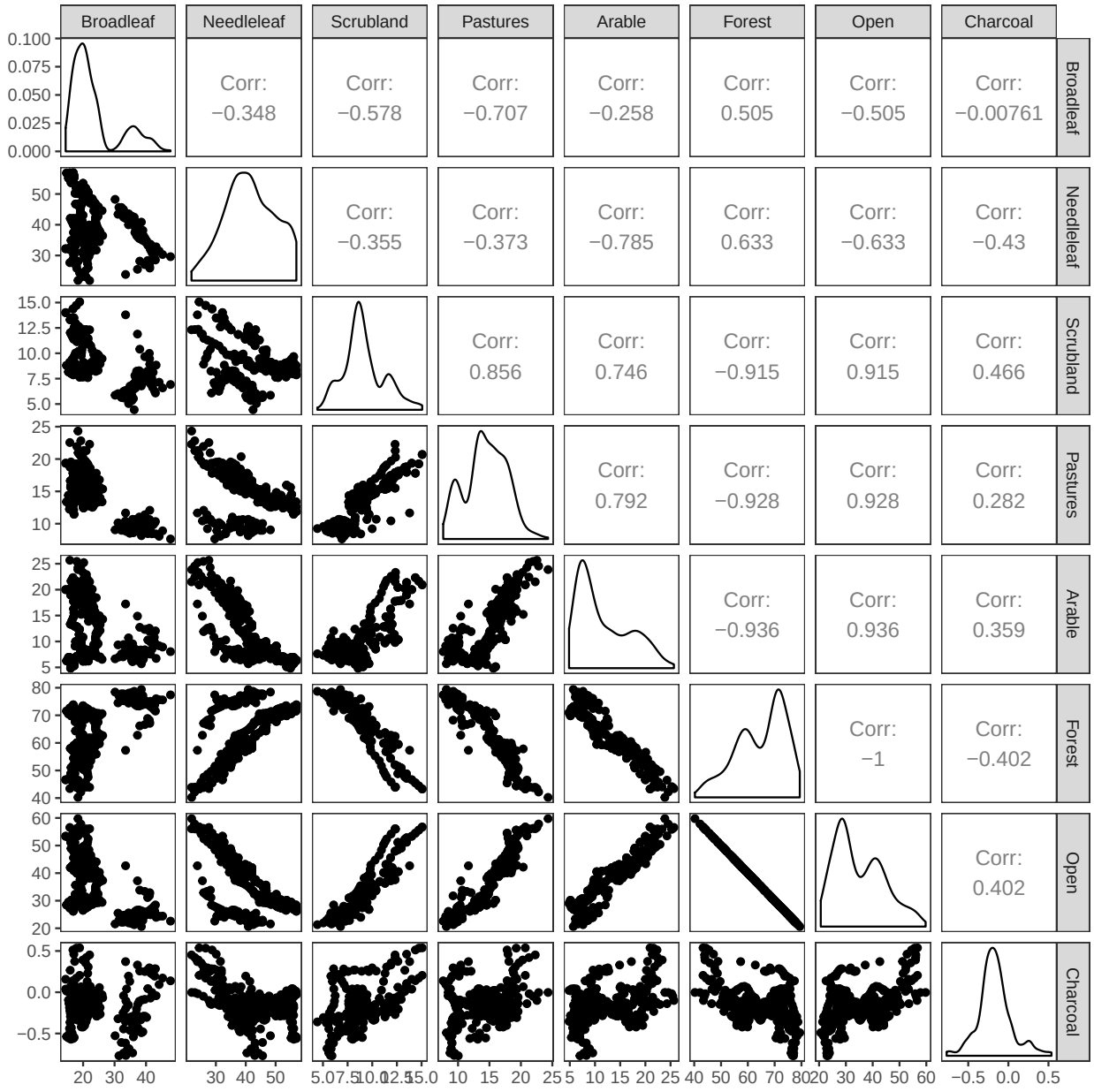
```
library(mgcv)
library(dplyr)
library(ggplot2)
library(GGally)
library(knitr)
library(qpcR)
library(voxel)
library(gridExtra)
library(grid)
library(DHARMa)
library(ggeffects)
setwd('~/Dropbox/BiK-F/Angelica Feurdean/Europe charcoal/v2')
AllEurope<-read.csv('char_anom_allregions.csv')
```

```
FullClimate <- read.csv('climate_anom_12k.csv')
region.cols <- c("Atlantic" = "dodgerblue", "Continental" = "green", "Boreo-nemoral" = "darkgreen" )
```

Predictor variable exploration

Here one can look at the predictors' distributions and the correlations between them.

```
ggpairs(AllEurope[,2:9], columnLabels = c("Broadleaf", "Needleleaf", "Scrubland", "Pastures", "Arable",
```



GAMs

Here we made GAMs for each predictor set and each region. We have used thin plate splines with a Gaussian error distribution, and restricted maximum likelihood to choose smoother complexity and eliminate model terms. Rather than dredge for combinations of land cover predictors that build the best possible model, we built one model that contains climate alone and then a separate model for each land cover variable and climate. We chose this approach because our goal is to look at the relative explanatory power of each variable over climate. Given that several of these land cover variables are somewhat correlated (see plot above), we decided that this approach more directly answered our research question.

GAM functions

```
# This one is for regular GAMs
charcoal.gam <- function(f, data, region = NA){

  # Restrict to targe region if any
  if(!is.na(region)){
    data <- data %>% filter(Region == region)
  }

  # Add time smoother to GAM formula
  # f <- update(f, ~. + s(Age, k = 20))

  # Build GAM
  this.gam <- gam(f, data = data, select = TRUE, method = "REML")

  # Checking GAM
  print("Checking GAM")
  print(gam.check(this.gam))
  print(summary(this.gam))

  # Plotting predictions
  print("Plotting predictions")
  print(plot(ggpredict(this.gam), rawdata = TRUE))

  # DHARMa fit simulation
  this.sim <- simulateResiduals(this.gam, n = 250)
  print(plot(this.sim))
  print(testTemporalAutocorrelation(this.sim, data$Age))

  # Plotting time series of residuals
  print("Time series of residuals")
  print(qplot(data$Age, residuals(this.gam), xlab = "Time", ylab = "Residual"))
  return(this.gam)


}

# Function to make combined plots of predictions by region
combined.gam.prediction <- function(data, xvar, gams, regions, nvals = 100){

  # Note: this expects a list of GAMs that are in the same order as the vector of region names!
```

```r
# Building a data frame to predict GAMs onto for plotting

# Create an empty data frame from data
predict.df <- data.frame(matrix(ncol = ncol(data), nrow = nvals))
colnames(predict.df) <- colnames(data)

# Set all values in predict.df to the mean value across all observations
for(j in 1:ncol(data)){
  if(is.numeric(data[,j])){
    predict.df[,j] <- rep(mean(data[,j], na.rm = TRUE), nvals)
  } else {
    predict.df[,j] <- rep(NA, nvals)
  }
}

# Now getting a sequence of values for the x variable
predict.df[,xvar] <- seq(min(data[,xvar], na.rm = TRUE), max(data[,xvar], na.rm = TRUE), length.out =


# Here we're going to predict each GAM across the range of
# Needle values, then add NAs everywhere that's outside of the
# range within the training region

# Creating an empty df with the right column names for plotting
plot.df <- data.frame(matrix(ncol = 4, nrow = 0))
colnames(plot.df) <- c(xvar, "Prediction", "se", "Region")

# Going through GAMs and making predictions
for(i in 1:length(gams)){
  this.predict.df <- cbind(predict.df[,xvar],
                           as.data.frame(predict(gams[[i]], newdata = predict.df, se.fit = TRUE)),
                           rep(regions[i], nvals))
  colnames(this.predict.df) <- c(xvar, "Prediction", "se", "Region")

  # This is convoluted as hell but it's just setting NAs outside
  # of training conditions for xvar
  this.predict.df[which(this.predict.df[,xvar] < min(gams[[i]]$model[,xvar], na.rm = TRUE)),] <- NA
  this.predict.df[which(this.predict.df[,xvar] > max(gams[[i]]$model[,xvar], na.rm = TRUE)),] <- NA

  plot.df <- rbind(plot.df, this.predict.df)
}



qplot(plot.df[,xvar], plot.df[,"Prediction"], geom = "line", color = plot.df[,"Region"]) +
  ylab("Biomass Burned (Z-score)") + theme_bw() +
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),
        panel.background = element_blank()) + geom_line(size=1) +
  scale_color_manual(values=region.cols) +
  geom_line(data = plot.df, aes(x = plot.df[,xvar], y = Prediction - se), linetype = "longdash", alpha
  geom_line(data = plot.df, aes(x = plot.df[,xvar], y = Prediction + se), linetype = "longdash", alpha
```

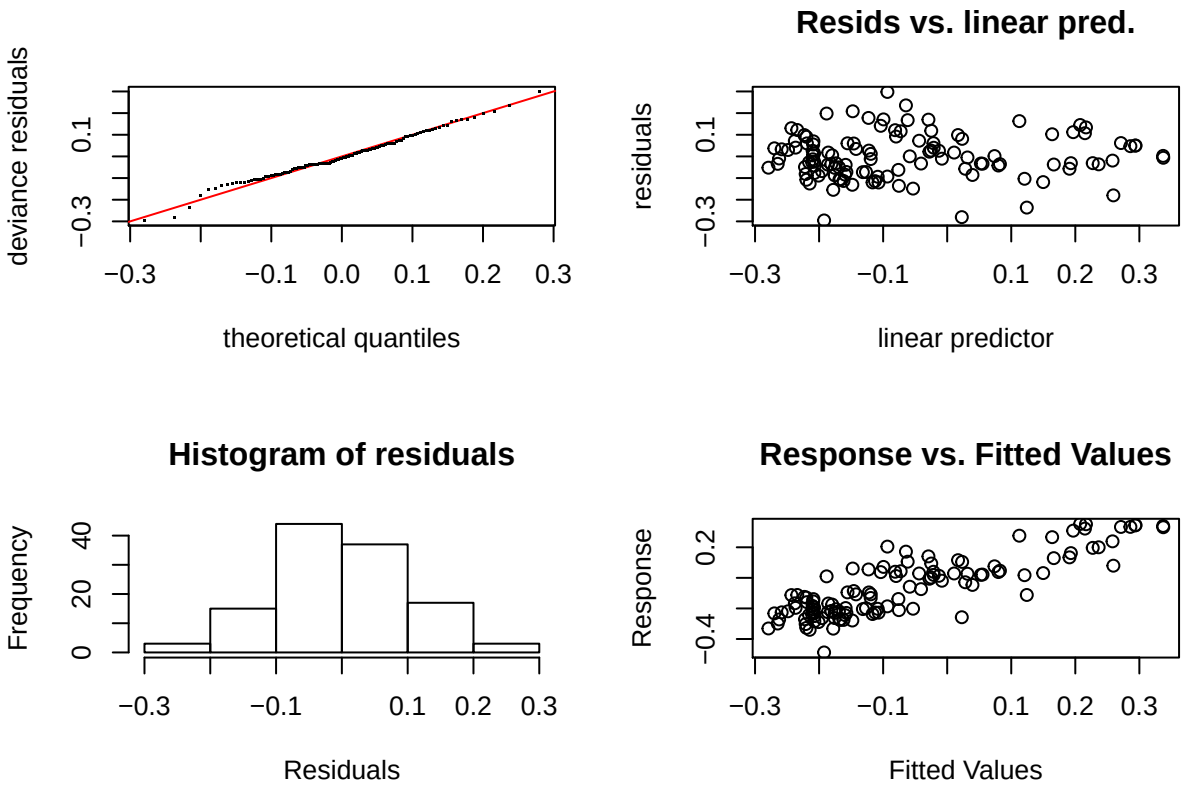
```
    qplot(plot.df[,xvar], plot.df[,"Prediction"], geom = "line", color = plot.df[,"Region"], fill = plo
    ylab("Biomass Burned (Z-score)") + theme_bw() +
    xlab(xvar) +
    theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),
          panel.background = element_blank()) + geom_line(size=1) +
    scale_color_manual(values=region.cols, name = "Region", na.translate = FALSE) +
    scale_fill_manual(values=region.cols, name = "Region", na.translate = FALSE) +
    geom_ribbon(data = plot.df, aes(x = plot.df[,xvar], ymin = Prediction - se, ymax = Prediction + se,
}
```

Climate only, full time period (12ka-present)

Climate only, Continental ecoregion

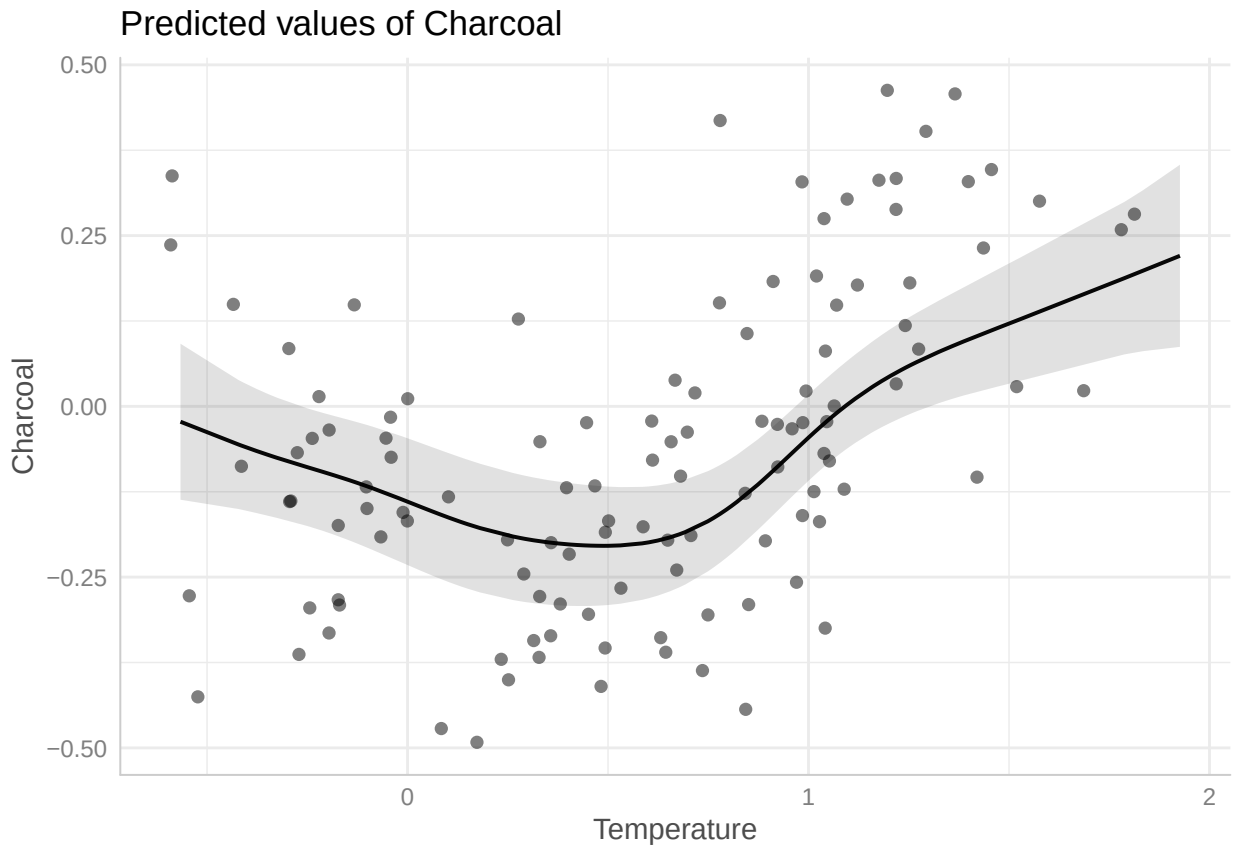
```
full.climate.continental <- charcoal.gam(f = Charcoal ~ s(Temperature)  + s(P.PET) , data = FullClimate
```

```
## [1] "Checking GAM"
```

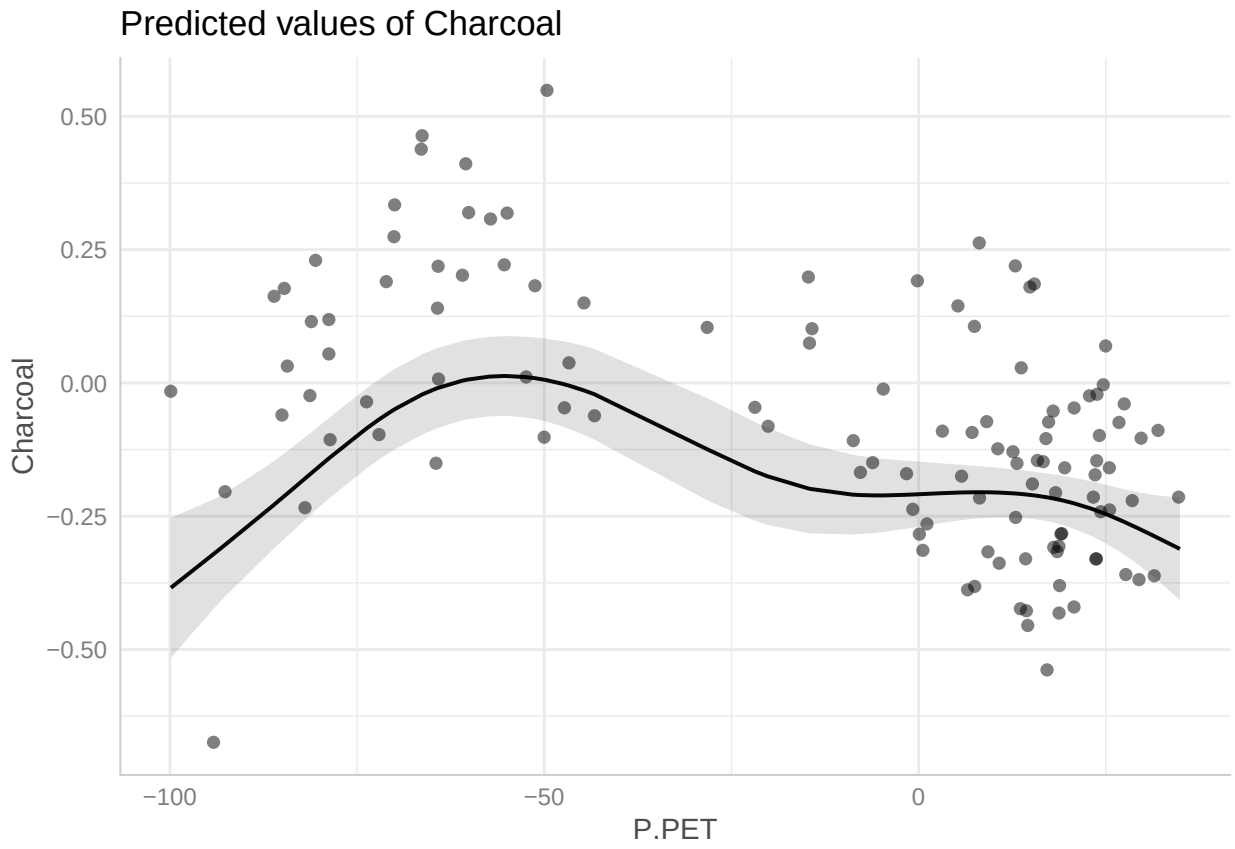


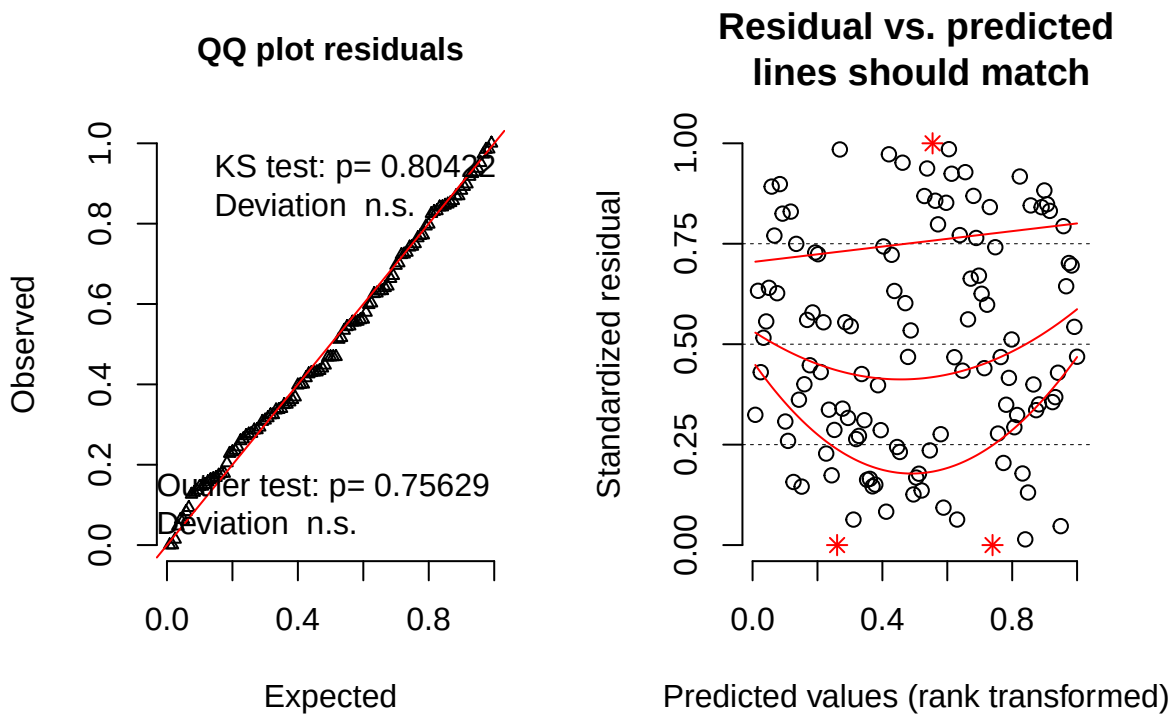

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-2.548673e-05,4.934358e-05]
```

```
## (score -80.24865 & scale 0.01126554).
## Hessian positive definite, eigenvalue range [2.548732e-05,59.16604].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 4.26    0.73  <2e-16 ***
## s(P.PET)       9.00 4.92    1.22    0.99
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.06344    0.00973   -6.52 2.27e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                  edf Ref.df     F  p-value
## s(Temperature) 4.262      9 6.831 8.83e-12 ***
## s(P.PET)       4.916      9 7.559 1.38e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.708   Deviance explained = 73.1%
## -REML = -80.249  Scale est. = 0.011266  n = 119
## [1] "Plotting predictions"
## $Temperature
```

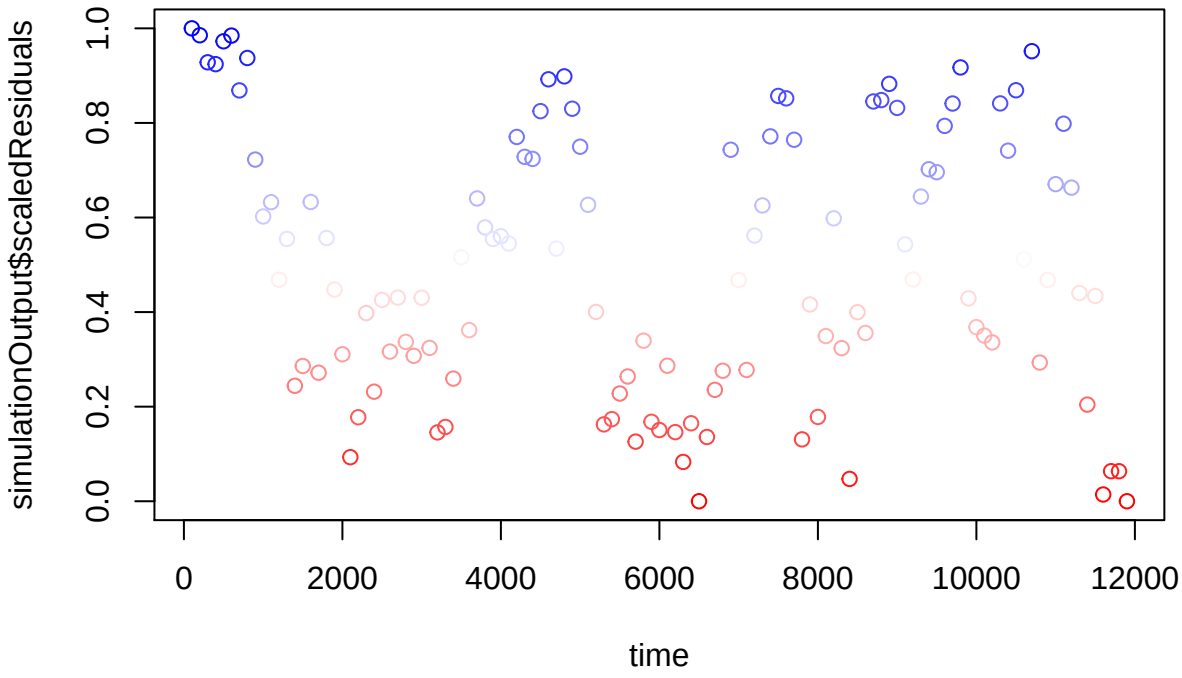

Predicted values of Charcoal
0.50
0.25
0.00
−0.25
−0.50
Charcoal
0
1
2
Temperature

```
##
## $P.PET
```

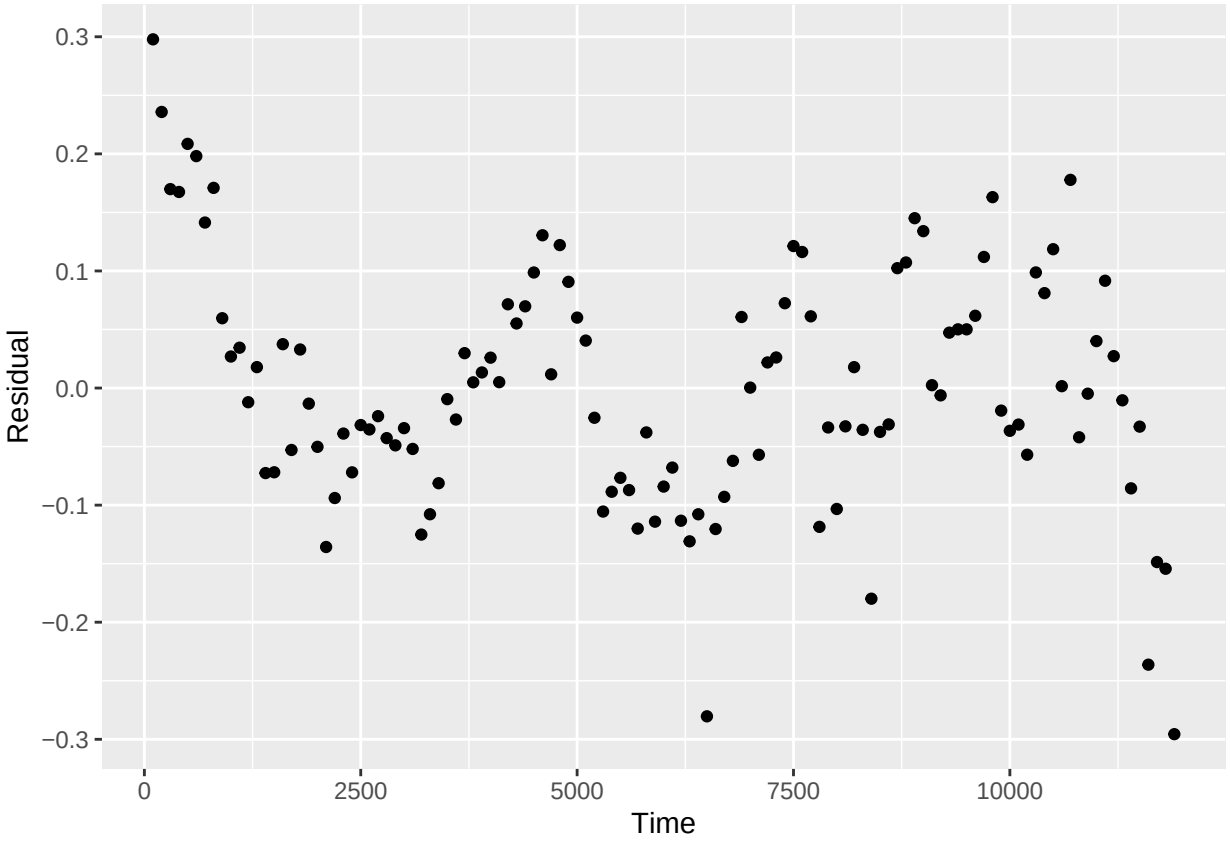

Predicted values of Charcoal
Charcoal
0.50
0.25
0.00
−0.25
−0.50
−100
−50
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



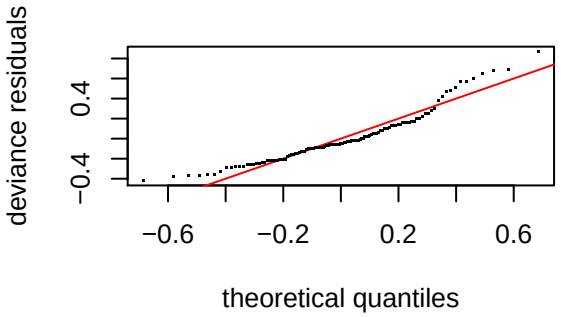

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.56893, p-value = 3.498e-15
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

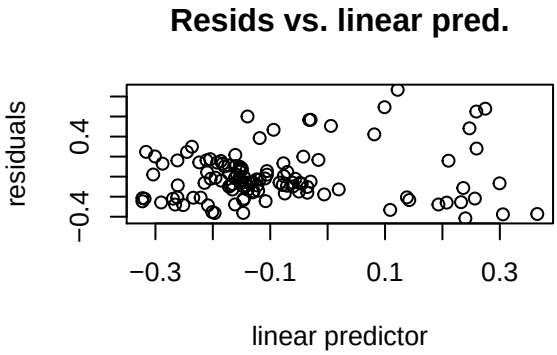


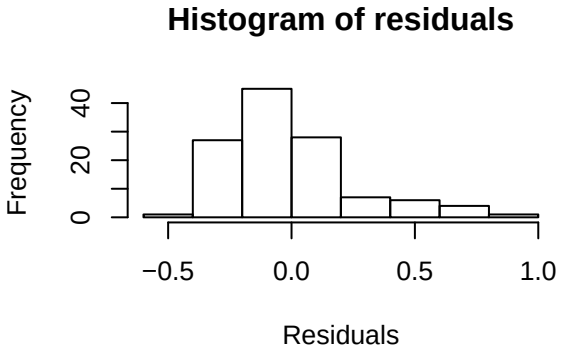
Climate only, Atlantic ecoregion

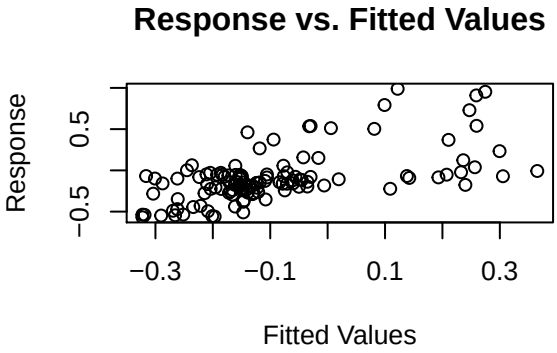
```
full.climate.atlantic <- charcoal.gam(f = Charcoal ~ s(Temperature)  + s(P.PET) , data = FullClimate, r
```

```
## [1] "Checking GAM"
```



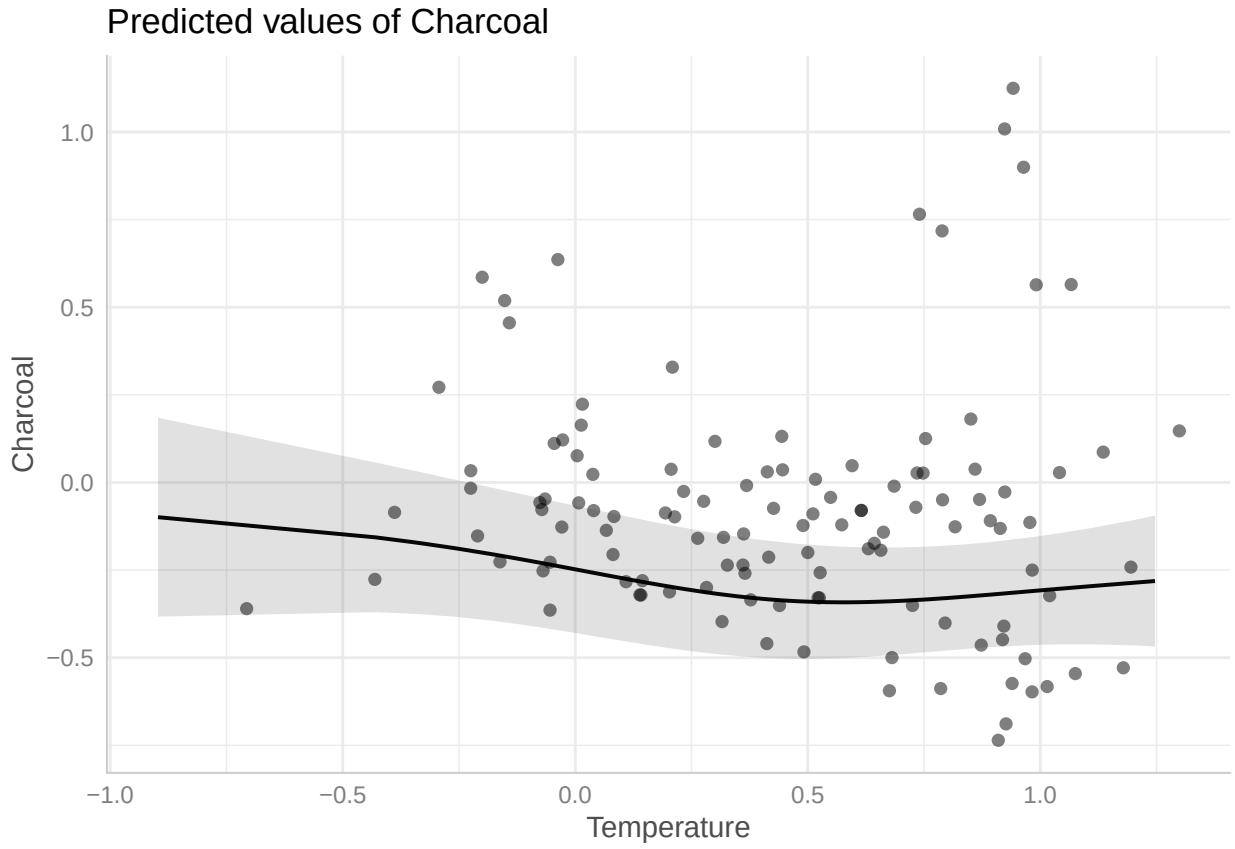




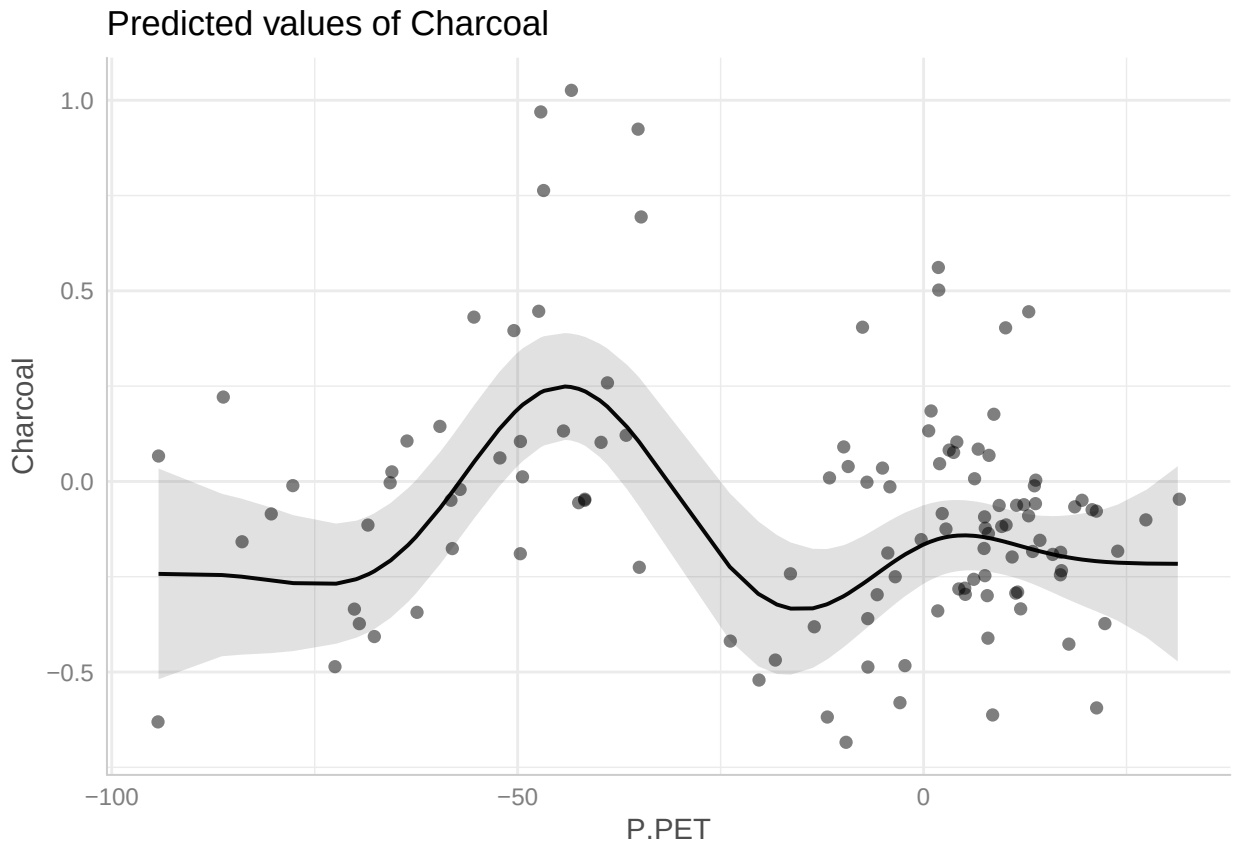



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-6.828921e-06,3.908113e-06]
## (score 23.45464 & scale 0.06760172).
## Hessian positive definite, eigenvalue range [2.147143e-07,59.16643].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 1.75    1.03    0.60
## s(P.PET)       9.00 5.94    1.04    0.66
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
```

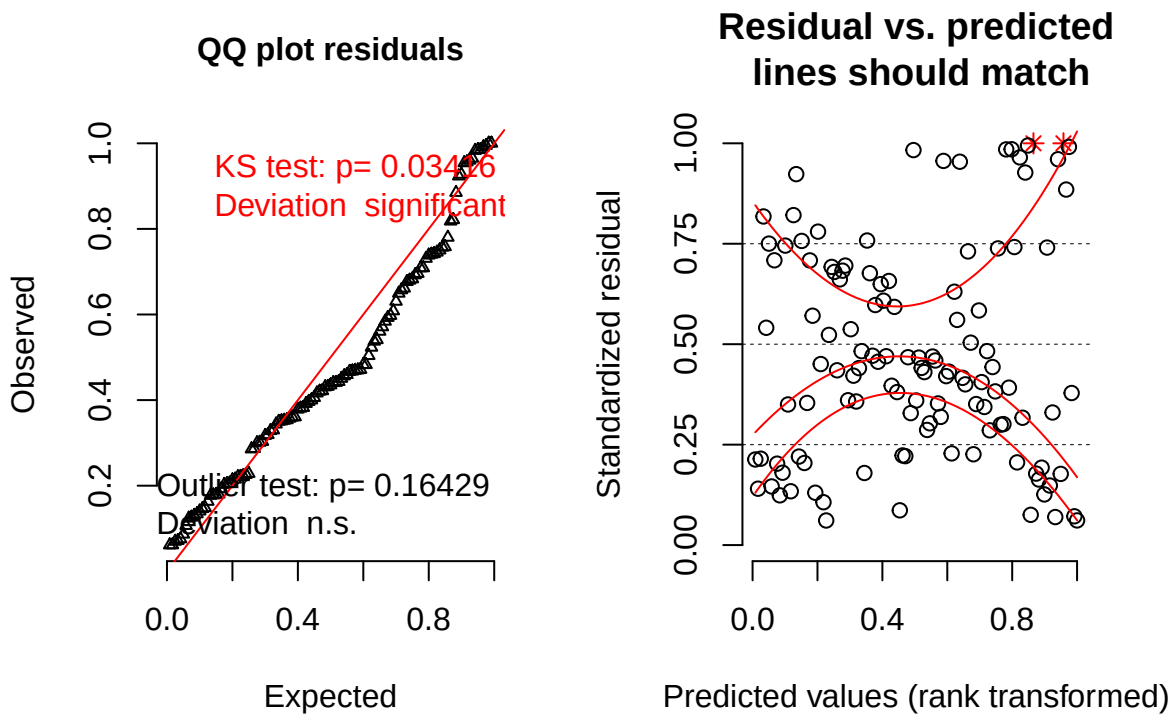
```
## (Intercept) -0.09108    0.02383  -3.821  0.00022 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 1.746      9 0.654   0.0265 *
## s(P.PET)       5.936      9 5.088 8.12e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.305   Deviance explained =   35%
## -REML = 23.455  Scale est. = 0.067602  n = 119
## [1] "Plotting predictions"
## $Temperature
```



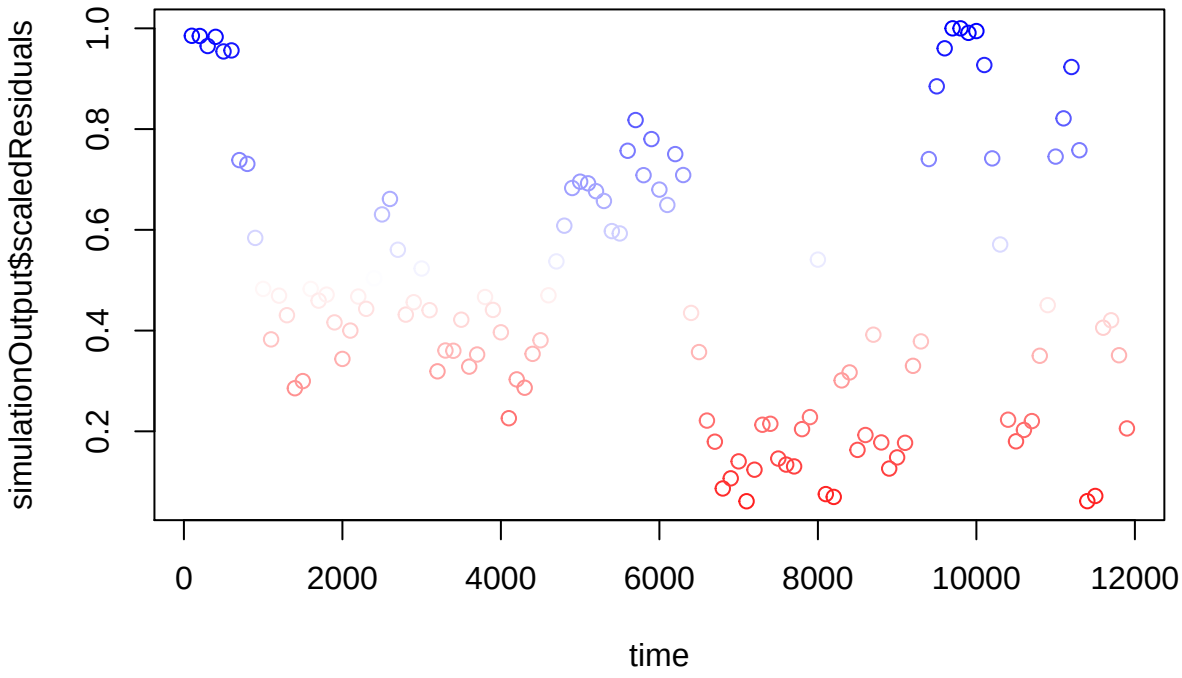

```
##
## $P.PET
```


Predicted values of Charcoal
1.0
0.5
0.0
−0.5
Charcoal
−100
−50
0
P.PET

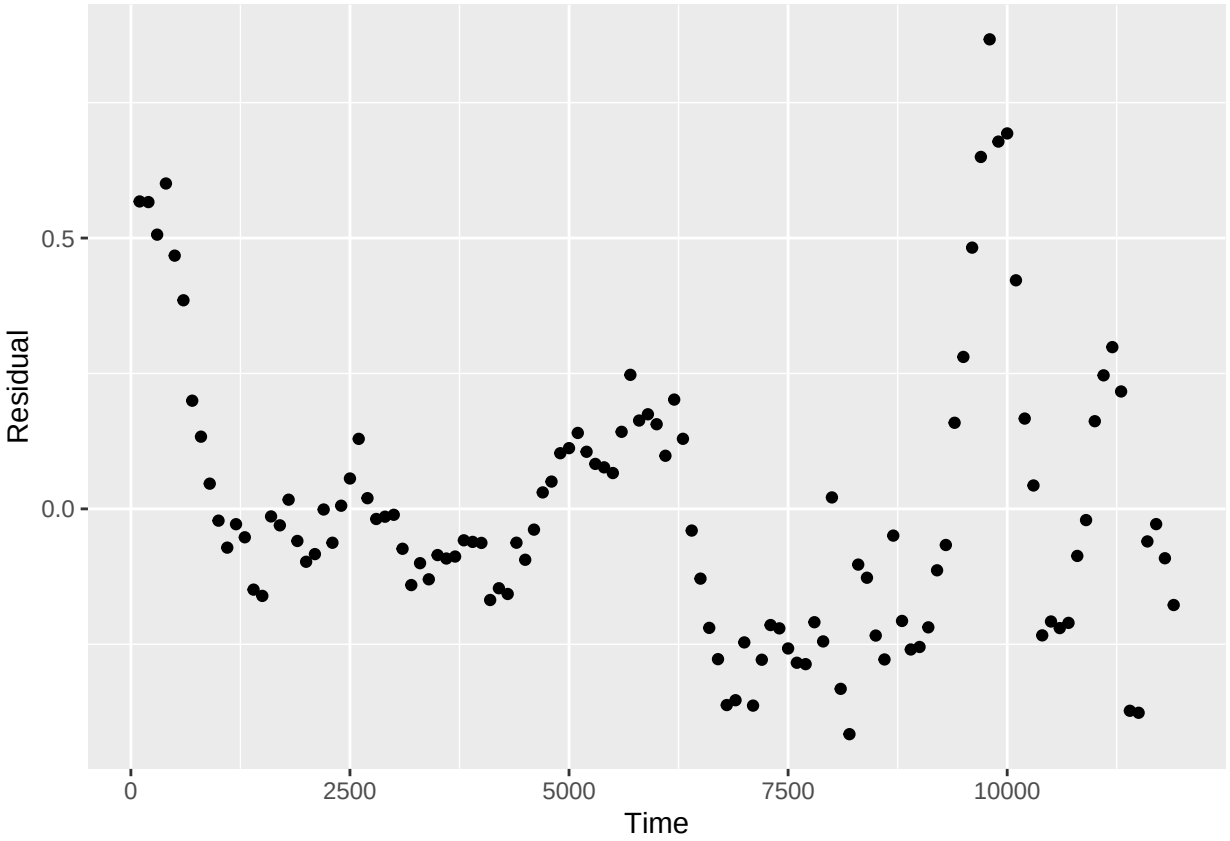
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



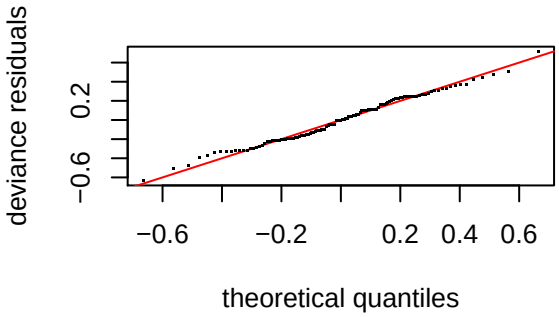

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.26143, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

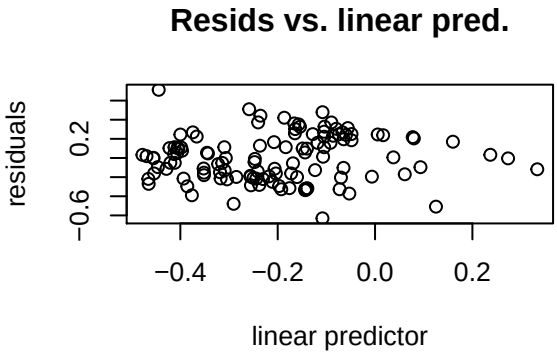


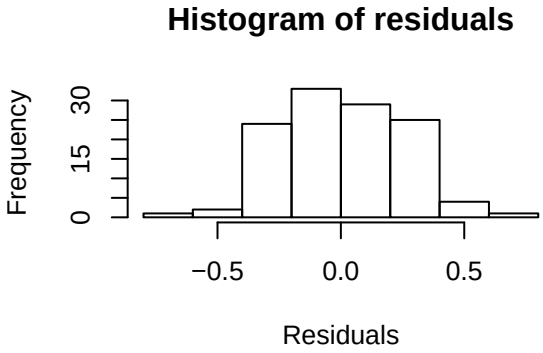
Climate only, Boreo-Nemoral ecoregion

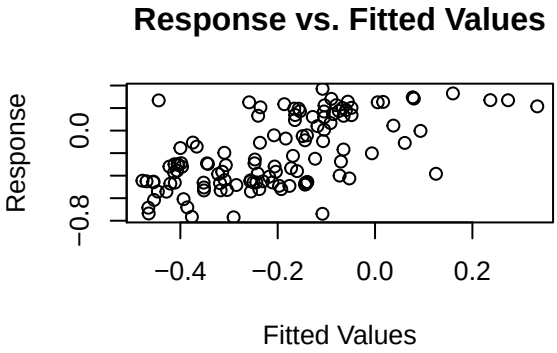
```
full.climate.boreonemoral <- charcoal.gam(f = Charcoal ~ s(Temperature)  + s(P.PET) , data = FullClimat
```

```
## [1] "Checking GAM"
```



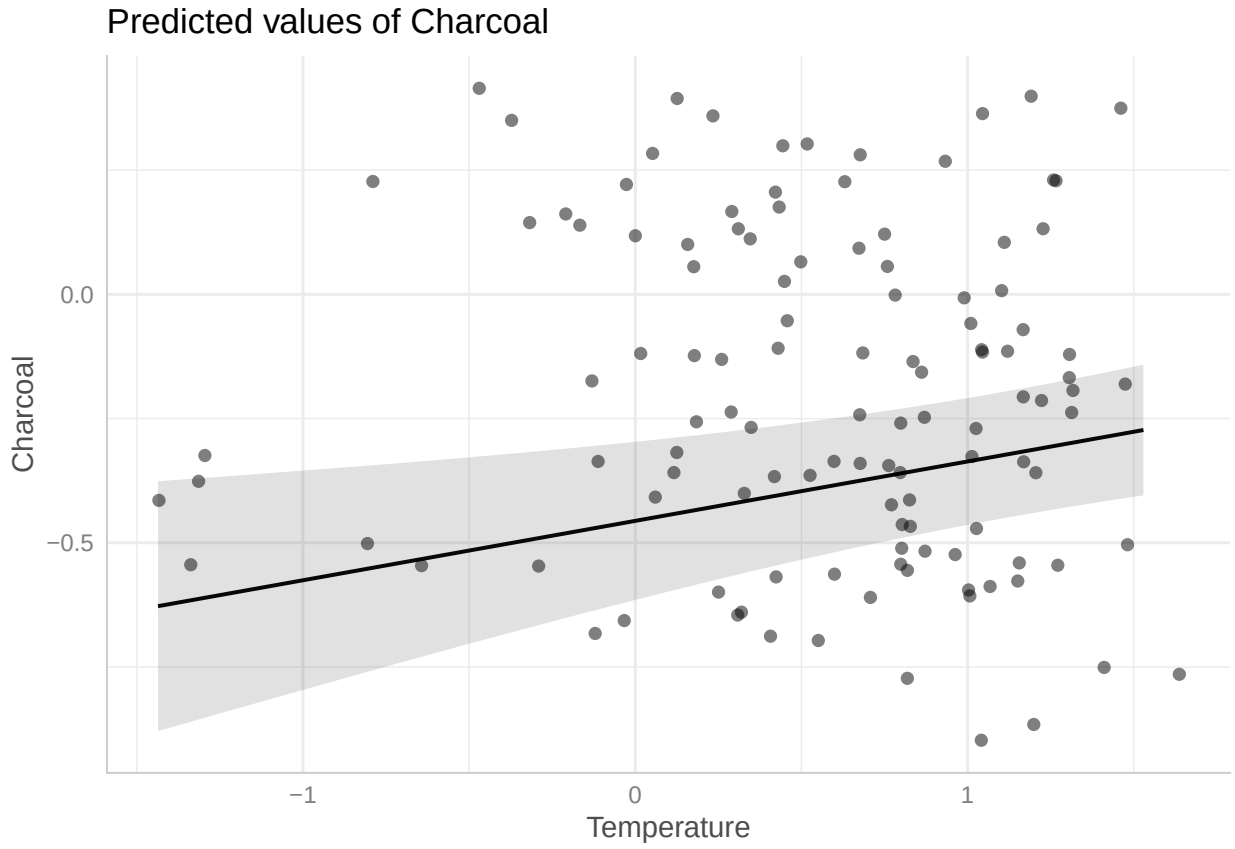




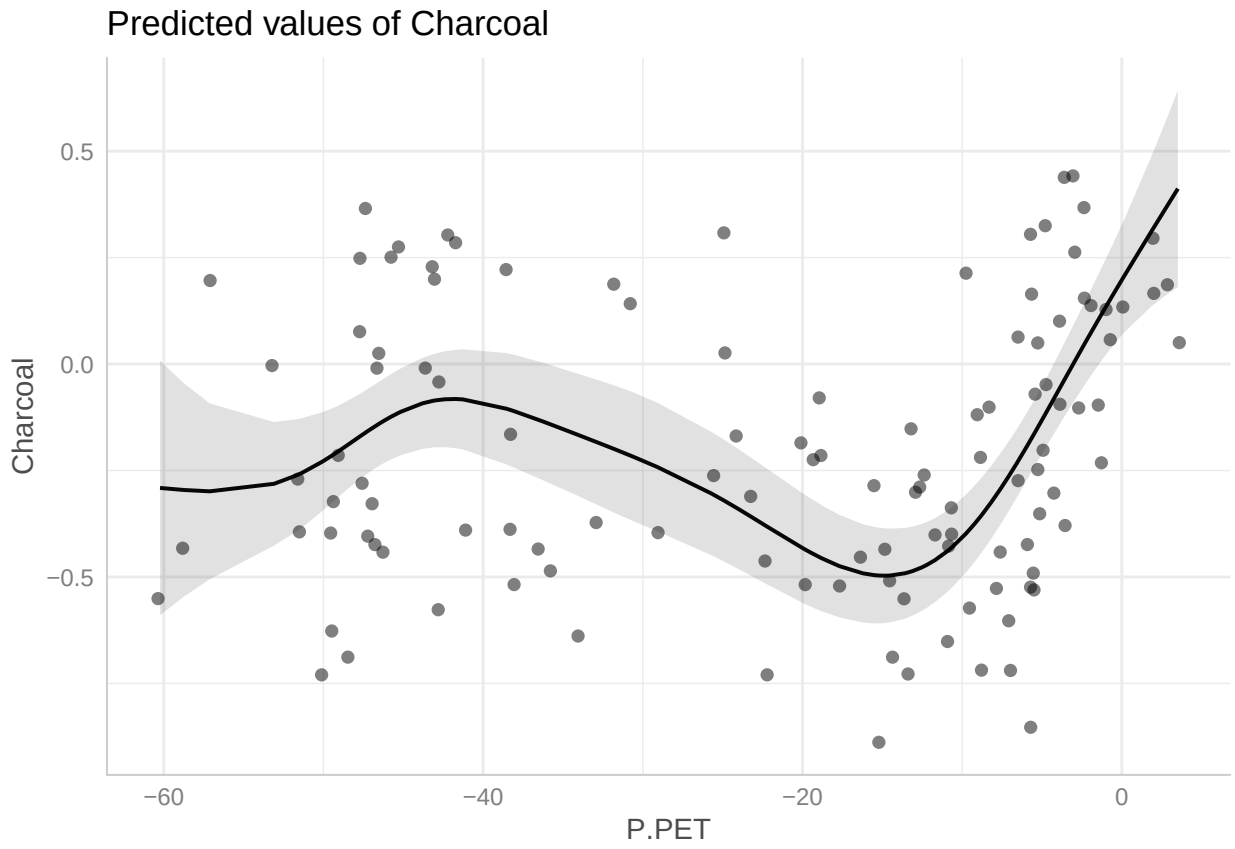


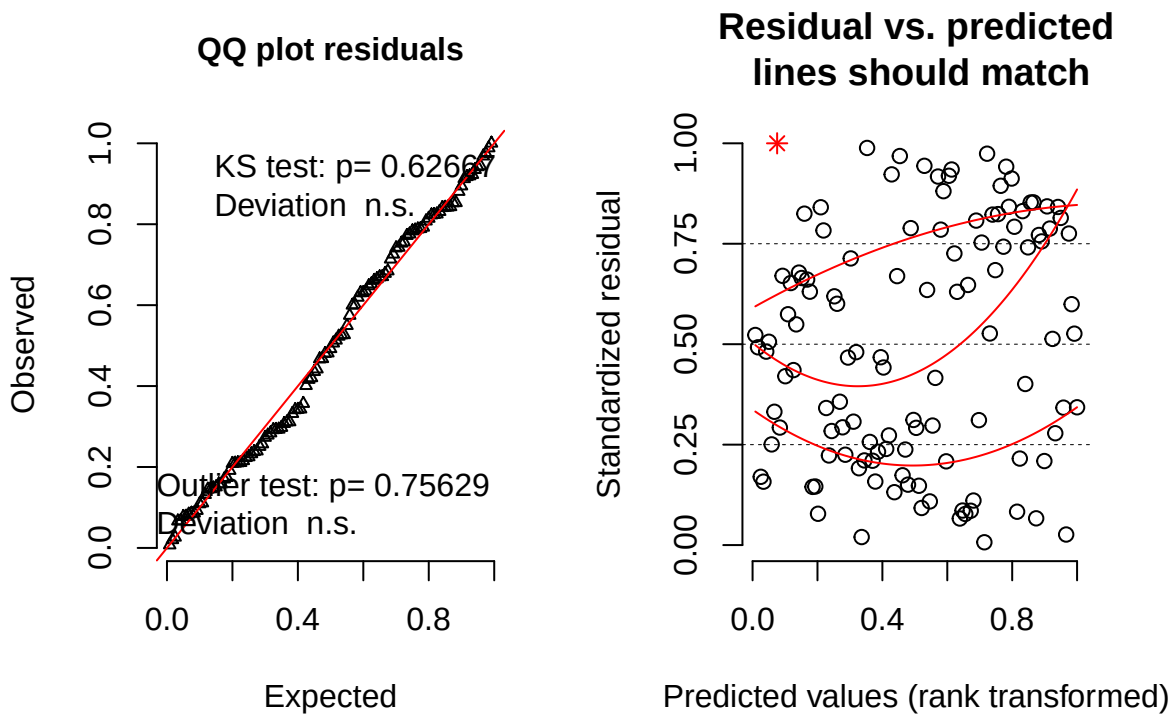

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 29 iterations.
## Gradient range [-6.557816e-06,4.822522e-05]
## (score 17.61464 & scale 0.06351672).
## Hessian positive definite, eigenvalue range [8.083345e-07,59.09895].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                   k'   edf k-index p-value
## s(Temperature) 9.000 0.885    0.95    0.24
## s(P.PET)       9.000 5.414    1.04    0.61
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)  -0.2040     0.0231  -8.828 1.68e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 0.885      9 0.855  0.00313 **
## s(P.PET)       5.414      9 6.469 2.41e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.334   Deviance explained =   37%
## -REML = 17.615  Scale est. = 0.063517  n = 119
## [1] "Plotting predictions"
## $Temperature
```

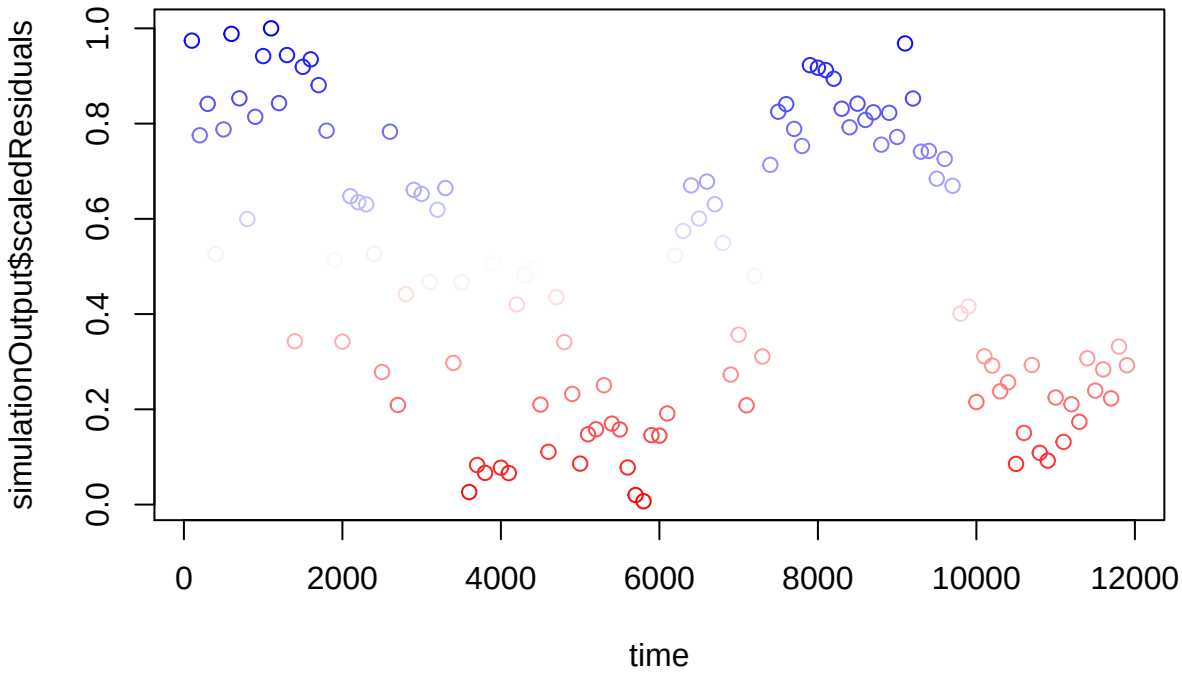



```
##
## $P.PET
```

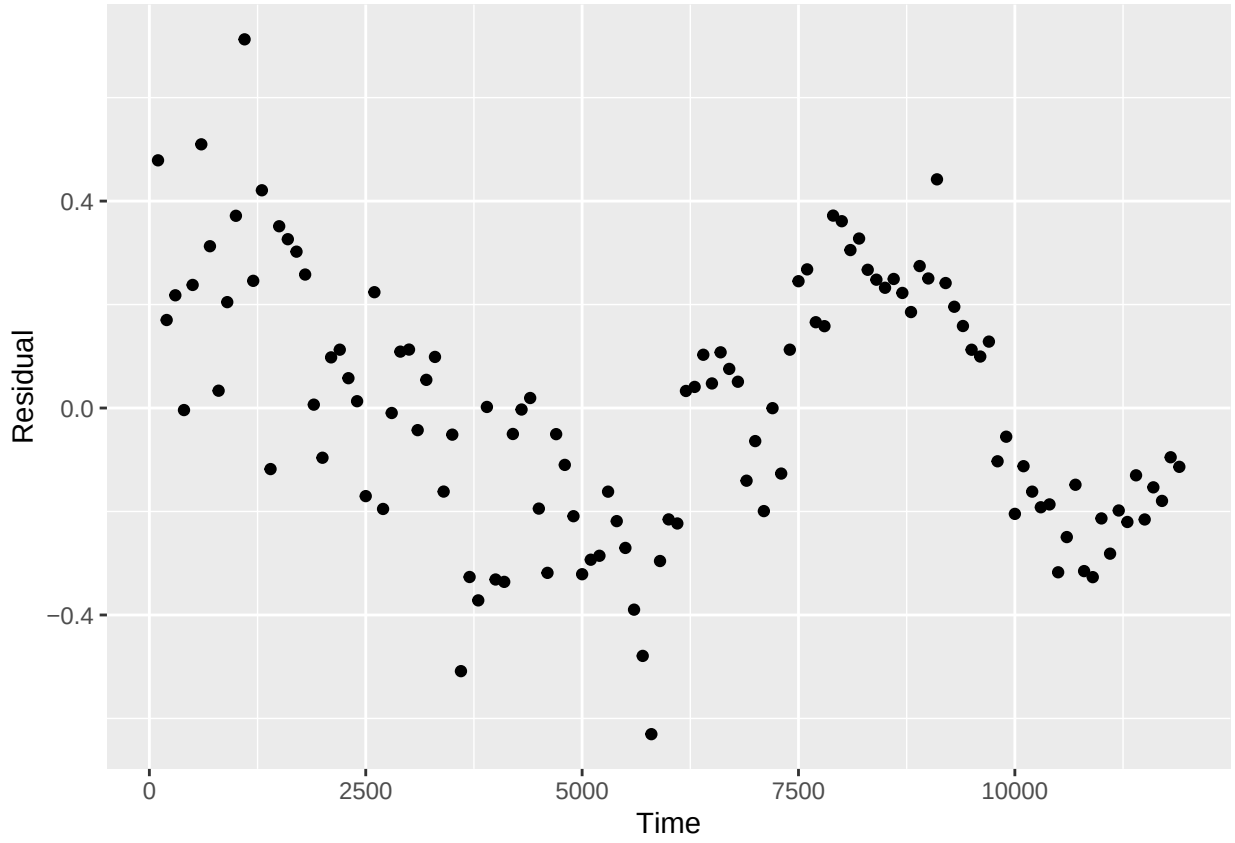

Predicted values of Charcoal
Charcoal
0.5
0.0
−0.5
−60
−40
−20
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



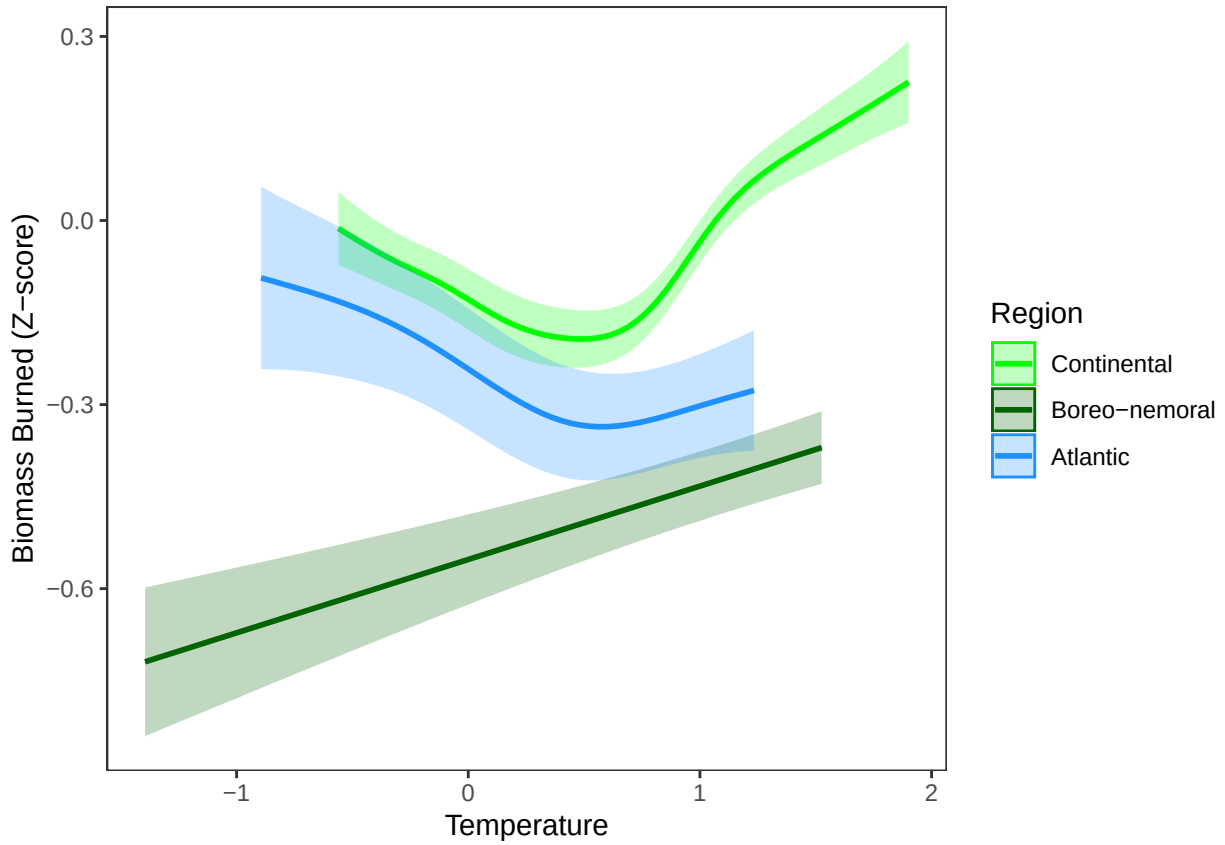

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.41866, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Temperature plot

Here we show the marginal response of biomass burned to temperature in each region, holding precipitation - potential evapotransporation (P-PET) constant at its average value over each region.

```
combined.gam.prediction(data = FullClimate,
                        xvar = "Temperature",
                        gams = list(full.climate.continental,
                                    full.climate.boreonemoral,
                                    full.climate.atlantic),
                        regions = c("Continental", "Boreo-nemoral", "Atlantic"))
```

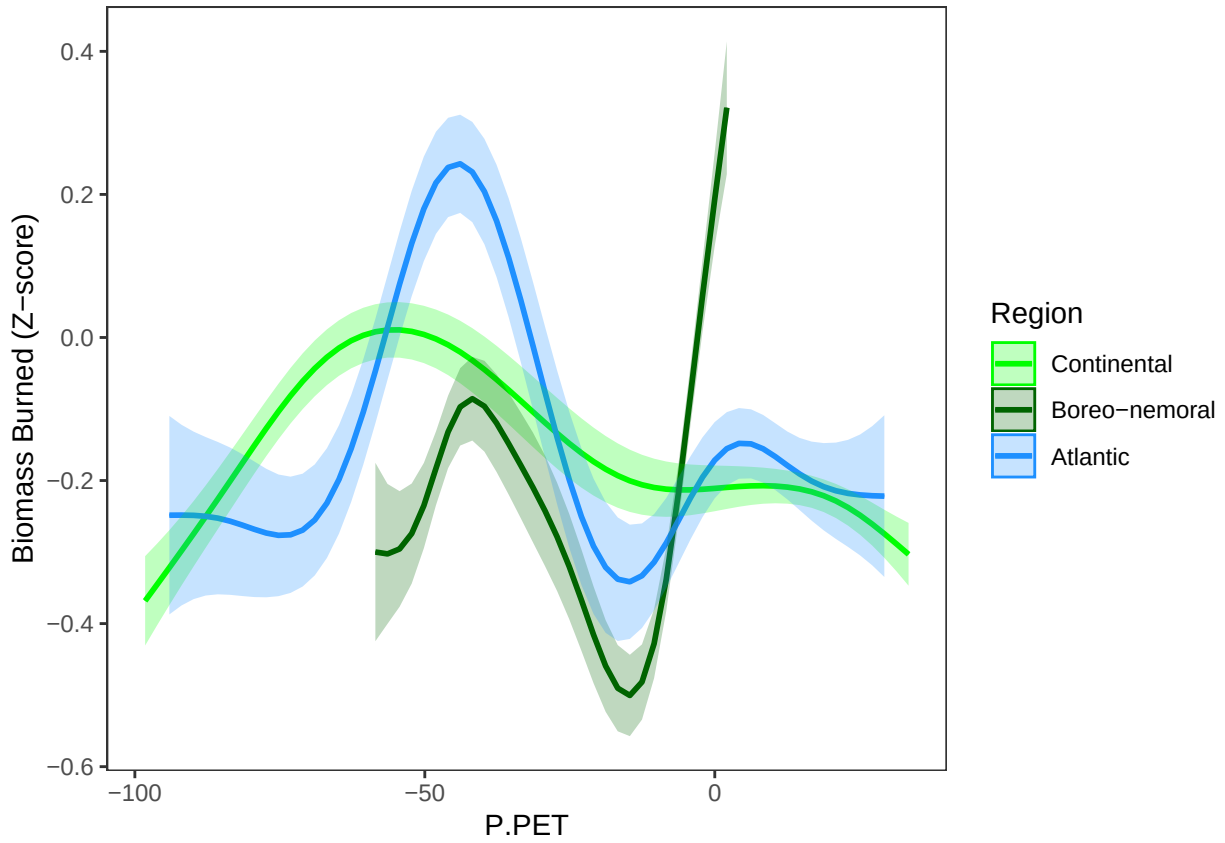



```
## pdf
##   2
```

P-PET plot

Here we show the marginal response of biomass burned to P-PET in each region, holding the temperature constant at its average value over each region.

```
combined.gam.prediction(data = FullClimate,
                        xvar = "P.PET",
                        gams = list(full.climate.continental,
                                    full.climate.boreonemoral,
                                    full.climate.atlantic),
                        regions = c("Continental", "Boreo-nemoral", "Atlantic"))
```




```
## pdf
##   2
```

Conclusion

When considering GAMs fitted with only climate predictor variables over the full times series, the marginal response of biomass burnt to temperature in the Boreo-nemoral region can be readily interpreted as it shows a steady increase with increasing temperature. However, the response to temperature in the Continental and Atlantic is harder to interpret as it shows first a decrease and then an increase with increasing temperature. Furthermore, the response to P-PET is erratic and difficult to interpret in all regions. We therefore dig deeper into the drivers of biomass burning in the following analysis by considering the pre- and post-8 ka BP time periods separately (i.e. periods in which humans were absent and present in significant numbers) and using land cover as additional predictors when they are available (i.e. for the post-8 ka BP period).

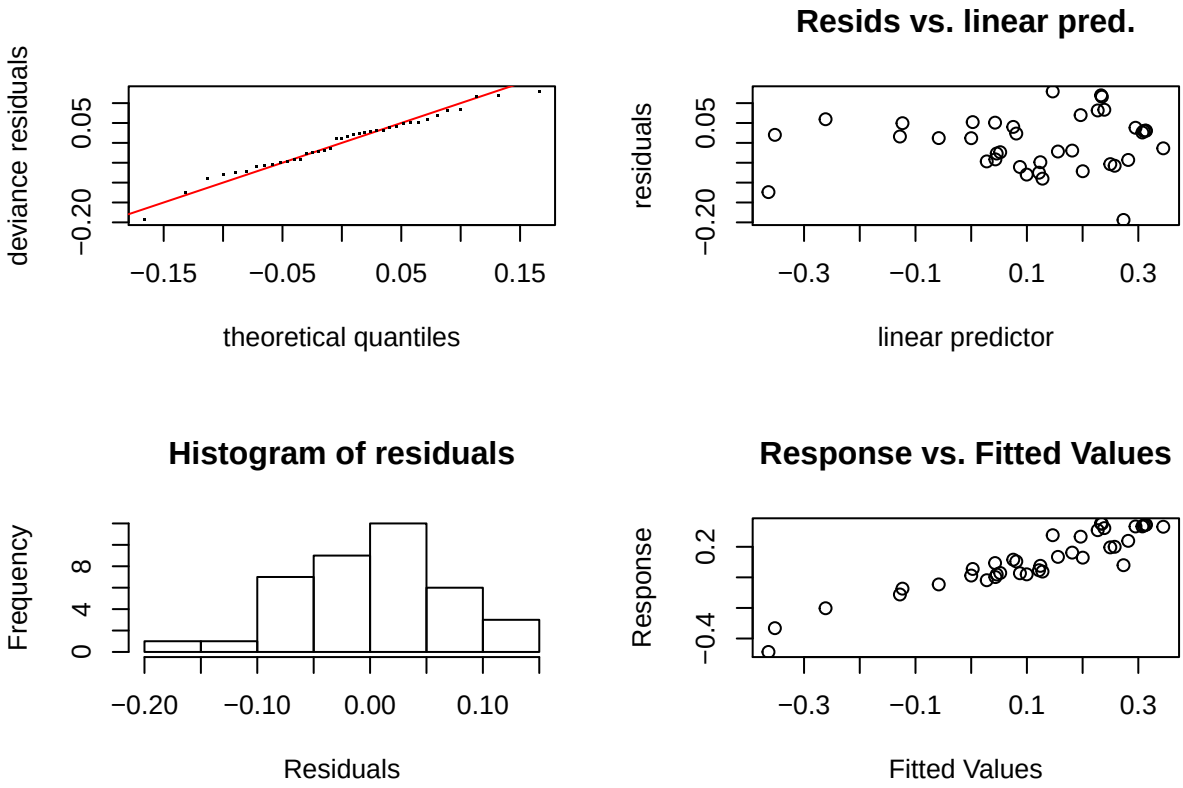
Climate only GAMs before and after 8ka BP

8 ka BP-12 ka BP, climate only

8 ka BP-12 ka BP climate data, Continental ecoregion

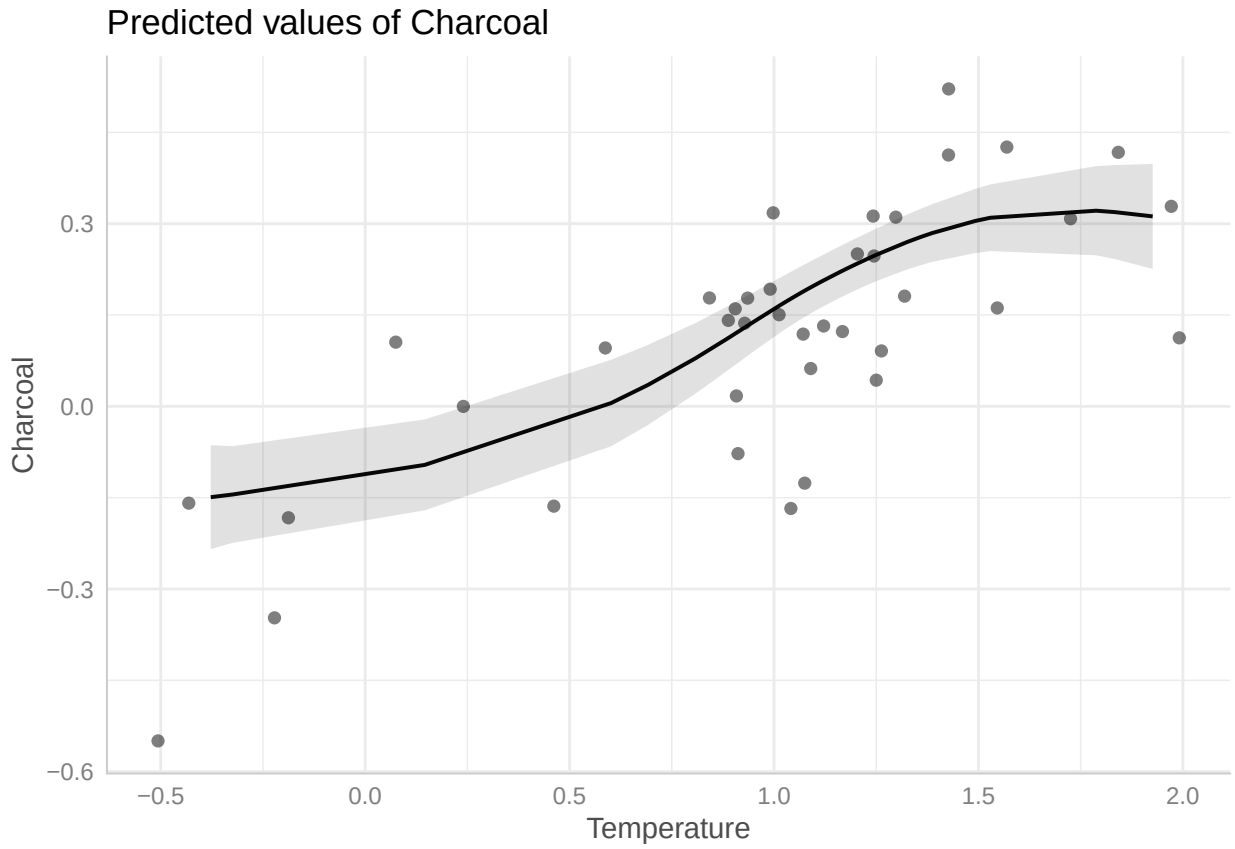
```
early.climate <- FullClimate[FullClimate$Age > 8000,]

early.climate.continental <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = early.climate,
```

```
## [1] "Checking GAM"
```

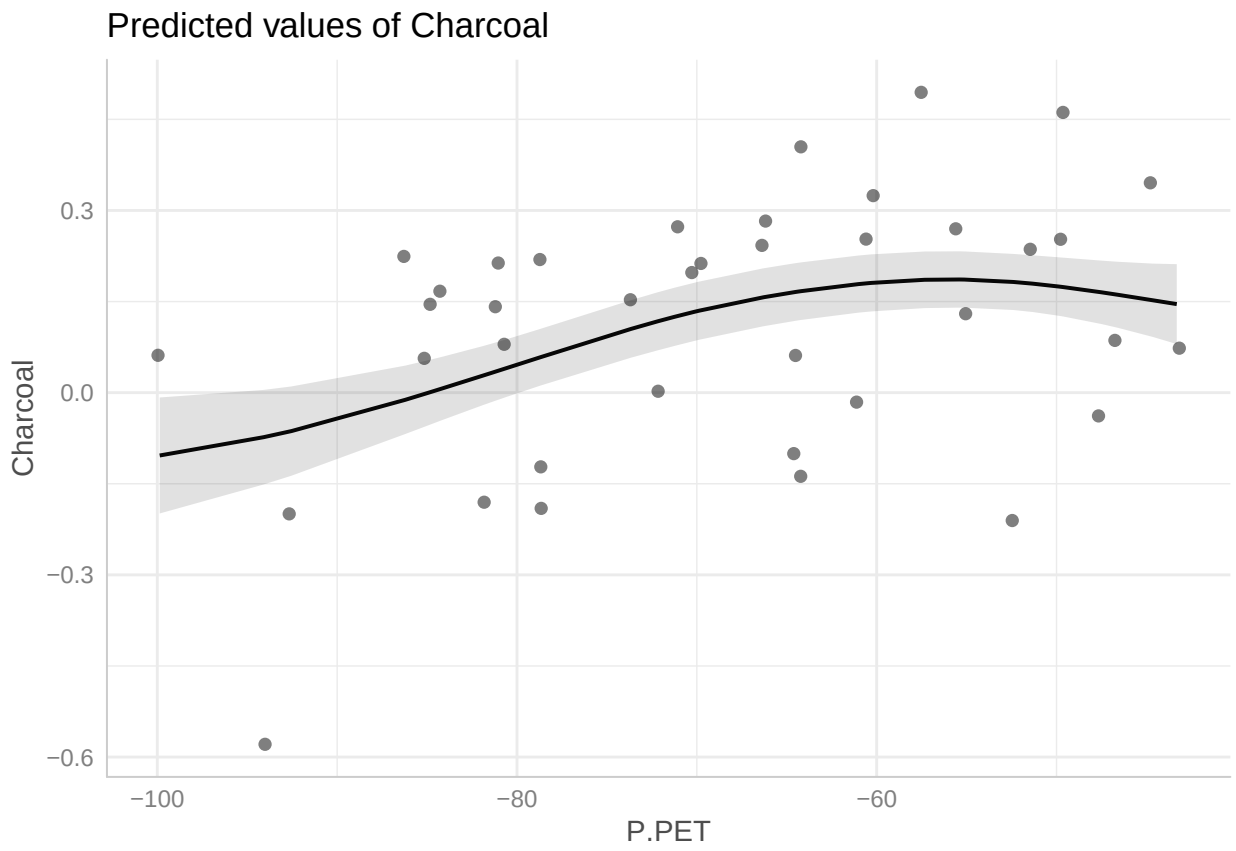



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 7 iterations.
## Gradient range [-1.199105e-05,1.070345e-05]
## (score -35.48881 & scale 0.005544089).
## Hessian positive definite, eigenvalue range [1.893156e-06,19.20561].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 2.94    1.01    0.41
## s(P.PET)       9.00 2.47    1.23    0.92
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
```

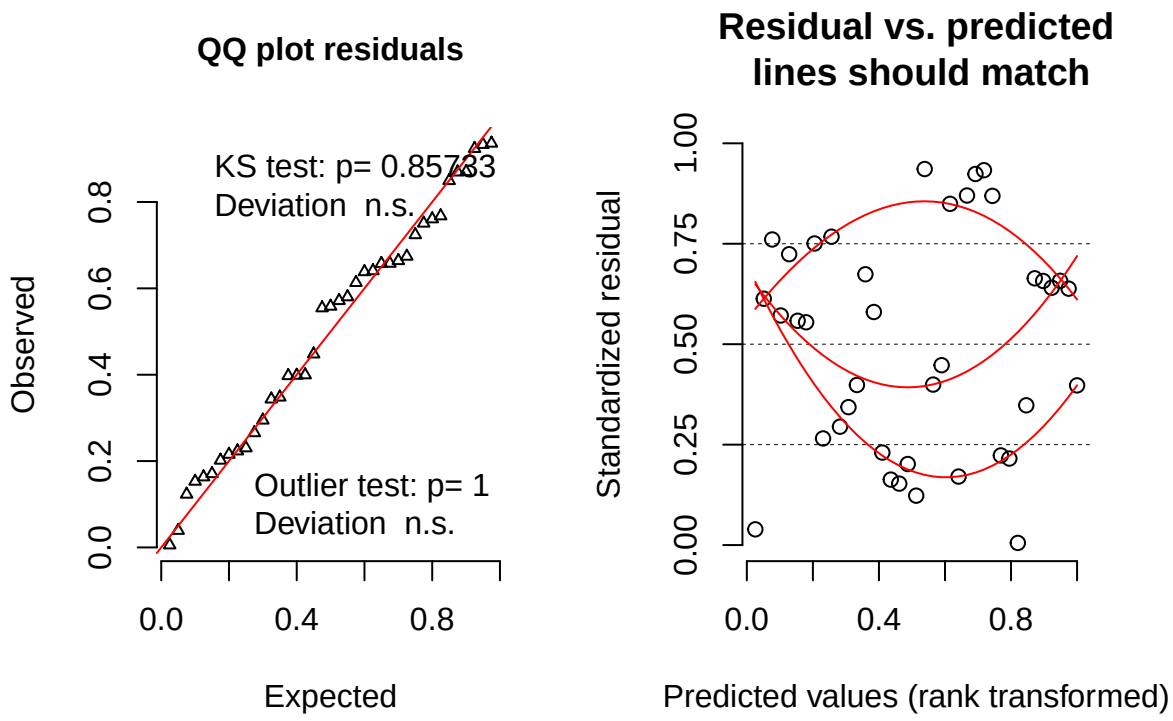
```
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.11295    0.01192   9.473 6.97e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 2.938      9 14.99  < 2e-16 ***
## s(P.PET)       2.467      9  4.68 1.73e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.854   Deviance explained = 87.4%
## -REML = -35.489  Scale est. = 0.0055441  n = 39
## [1] "Plotting predictions"
## $Temperature
```



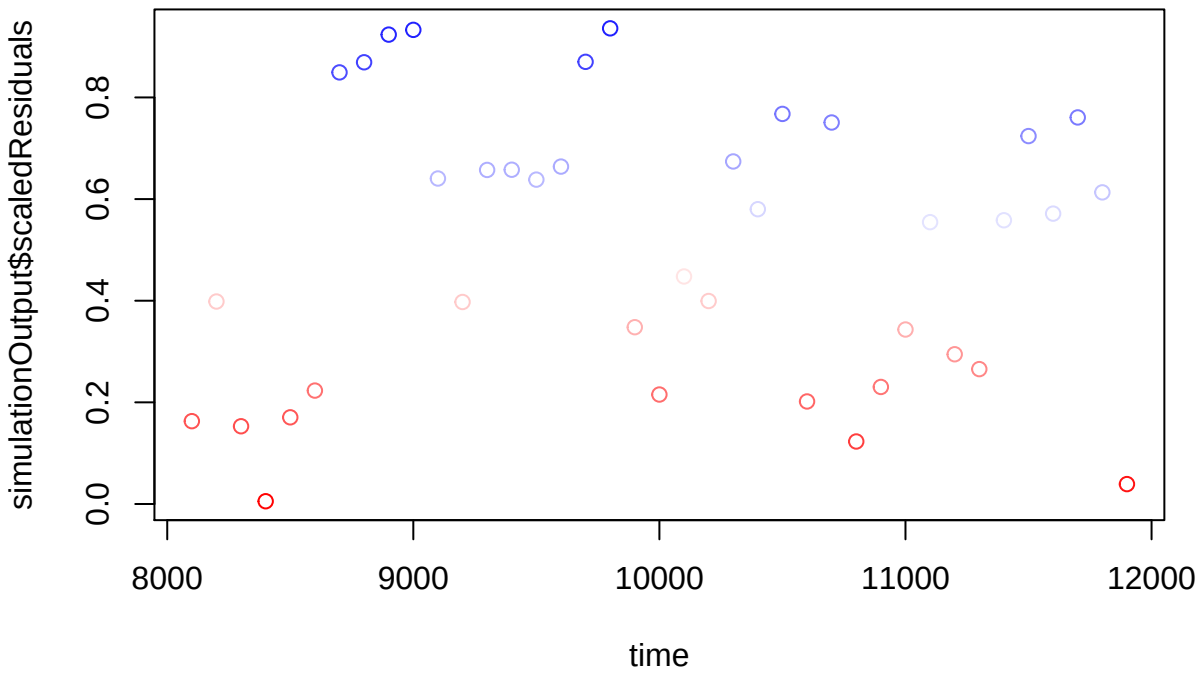

```
##
## $P.PET
```


Predicted values of Charcoal
Charcoal
0.3
0.0
−0.3
−0.6
−100
−80
−60
P.PET

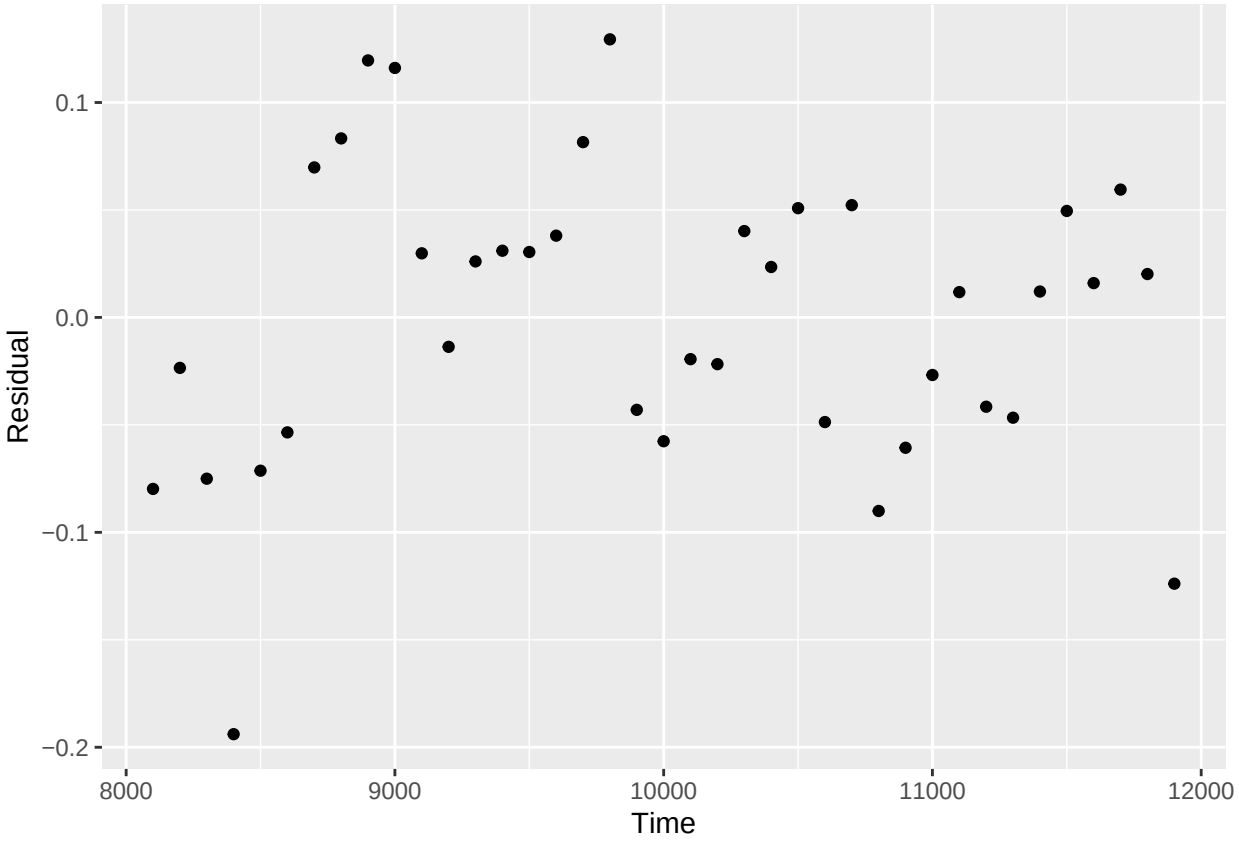
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



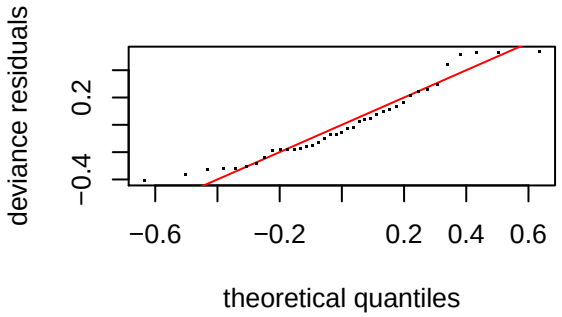

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 1.0773, p-value = 0.00208
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

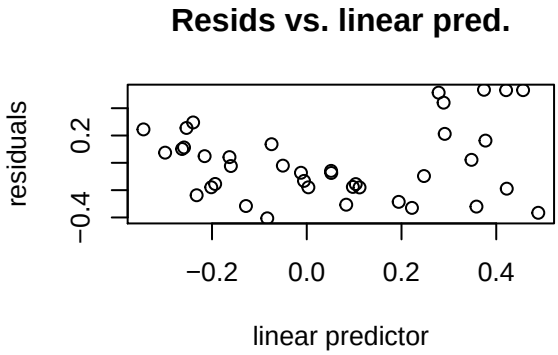


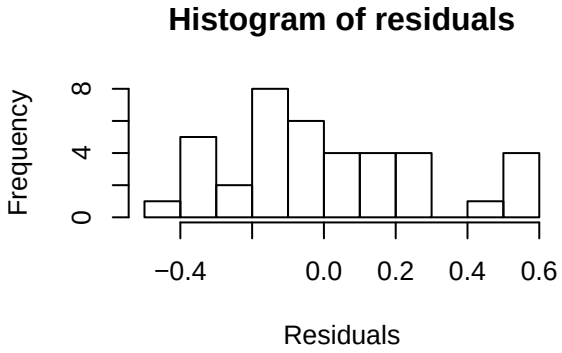
8 ka BP-12 ka BP climate data, Atlantic ecoregion

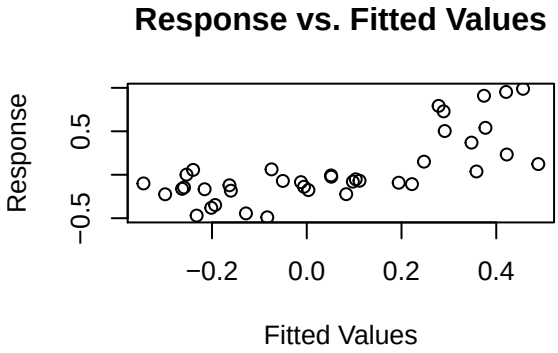
```
early.climate.atlantic <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = early.climate, reg
```

```
## [1] "Checking GAM"
```



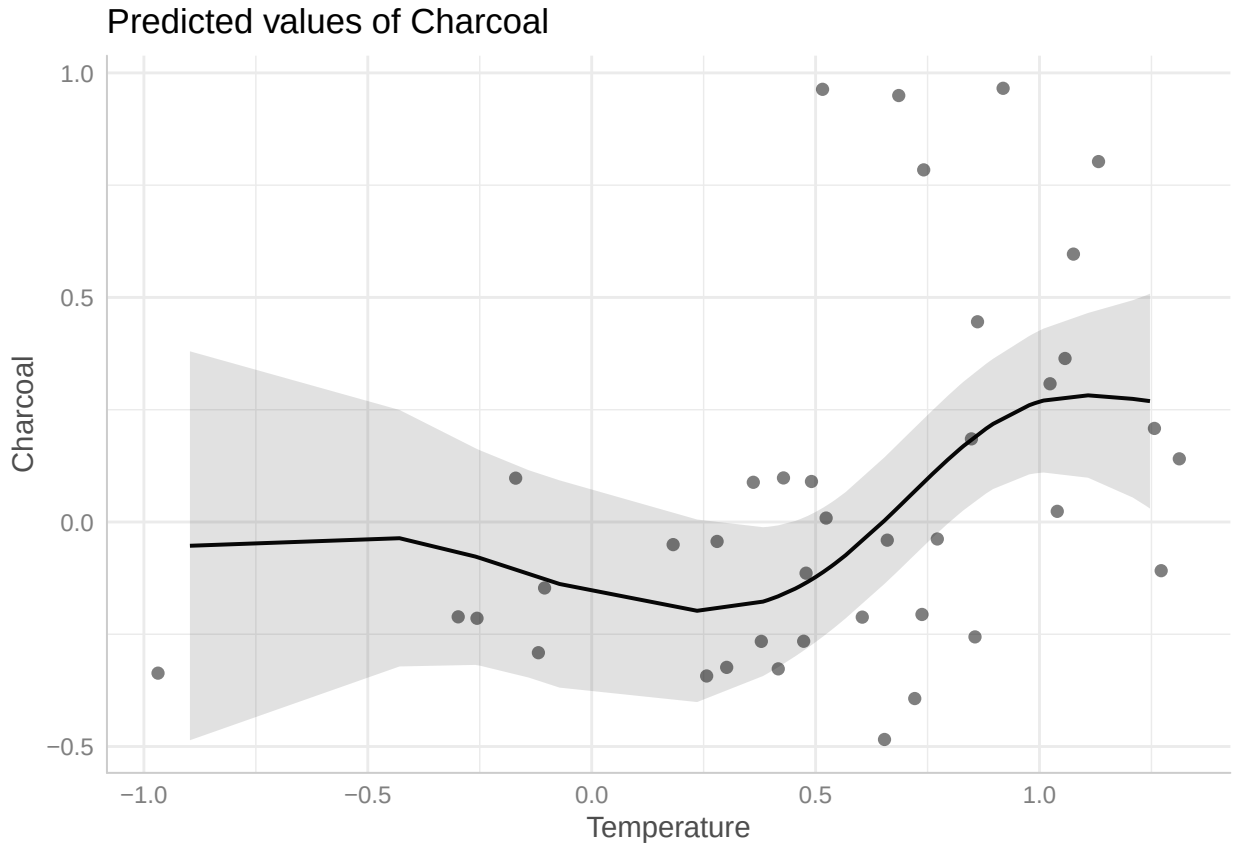




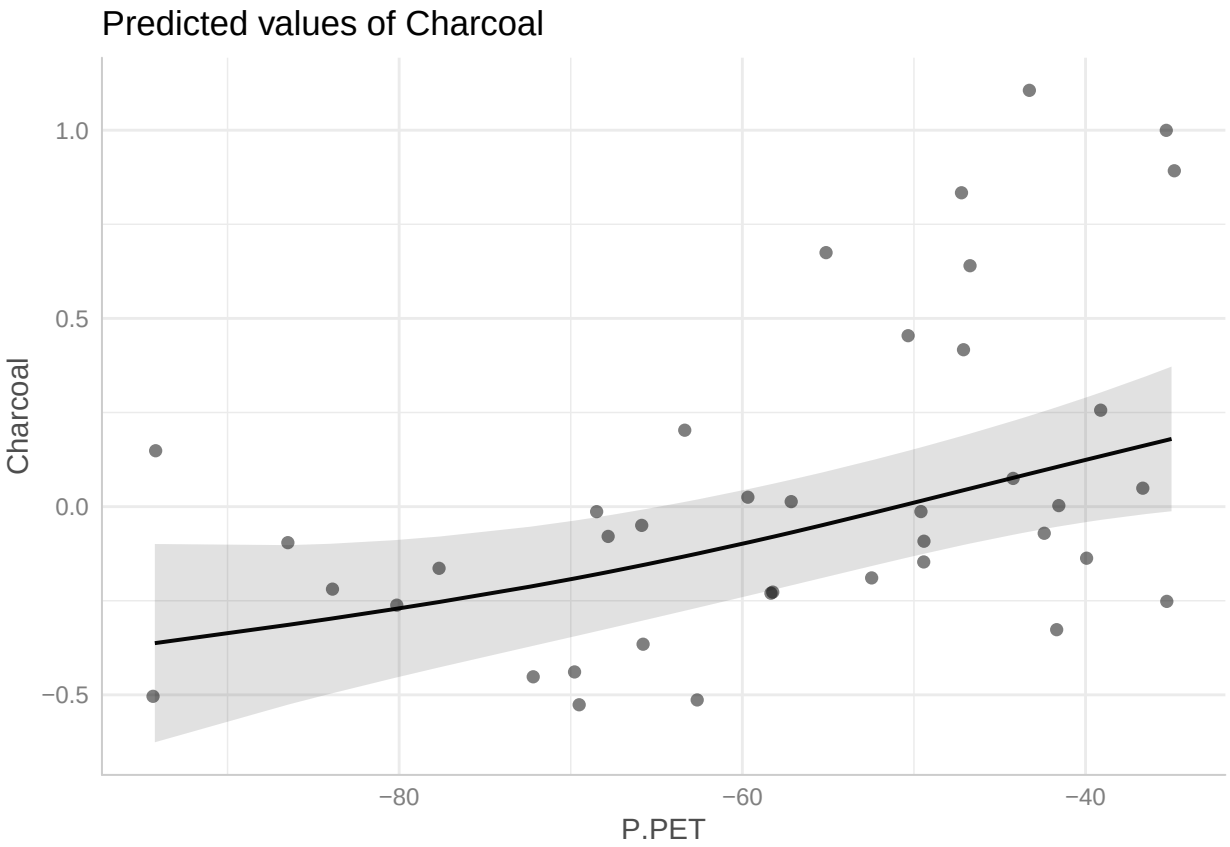


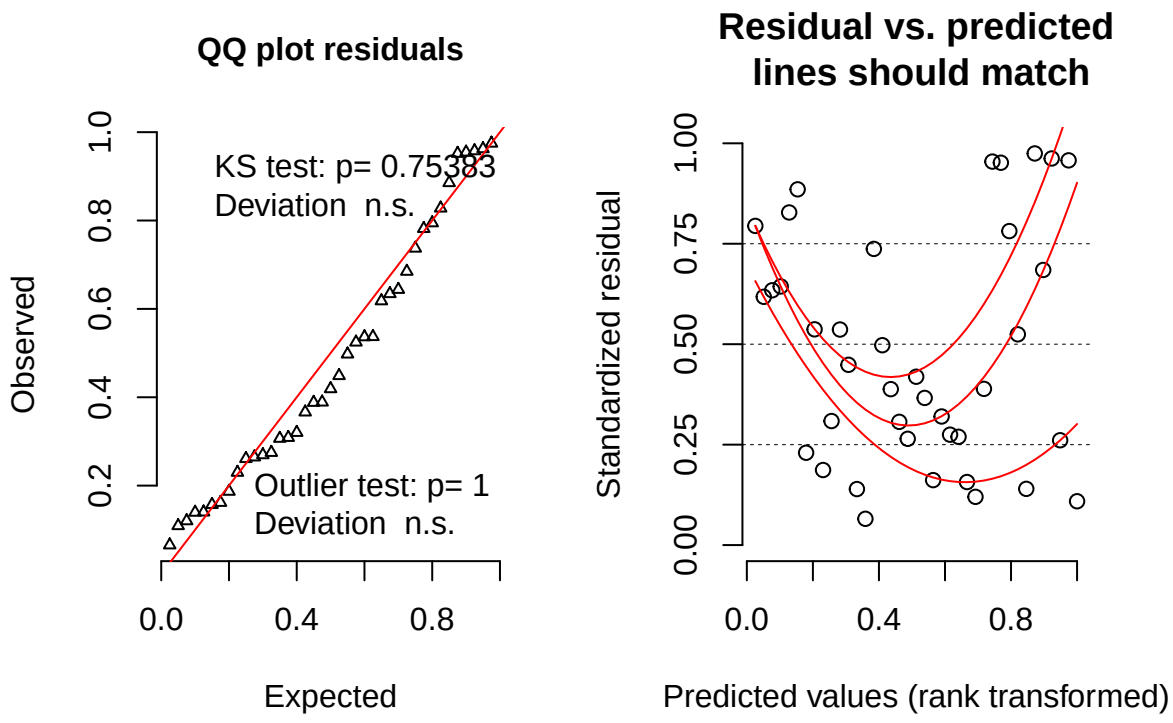

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-3.578941e-06,2.76732e-06]
## (score 13.38783 & scale 0.08089621).
## Hessian positive definite, eigenvalue range [3.578872e-06,19.11939].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 2.85    0.76    0.04 *
## s(P.PET)       9.00 1.25    1.01    0.47
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
```

```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.05358    0.04554   1.177    0.248
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 2.849      9 1.798 0.001678 **
## s(P.PET)       1.252      9 1.333 0.000962 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =   0.47   Deviance explained = 52.7%
## -REML = 13.388  Scale est. = 0.080896  n = 39
## [1] "Plotting predictions"
## $Temperature
```

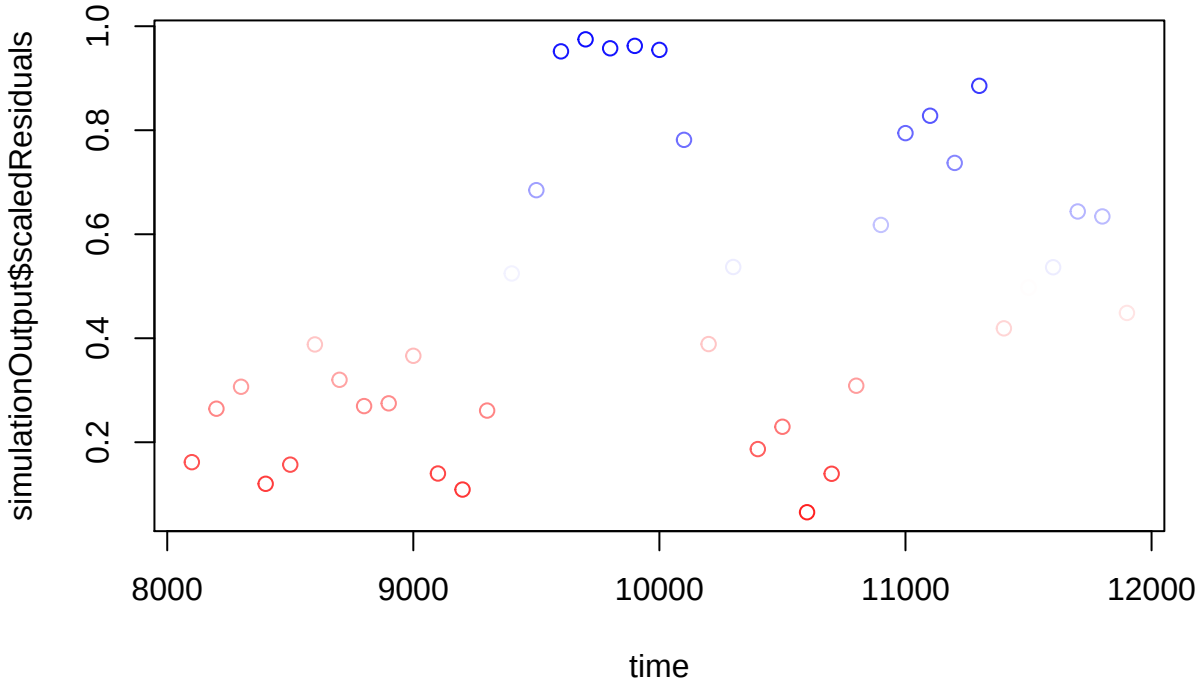



```
##
## $P.PET
```

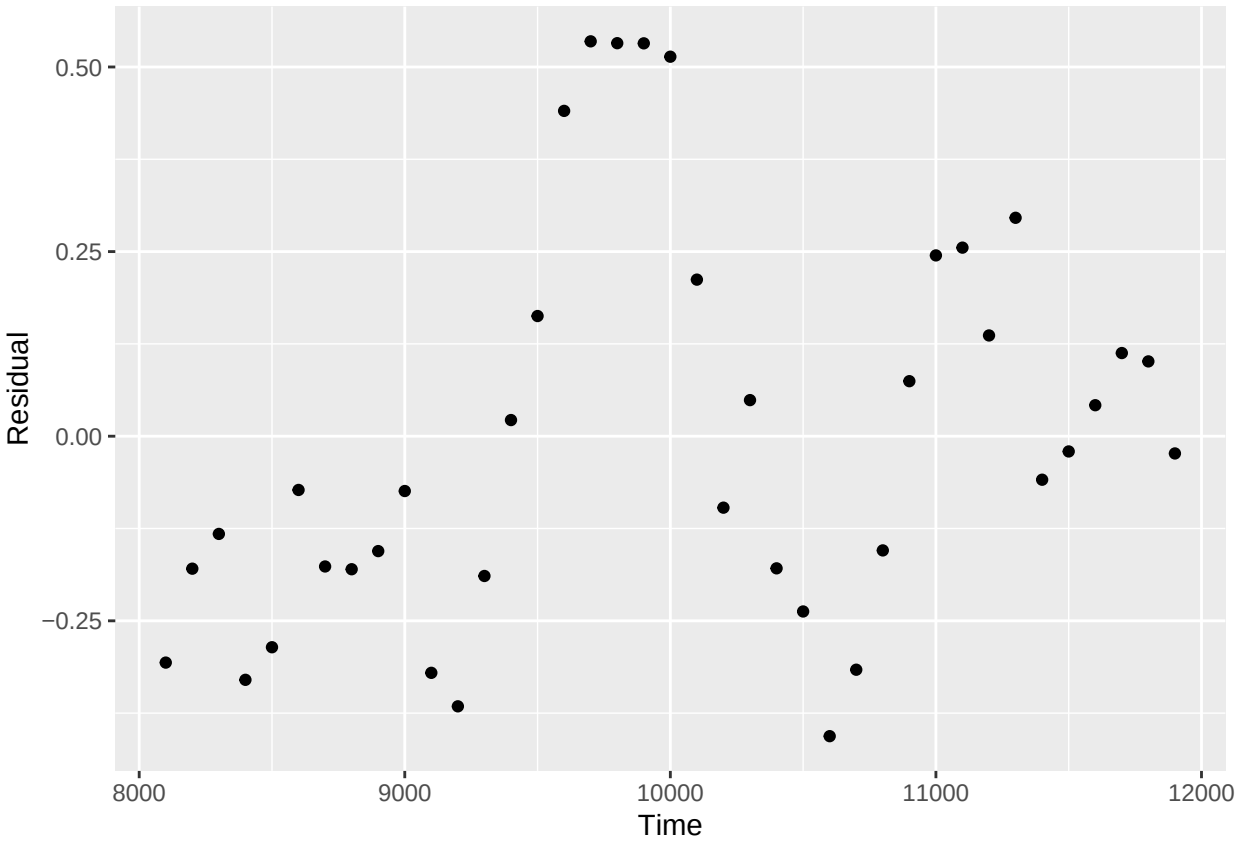

Predicted values of Charcoal
Charcoal
1.0
0.5
0.0
−0.5
−80
−60
−40
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



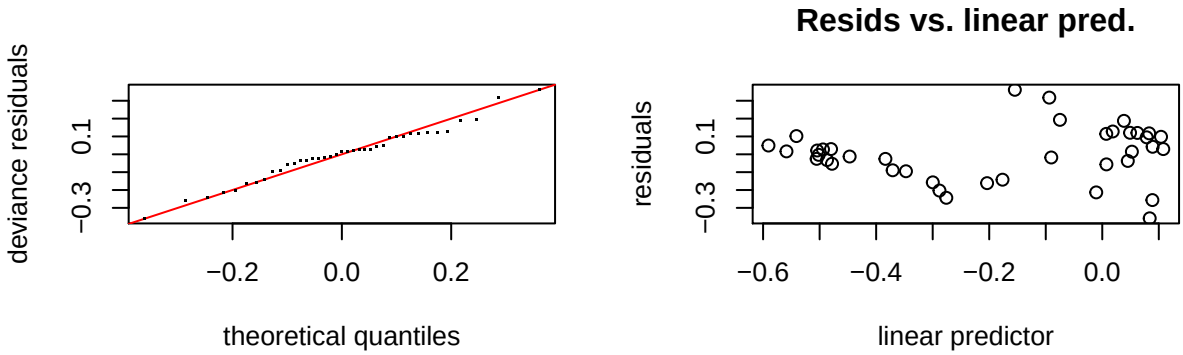

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.37625, p-value = 6.324e-11
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

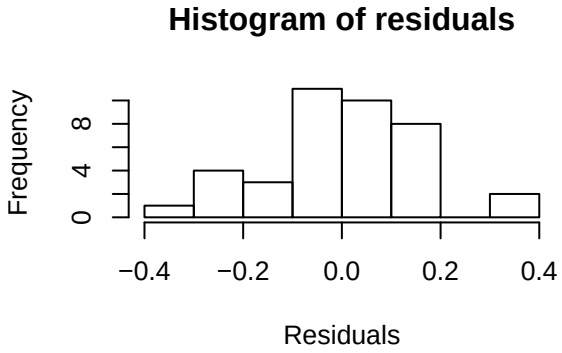


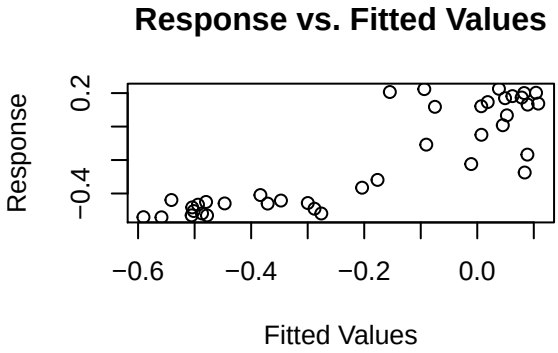
8 ka BP-12 ka BP climate data, Boreo-Nemoral ecoregion

```
early.climate.boreonemoral <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = early.climate
```

```
## [1] "Checking GAM"
```

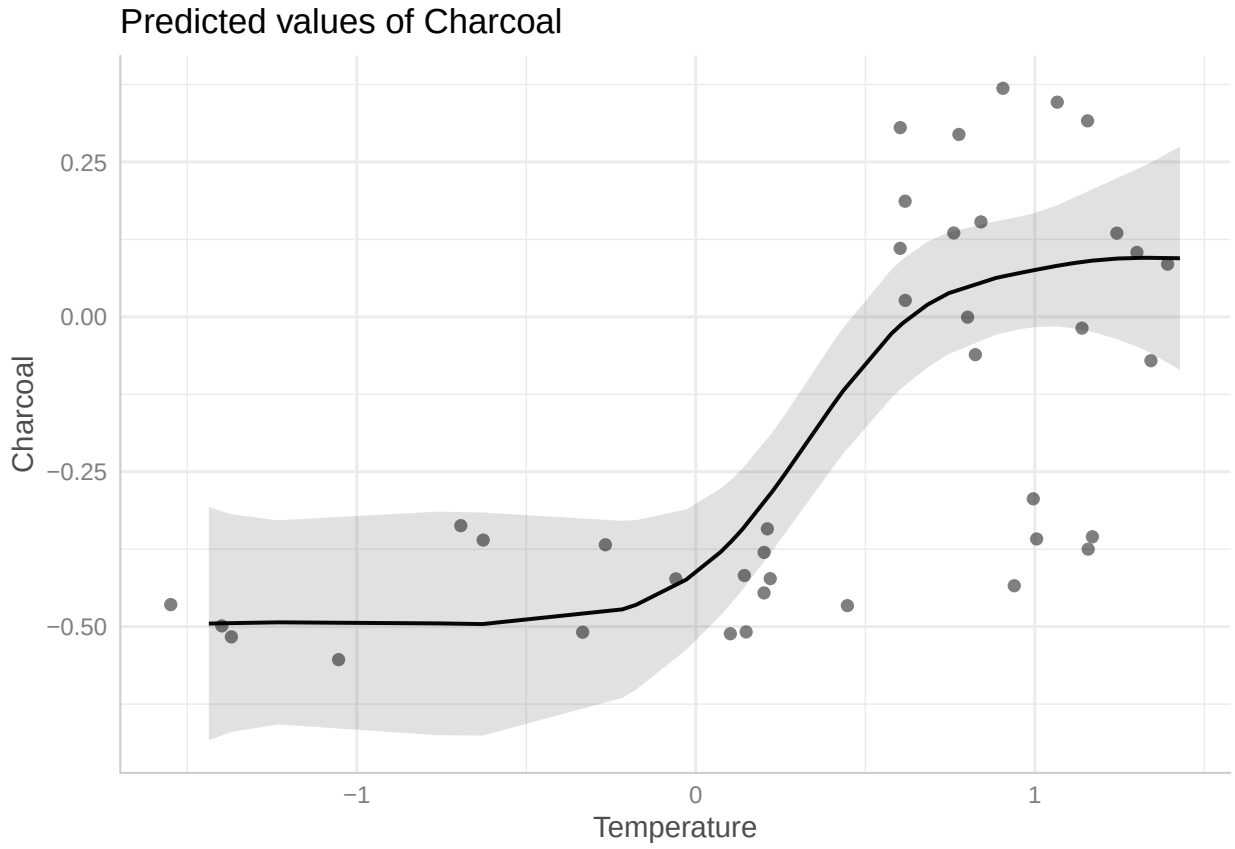




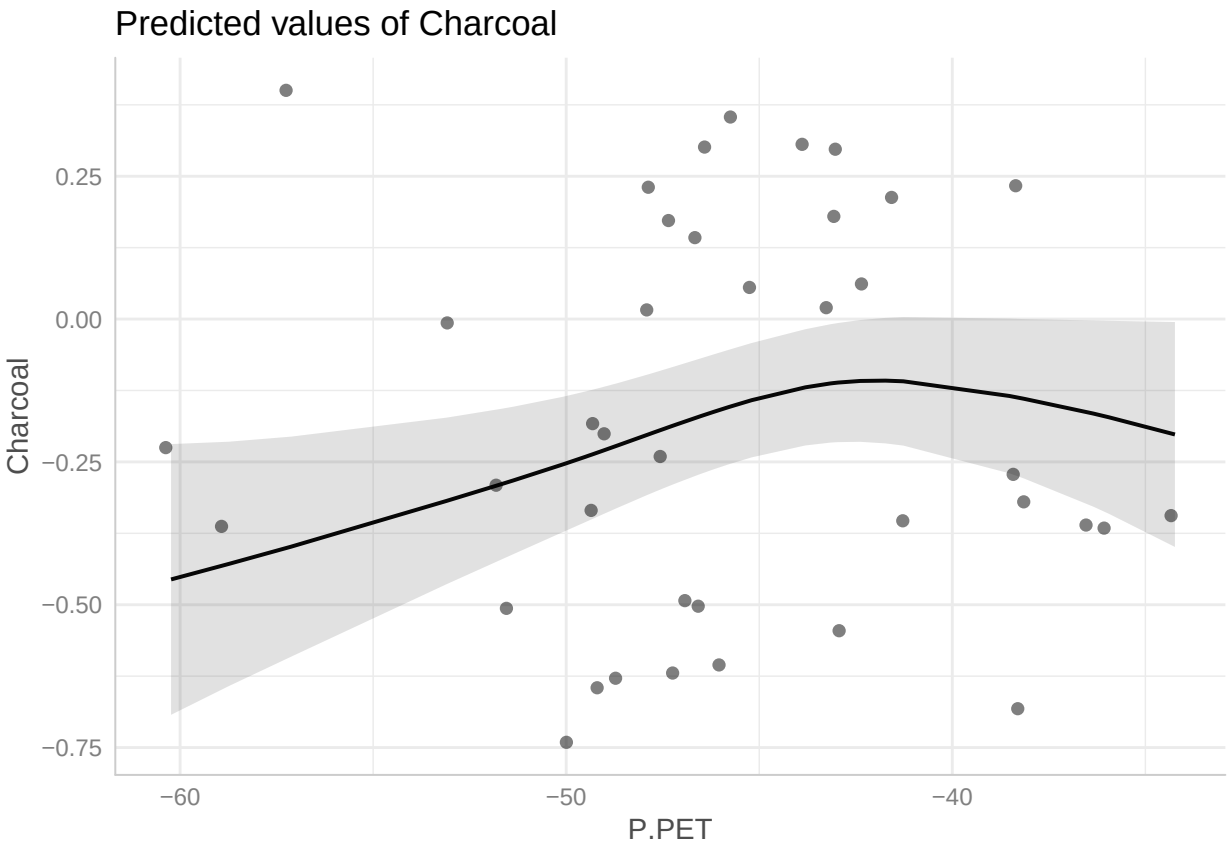


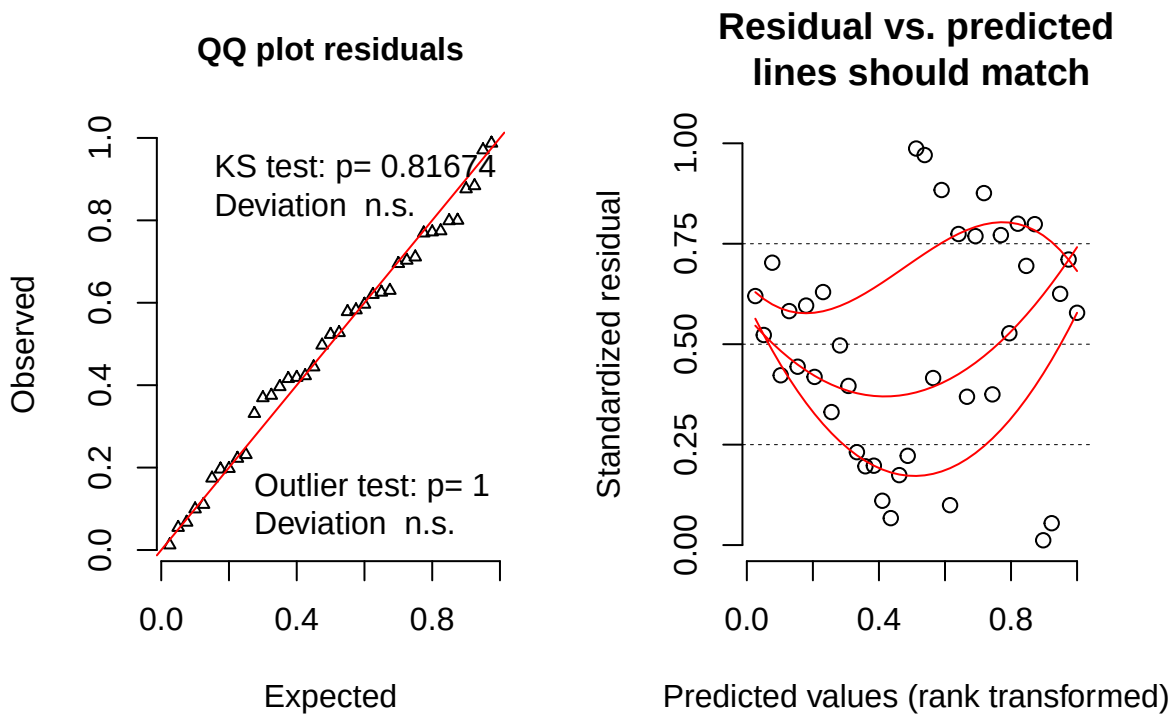

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 9 iterations.
## Gradient range [-2.868178e-06,4.43397e-06]
## (score -5.755863 & scale 0.02618218).
## Hessian positive definite, eigenvalue range [8.680564e-08,19.21605].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 3.45    0.94    0.30
## s(P.PET)       9.00 2.05    0.88    0.23
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept) -0.19081    0.02591  -7.364 2.04e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 3.447      9 8.947 5.76e-12 ***
## s(P.PET)       2.049      9 1.133  0.00574 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.709   Deviance explained = 75.1%
## -REML = -5.7559  Scale est. = 0.026182  n = 39
## [1] "Plotting predictions"
## $Temperature
```

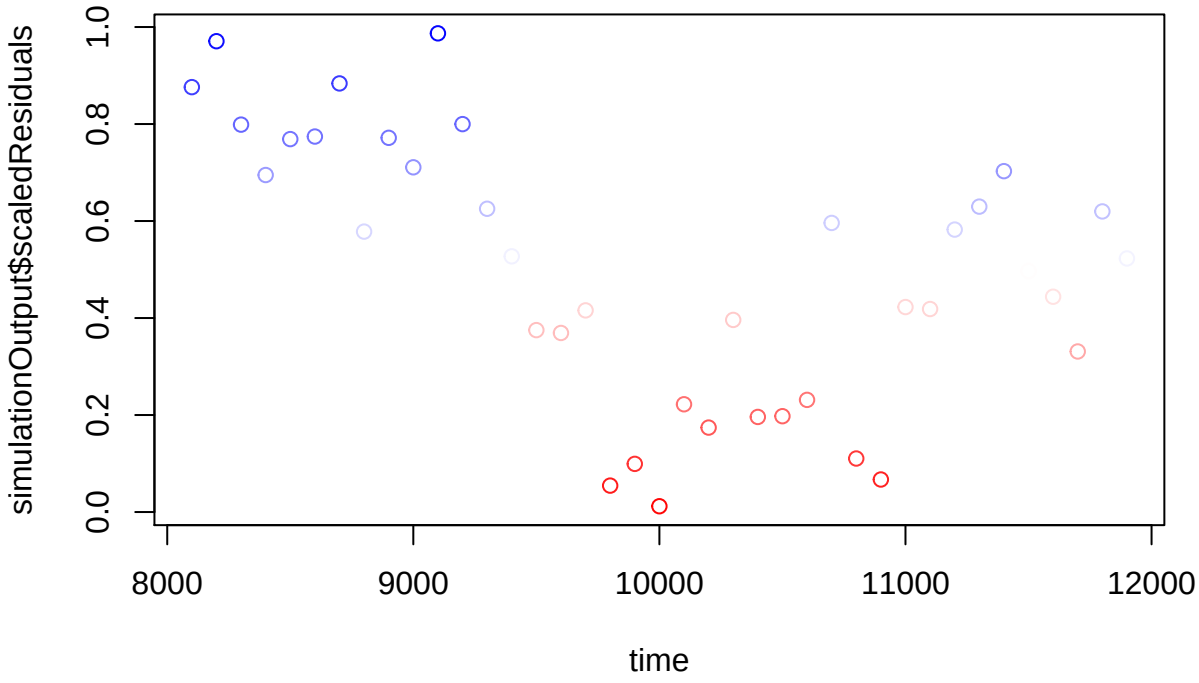



```
##
## $P.PET
```

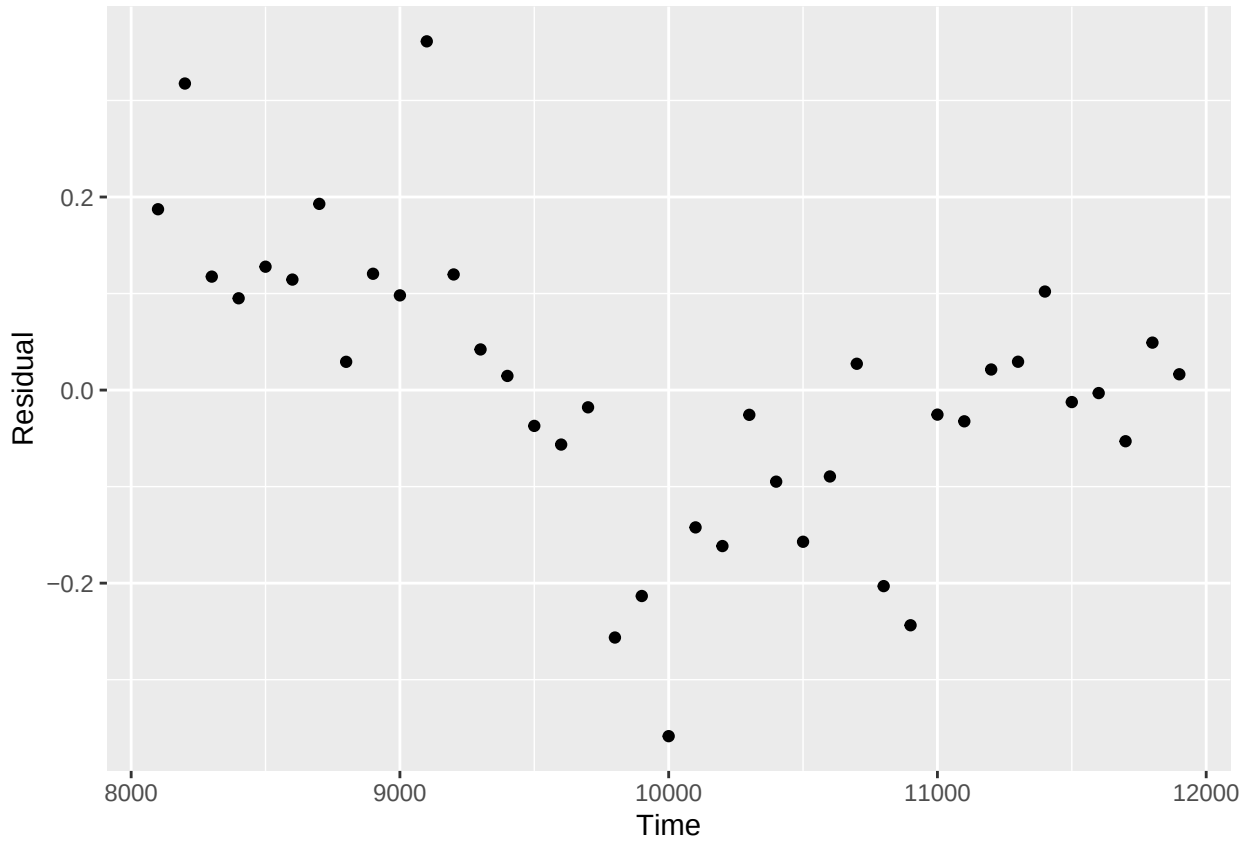

Predicted values of Charcoal
0.25
0.00
−0.25
−0.50
−0.75
Charcoal
−60
−50
−40
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```




```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.47565, p-value = 4.273e-09
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

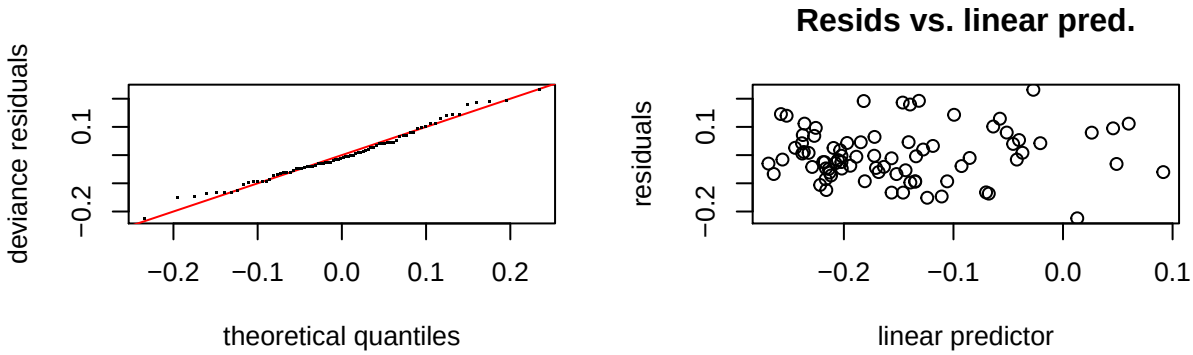


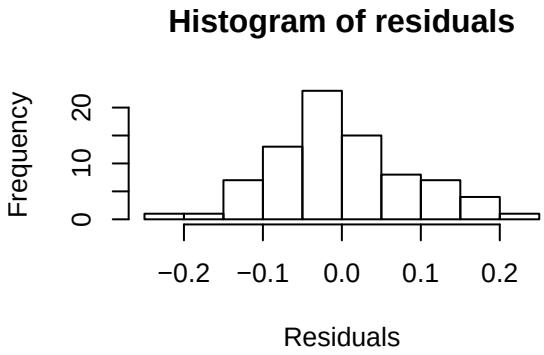
0 ka BP-8 ka BP, climate only

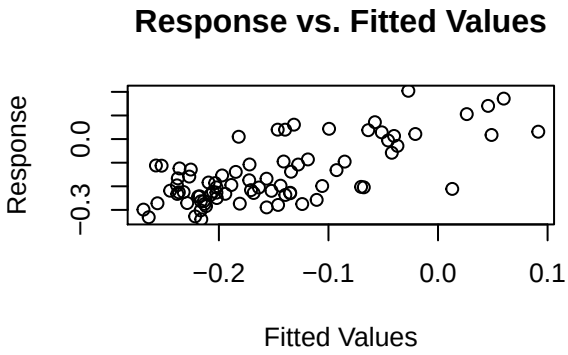
0 ka BP-8 ka BP climate data, Continental ecoregion

```
late.climate <- FullClimate[FullClimate$Age <= 8000,]

late.climate.continental <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = late.climate, r
```

```
## [1] "Checking GAM"
```

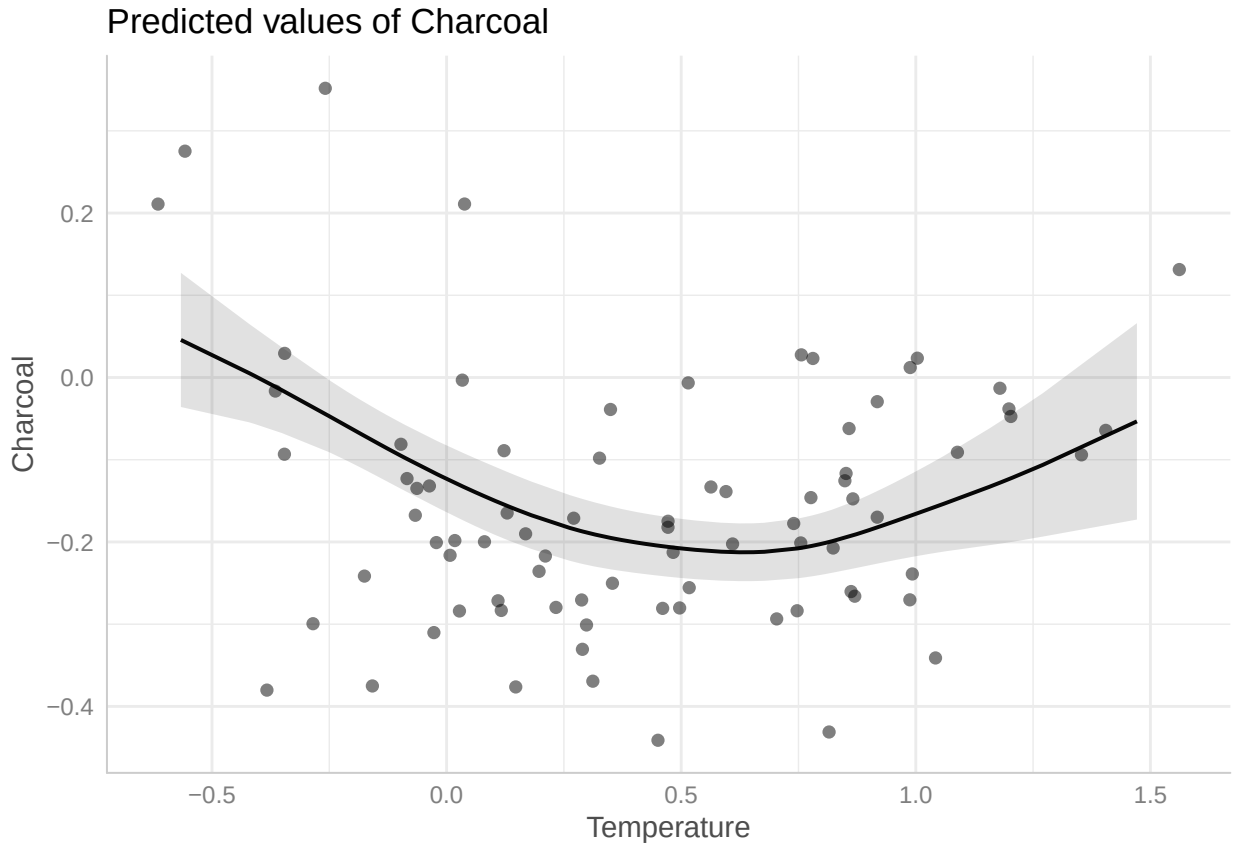




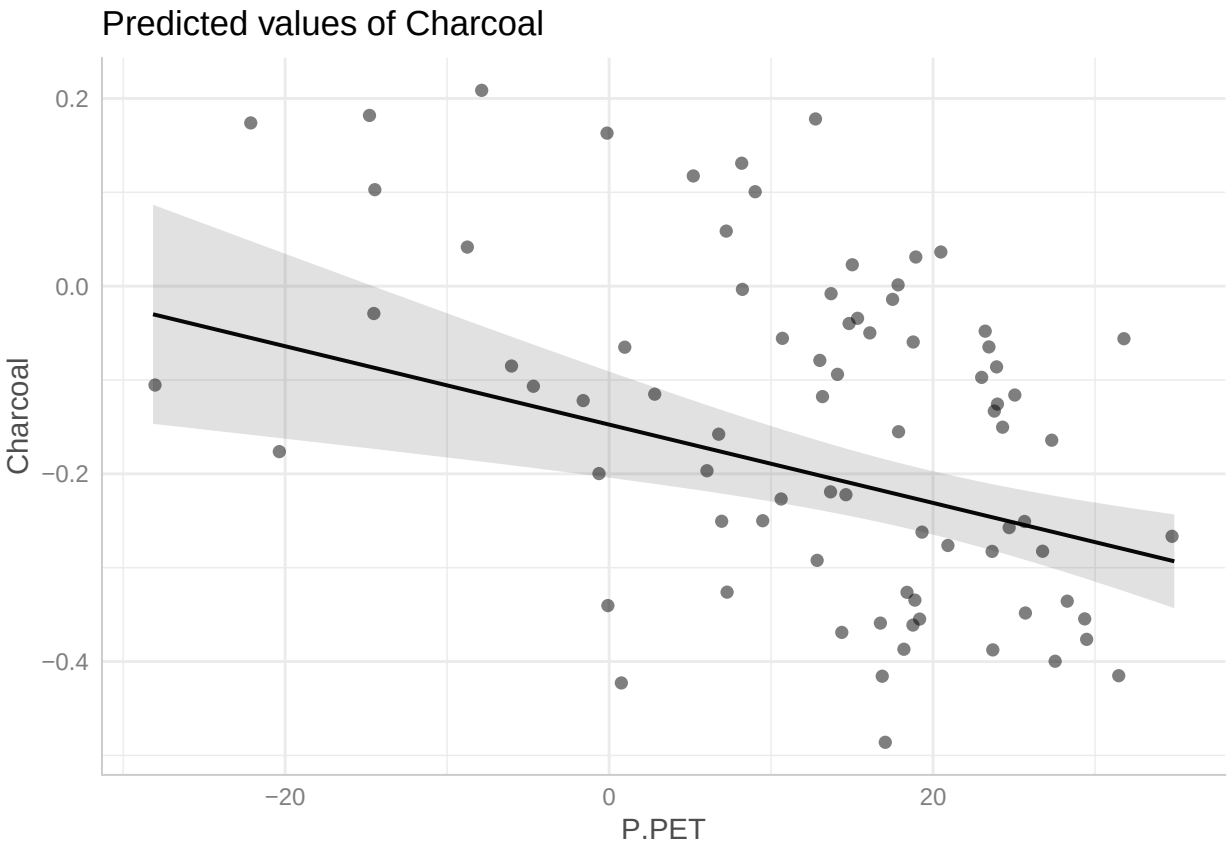



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-3.678624e-05,3.37166e-05]
## (score -67.52538 & scale 0.008806763).
## Hessian positive definite, eigenvalue range [6.594764e-07,39.55671].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                   k'   edf k-index p-value
## s(Temperature) 9.000 2.806    0.99    0.41
## s(P.PET)       9.000 0.924    1.26    0.98
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
```

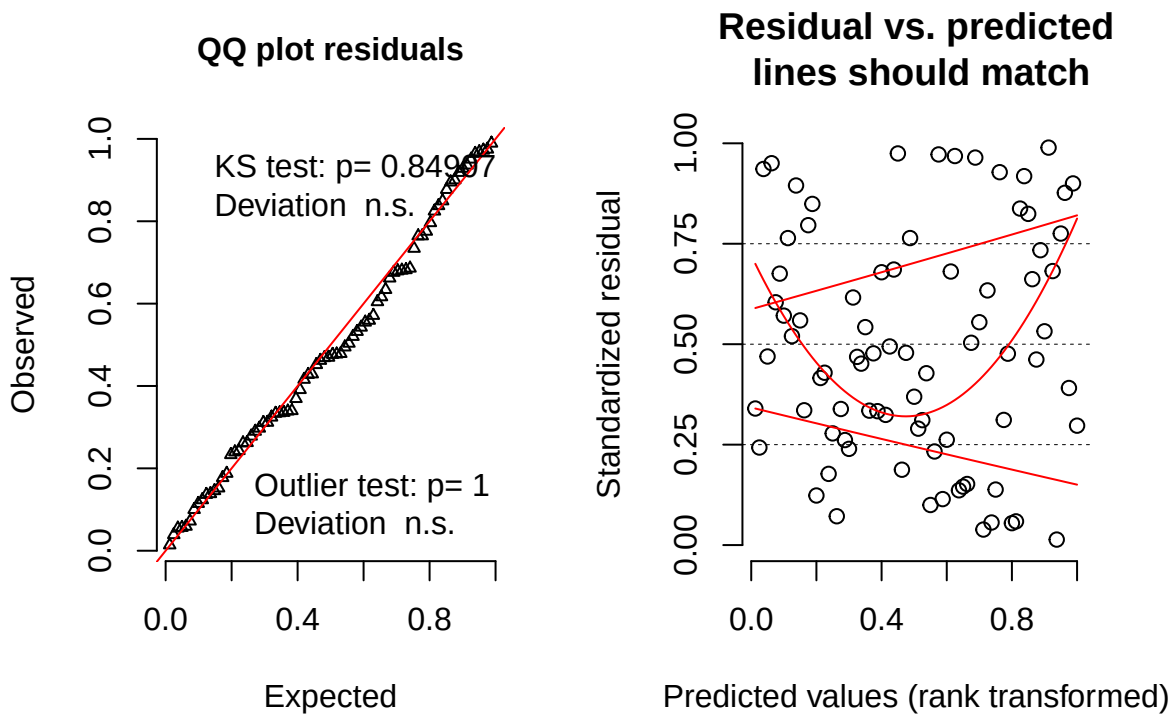
```
## (Intercept) -0.14942    0.01049  -14.24   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 2.8058      9 4.233 3.49e-08 ***
## s(P.PET)       0.9236      9 1.340 0.000339 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.467   Deviance explained = 49.2%
## -REML = -67.525  Scale est. = 0.0088068  n = 80
## [1] "Plotting predictions"
## $Temperature
```



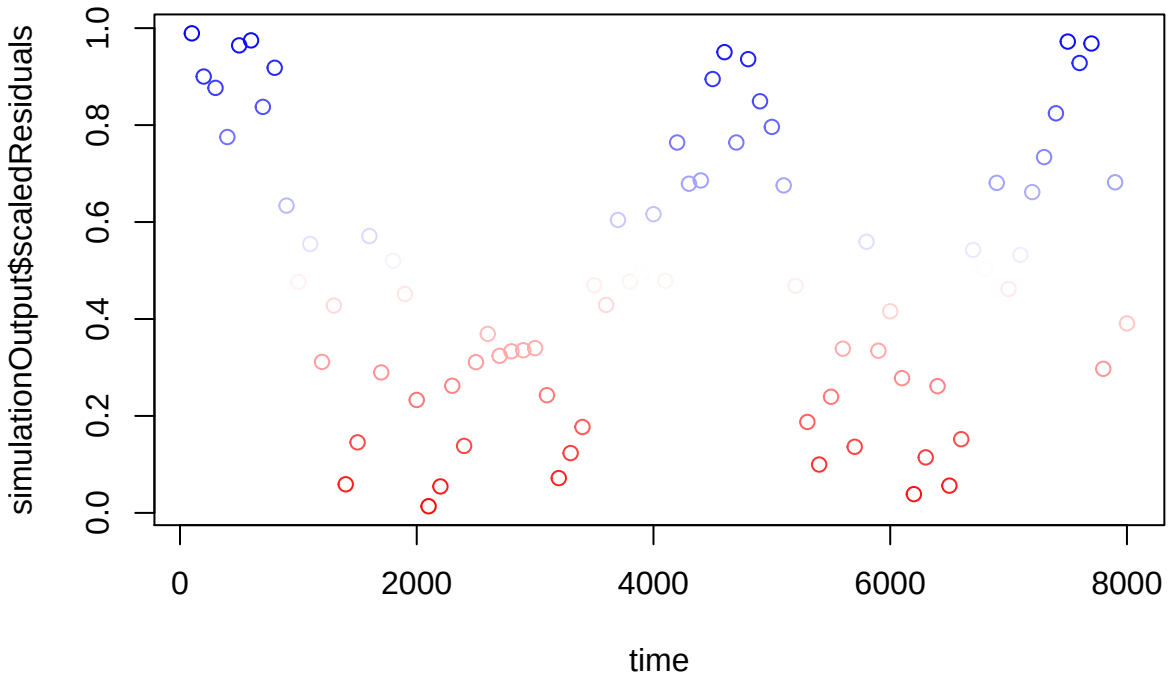

```
##
## $P.PET
```


Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−20
0
20
P.PET

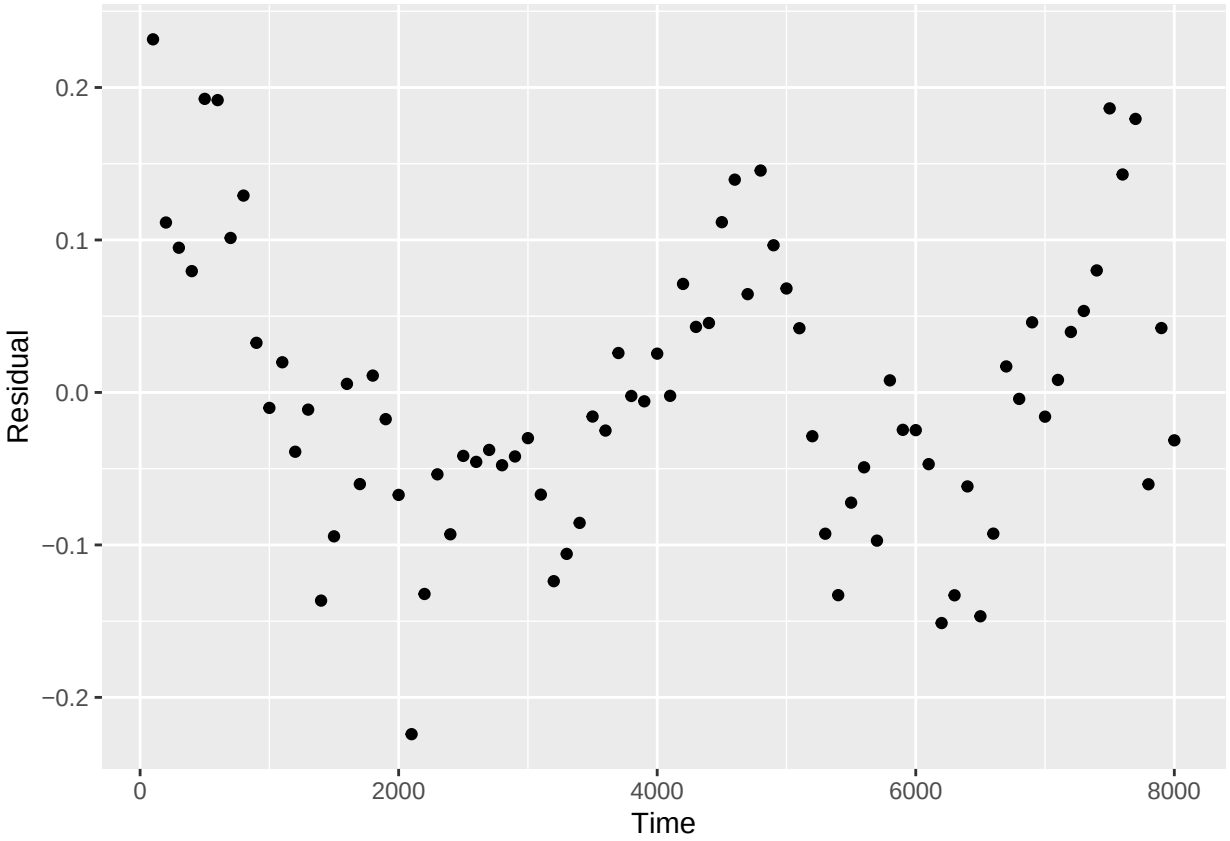
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



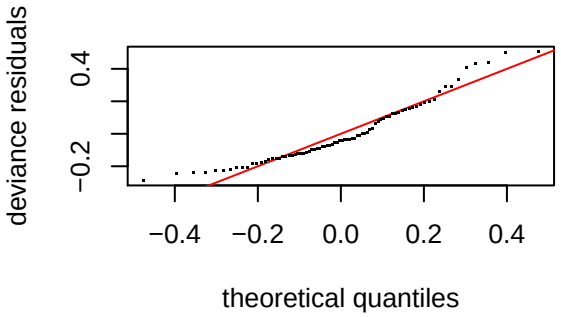

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.45646, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

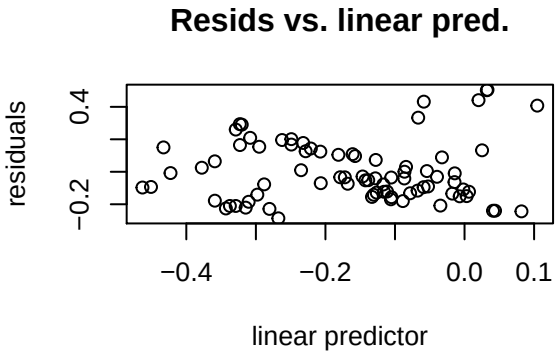


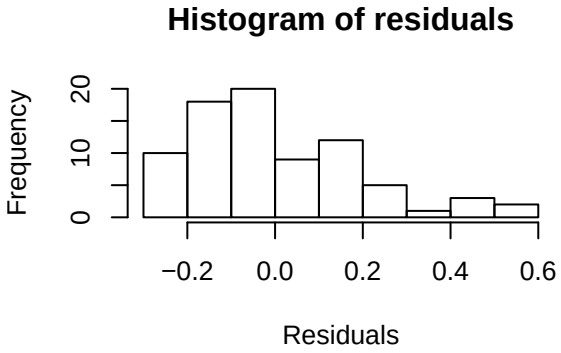
0 ka BP-8 ka BP climate data, Atlantic ecoregion

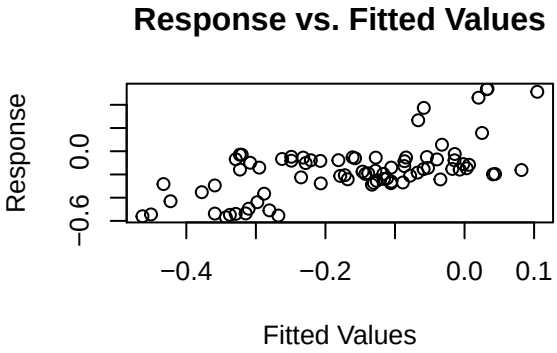
```
late.climate.atlantic <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = late.climate, regi
```

```
## [1] "Checking GAM"
```



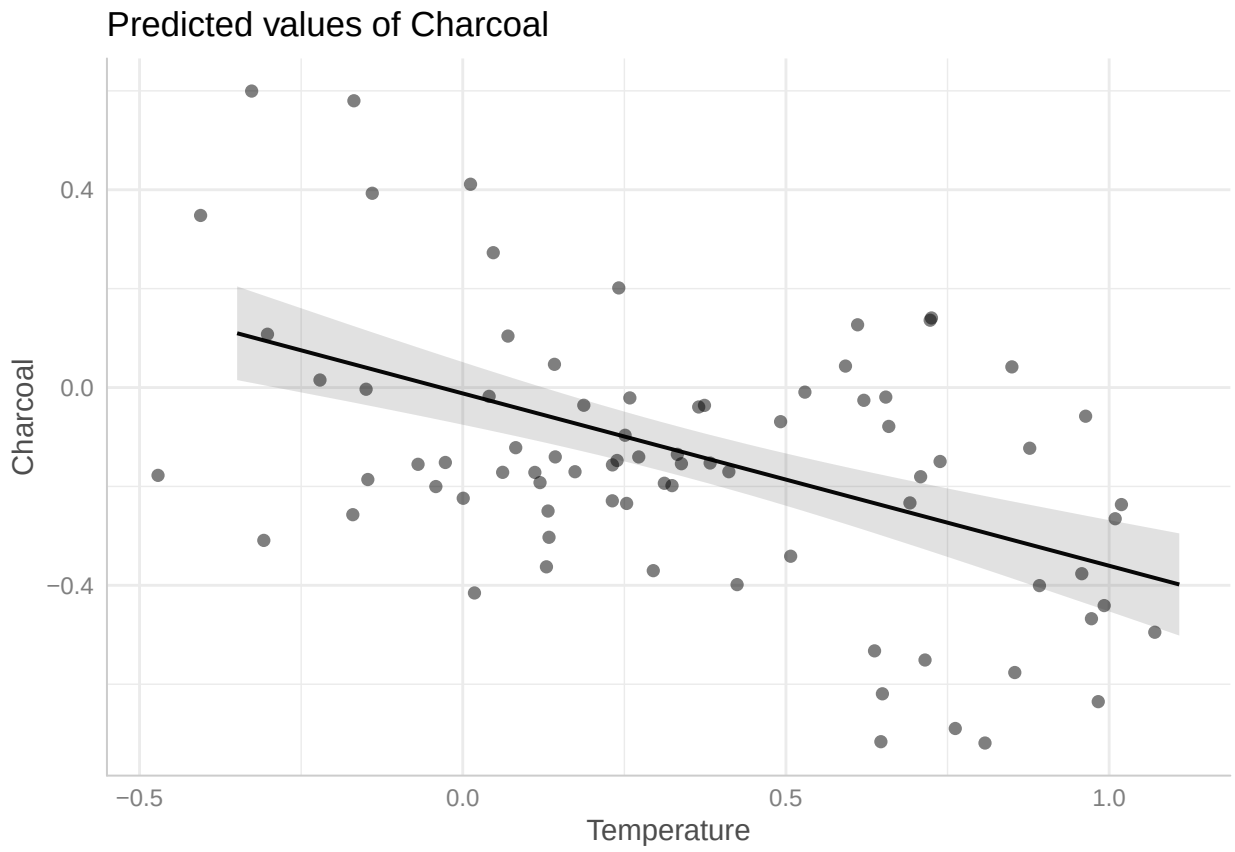




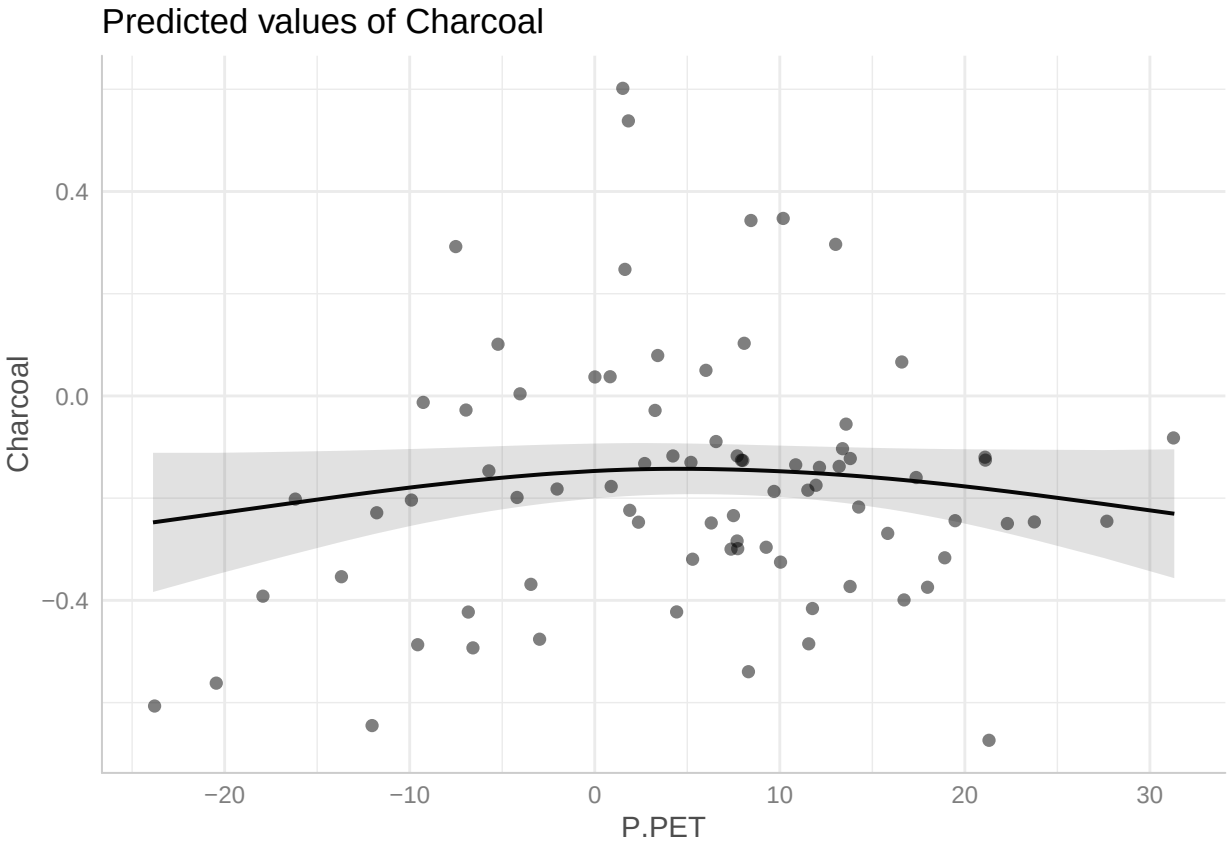


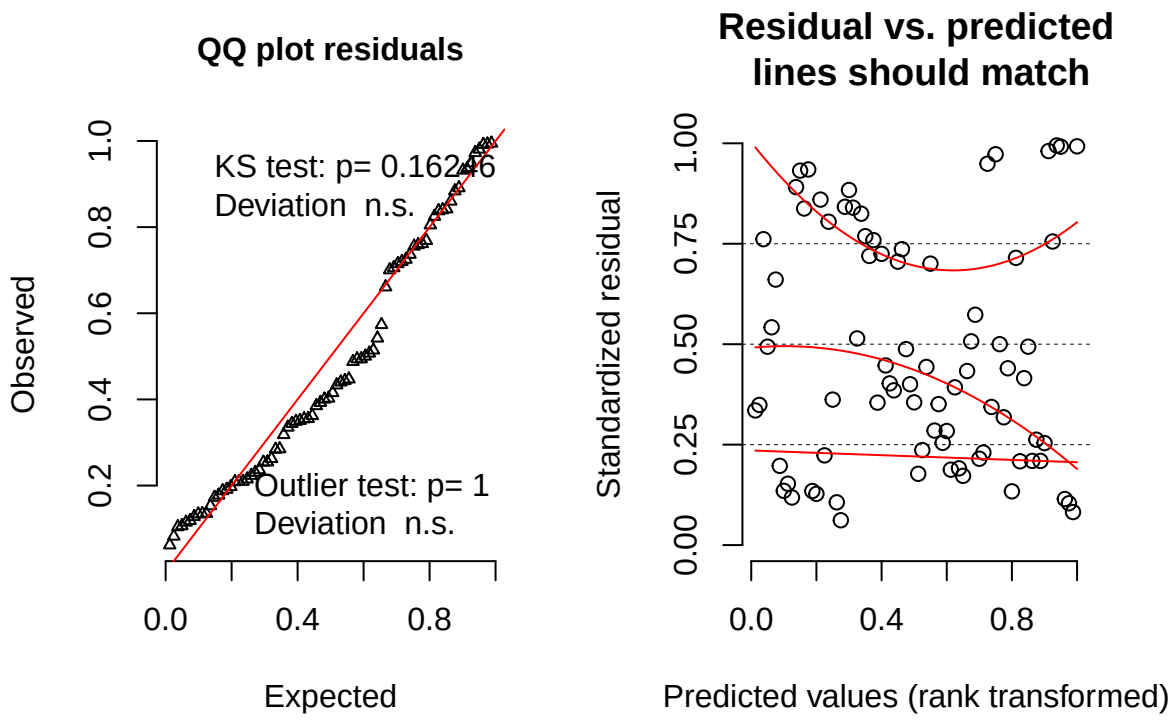

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 13 iterations.
## Gradient range [-4.524082e-06,8.624739e-06]
## (score -13.82682 & scale 0.03624344).
## Hessian positive definite, eigenvalue range [3.40692e-07,39.51739].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                   k'   edf k-index p-value
## s(Temperature) 9.000 0.971    0.85    0.06 .
## s(P.PET)       9.000 1.336    0.96    0.34
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
```

```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.02128  -7.592 6.31e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 0.9711      9 3.734 4.38e-08 ***
## s(P.PET)       1.3365      9 0.267    0.161
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.359   Deviance explained = 37.8%
## -REML = -13.827  Scale est. = 0.036243  n = 80
## [1] "Plotting predictions"
## $Temperature
```

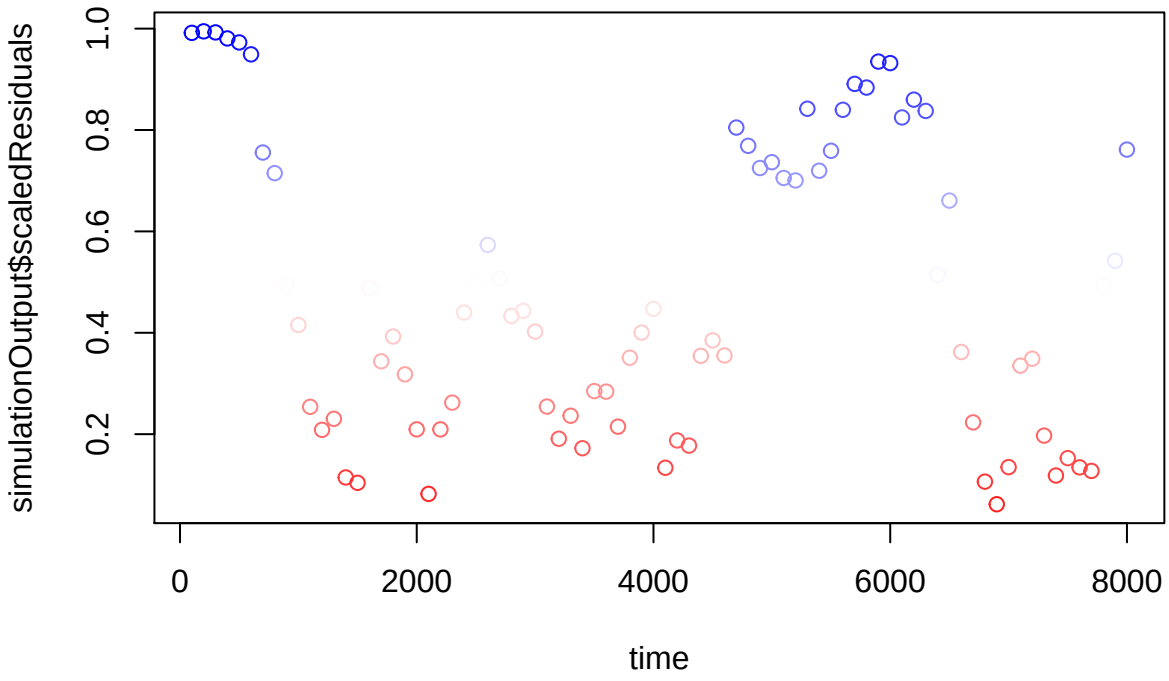



```
##
## $P.PET
```

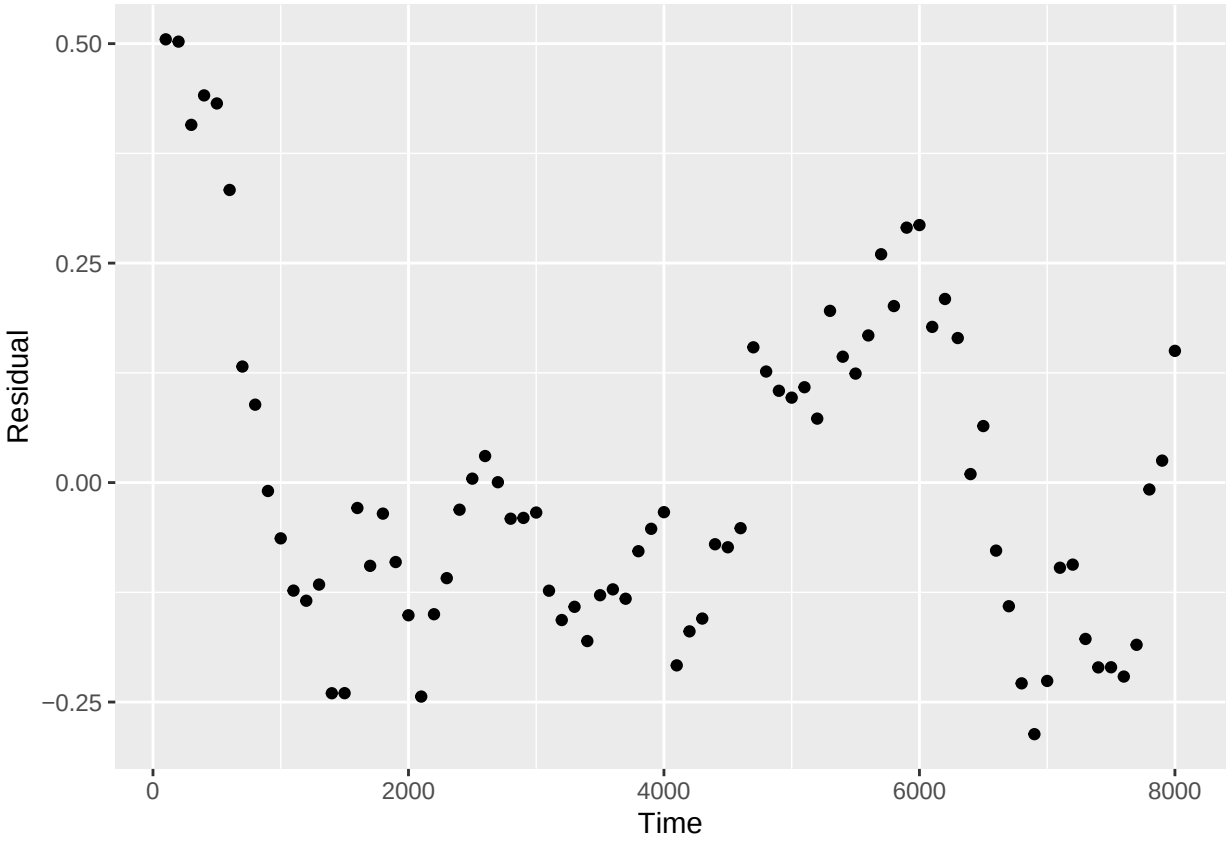

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



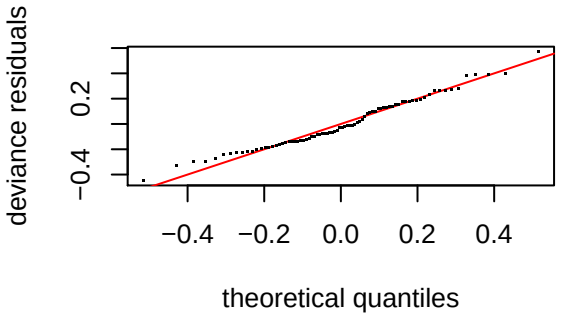

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.21525, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

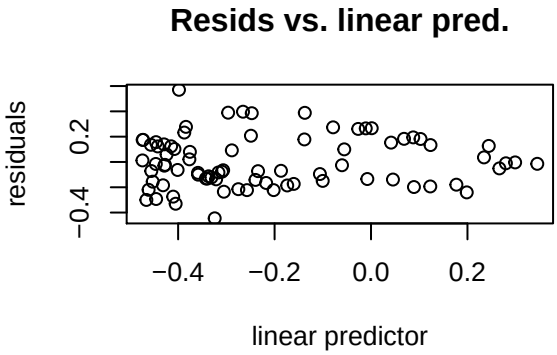


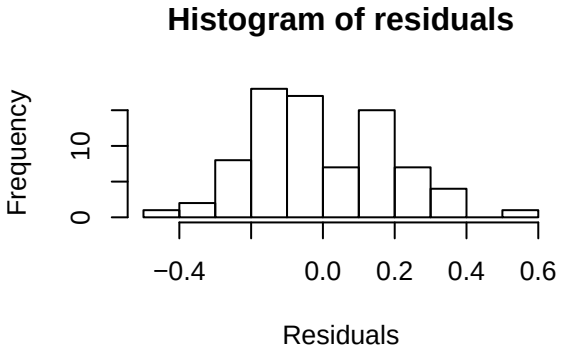
0 ka BP-8 ka BP climate data, Boreo-Nemoral ecoregion

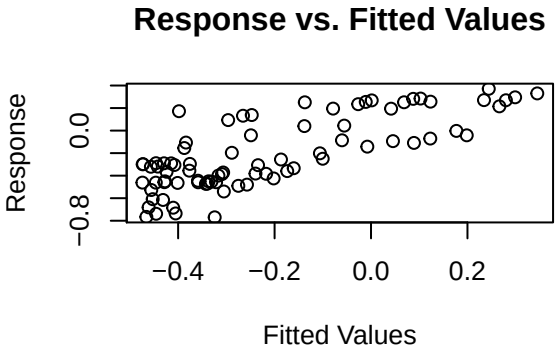
```
late.climate.boreonemoral <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET) , data = late.climate, i
```

```
## [1] "Checking GAM"
```



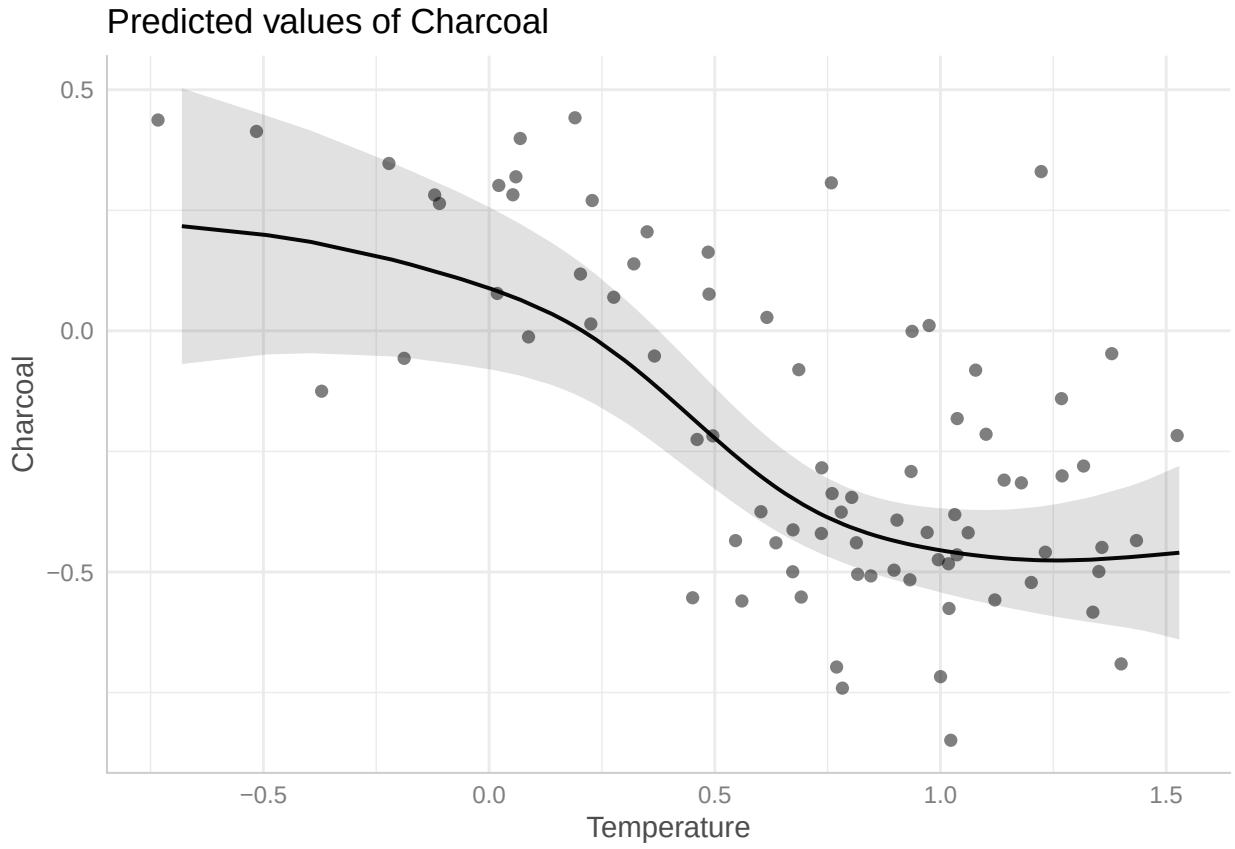




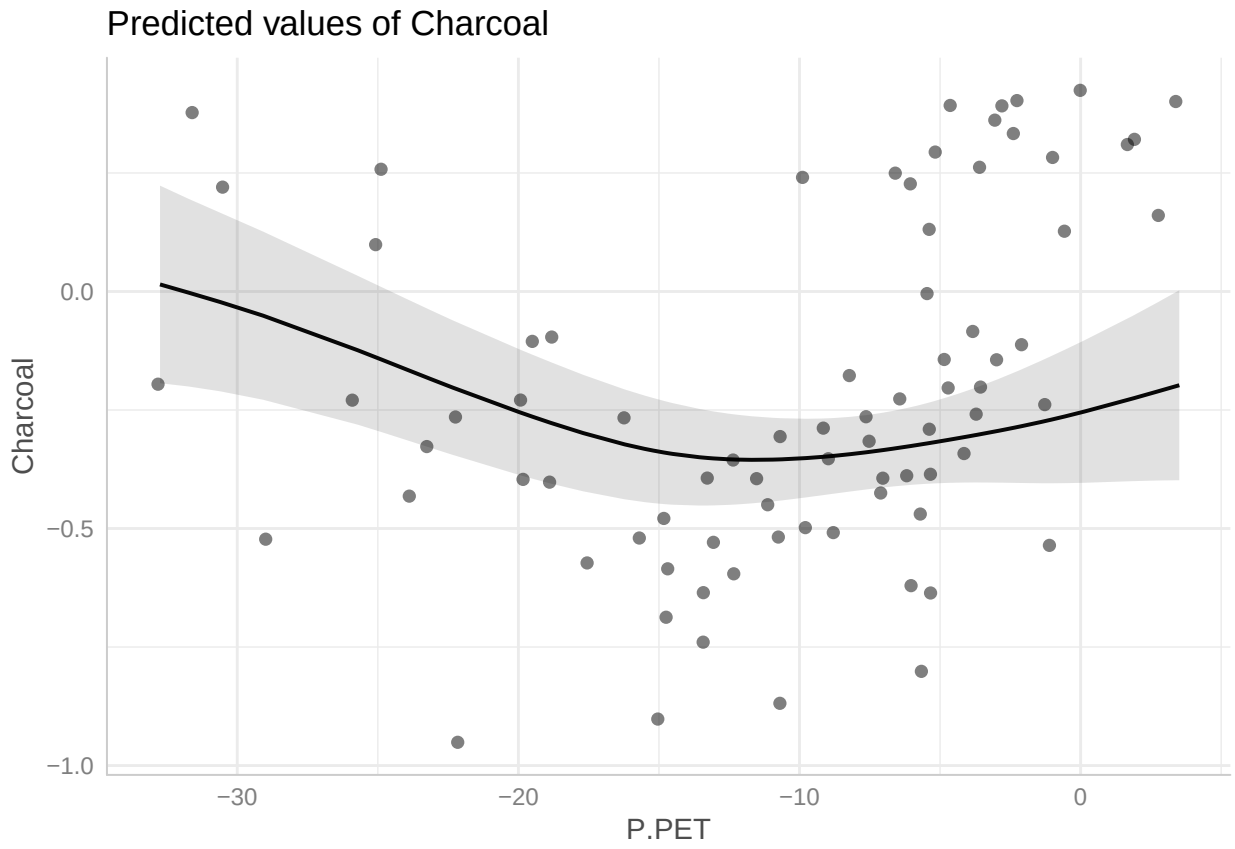


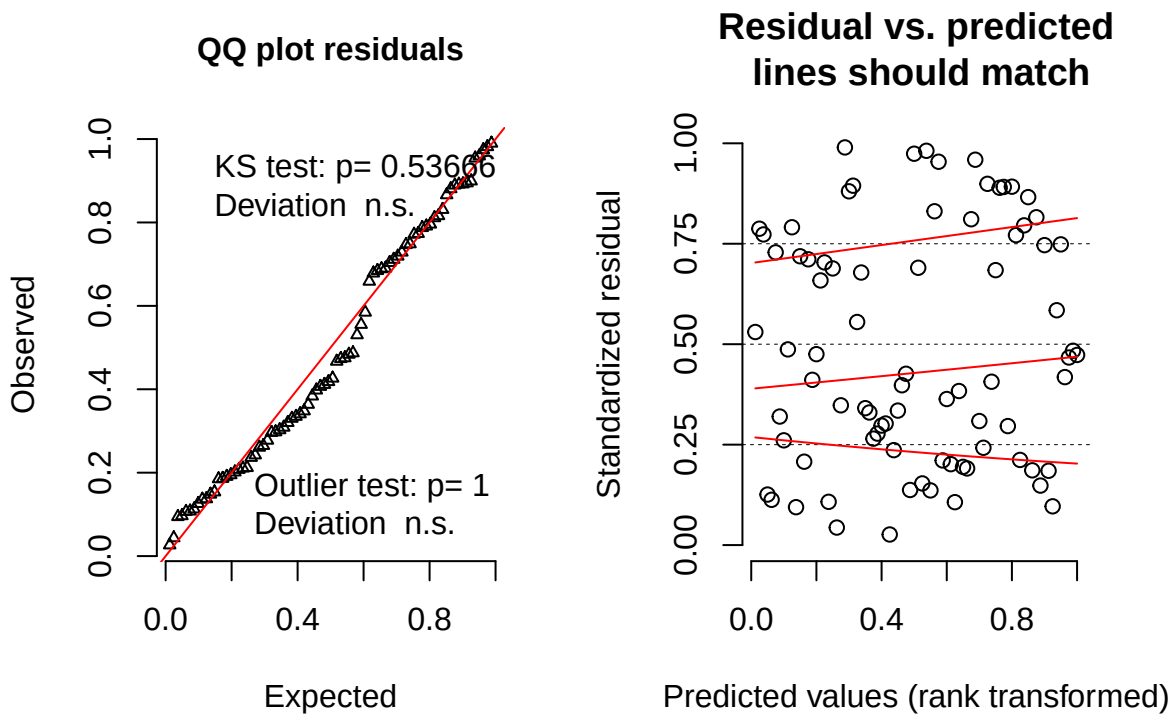

```
##
## Method: REML   Optimizer: outer newton
## full convergence after 10 iterations.
## Gradient range [-1.036606e-06,1.653724e-06]
## (score -3.844071 & scale 0.04253241).
## Hessian positive definite, eigenvalue range [6.457457e-07,39.59389].
## Model rank =  19 / 19
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                  k'  edf k-index p-value
## s(Temperature) 9.00 3.13    0.92    0.20
## s(P.PET)       9.00 2.17    1.14    0.86
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept) -0.21038    0.02306  -9.124 1.01e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df     F  p-value
## s(Temperature) 3.135      9 4.260 2.48e-08 ***
## s(P.PET)       2.165      9 1.495 0.000835 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.571   Deviance explained =   60%
## -REML = -3.8441  Scale est. = 0.042532  n = 80
## [1] "Plotting predictions"
## $Temperature
```

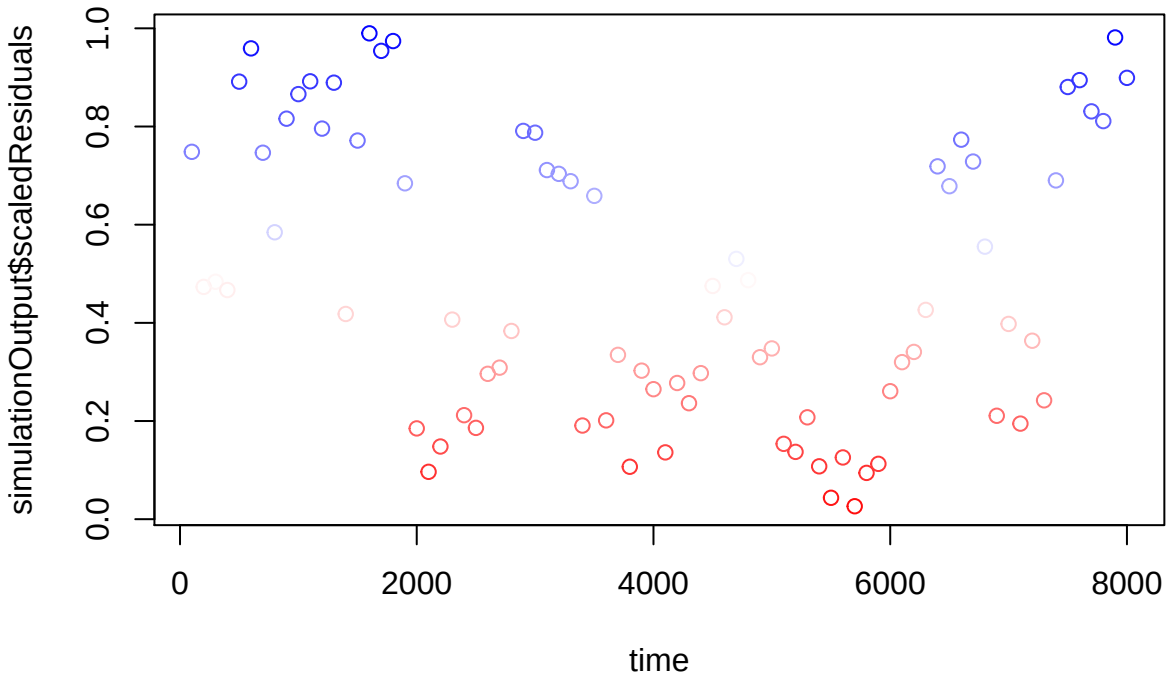



```
##
## $P.PET
```

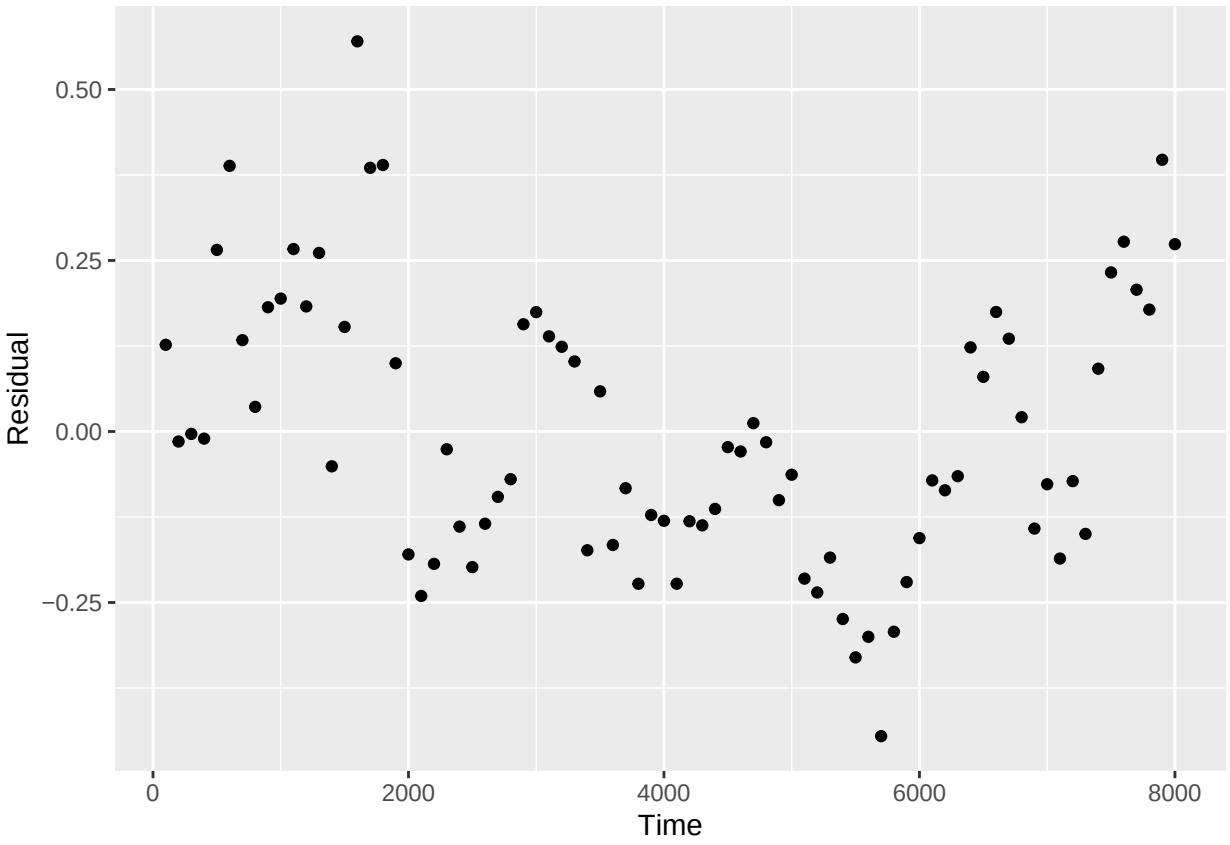

Predicted values of Charcoal
Charcoal
0.0
−0.5
−1.0
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```




```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.4694, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



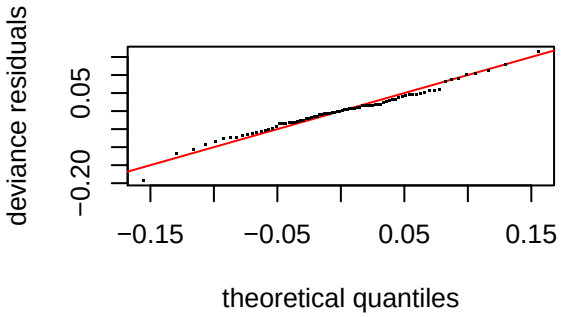
Climate and some land cover GAMs, after 8ka BP

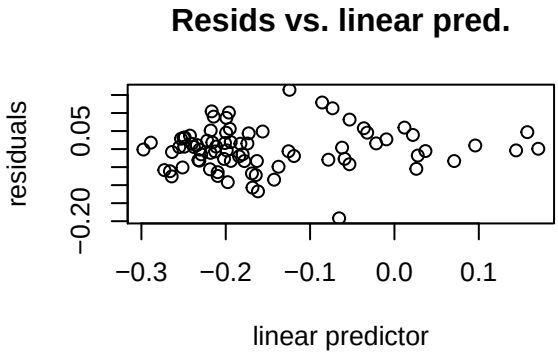
0 ka BP-8 ka BP, climate plus land cover

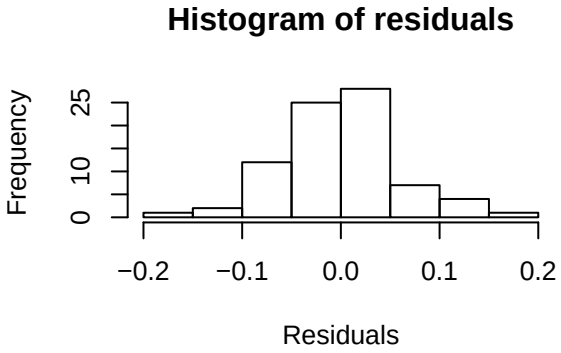
0 ka BP-8 ka BP climate plus total tree and arable cover, Continental ecoregion

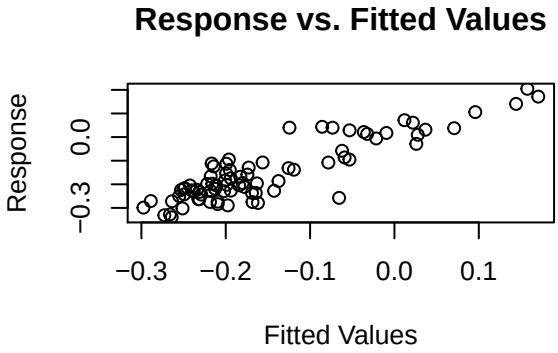
```
late.climate.cover.continental <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET)  + + s(Sumoftotalf
```

```
## [1] "Checking GAM"
```



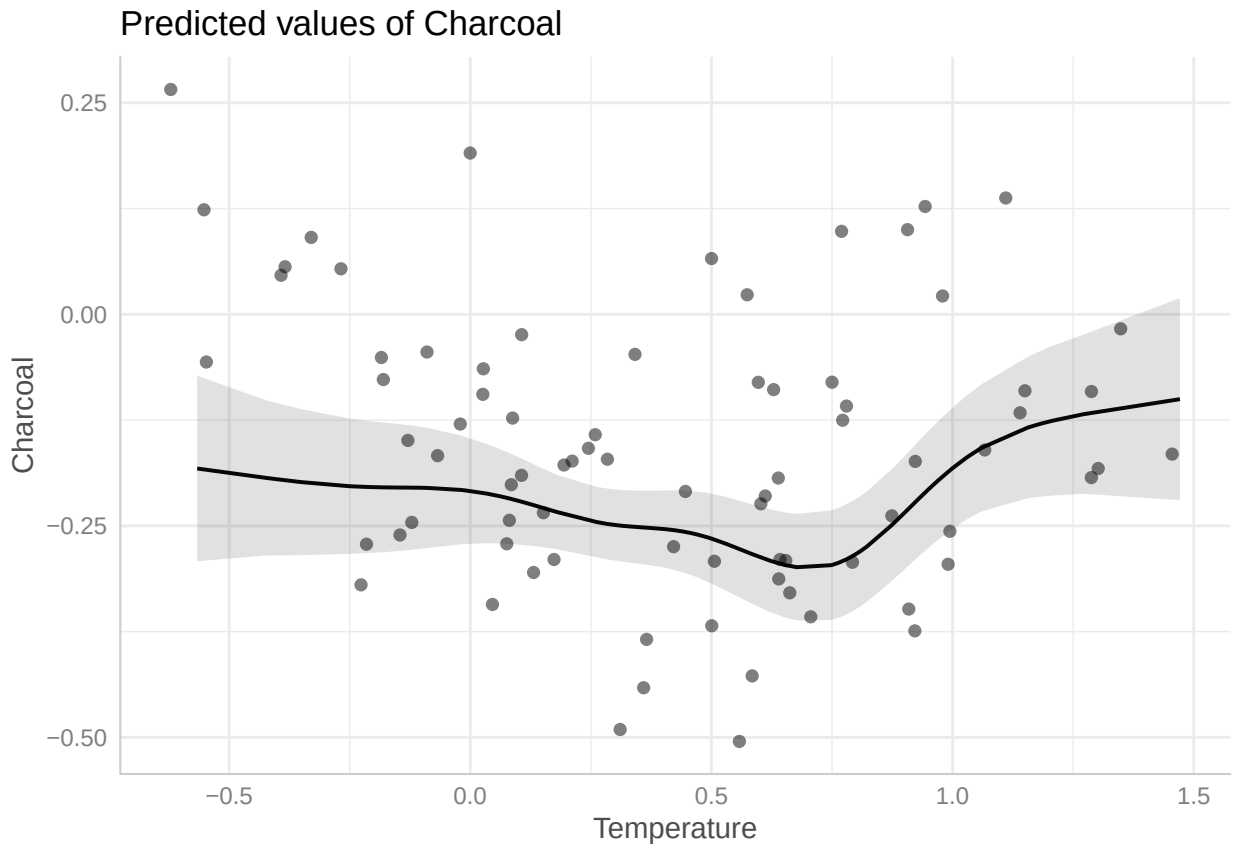




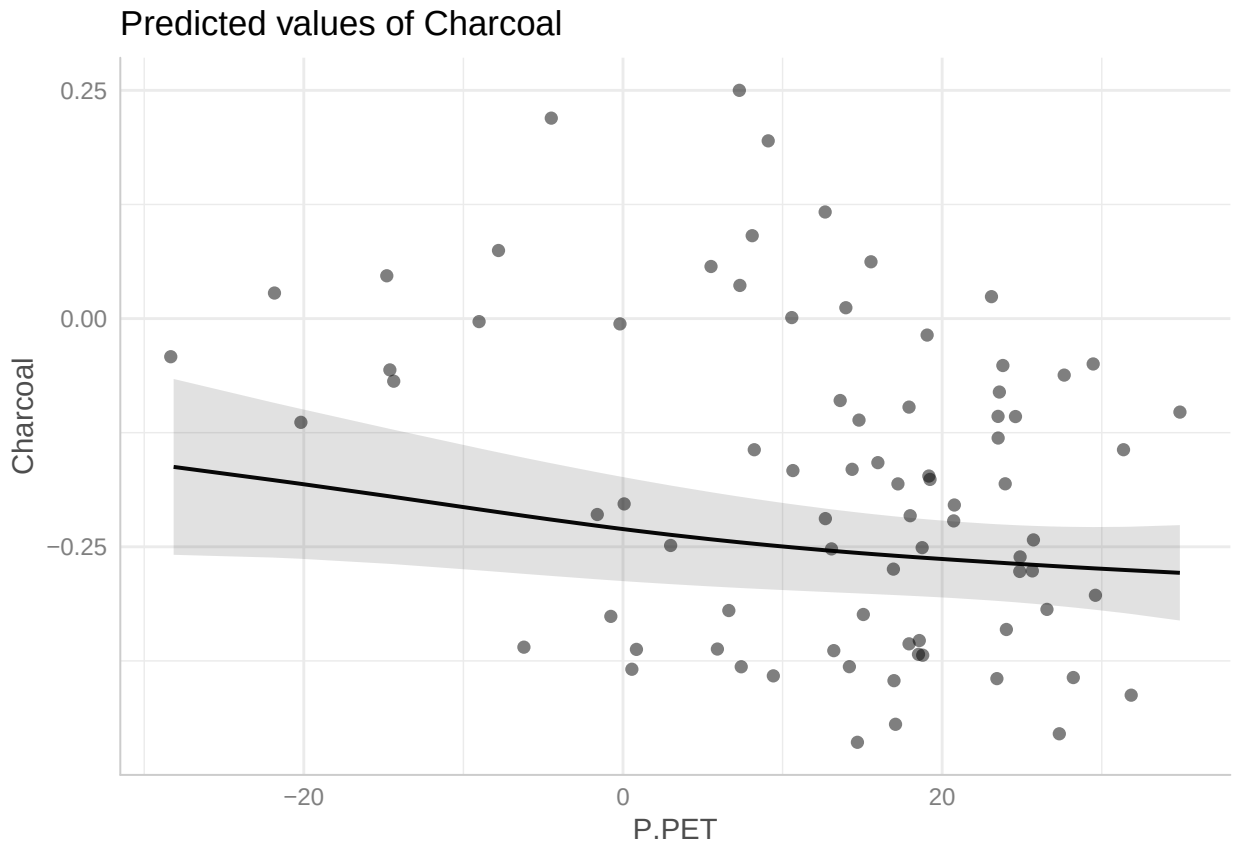



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-3.787913e-05,4.118093e-05]
## (score -90.10825 & scale 0.003874367).
## Hessian positive definite, eigenvalue range [3.547143e-08,39.74207].
## Model rank =  37 / 37
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                   k'   edf k-index p-value
## s(Temperature)                 9.000 5.275    1.04   0.530
## s(P.PET)                       9.000 1.335    1.05   0.600
## s(SumoftotalforestclosedtoLCCs) 9.000 2.937    0.85   0.080 .
## s(Arabledisturbedlandin)       9.000 0.683    0.72   0.005 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
```

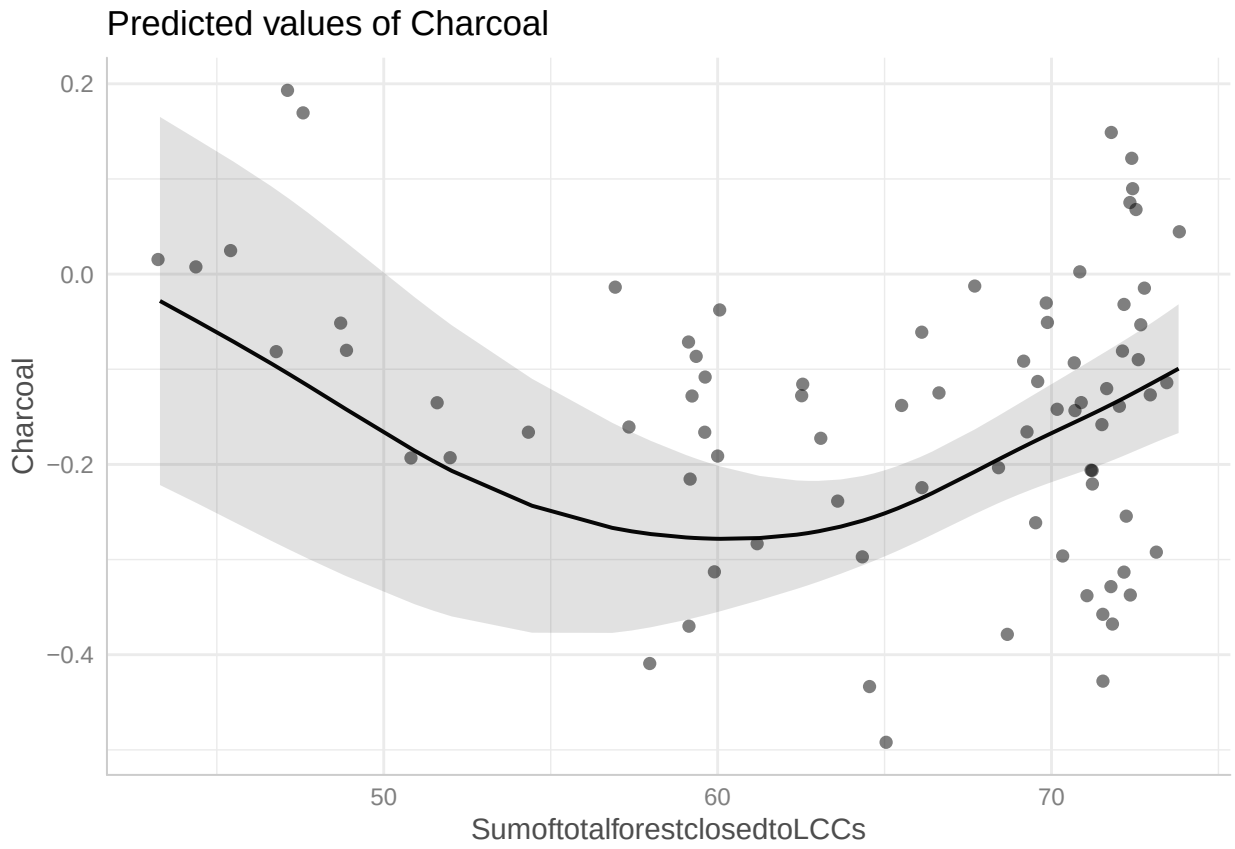
```
## Charcoal ~ s(Temperature) + s(P.PET) + +s(SumoftotalforestclosedtoLCCs) +
##     s(Arabledisturbedlandin)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.006959  -21.47   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df     F  p-value
## s(Temperature)                 5.2752      9 3.119 3.68e-05 ***
## s(P.PET)                       1.3347      9 0.622   0.0181 *
## s(SumoftotalforestclosedtoLCCs) 2.9374      9 4.468 1.49e-09 ***
## s(Arabledisturbedlandin)       0.6834      9 0.240   0.0297 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.765   Deviance explained = 79.6%
## -REML = -90.108  Scale est. = 0.0038744  n = 80
## [1] "Plotting predictions"
## $Temperature
```



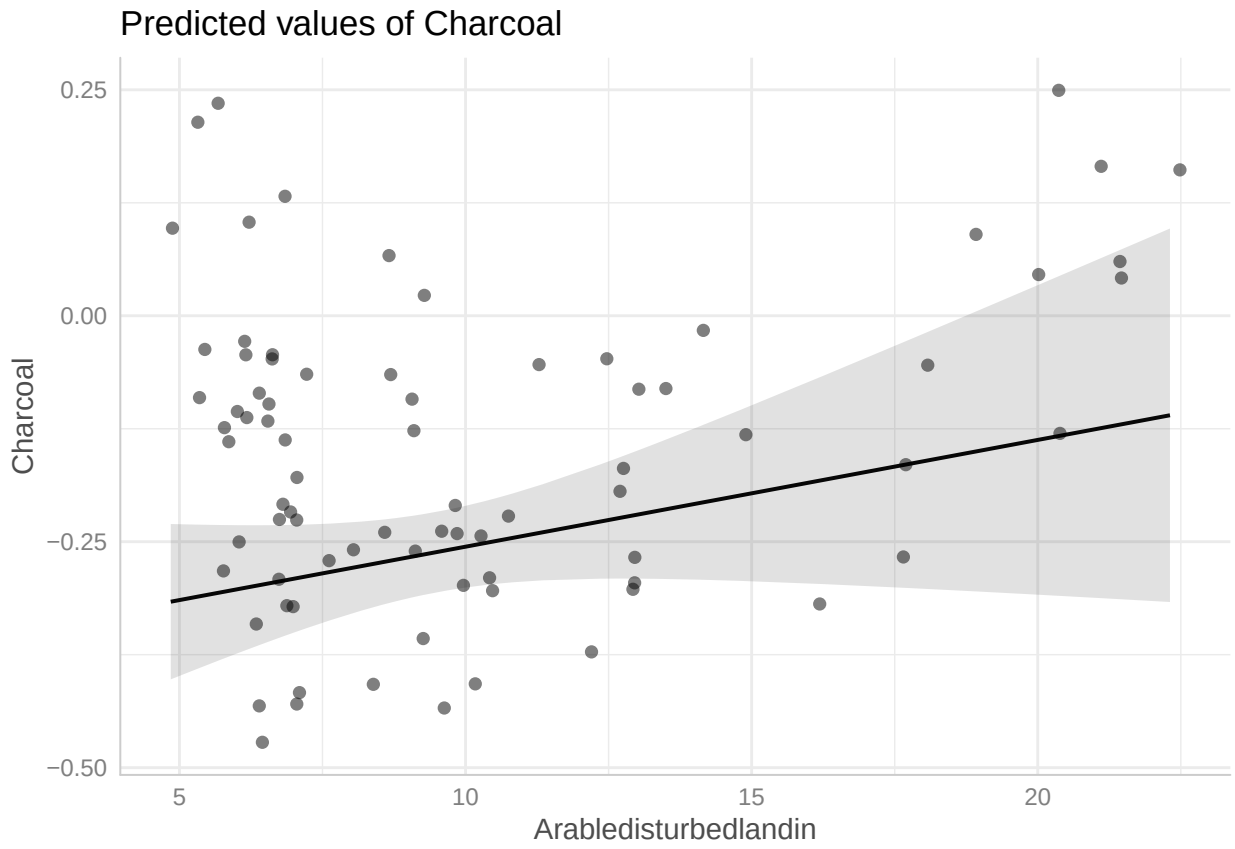

```
##
## $P.PET
```

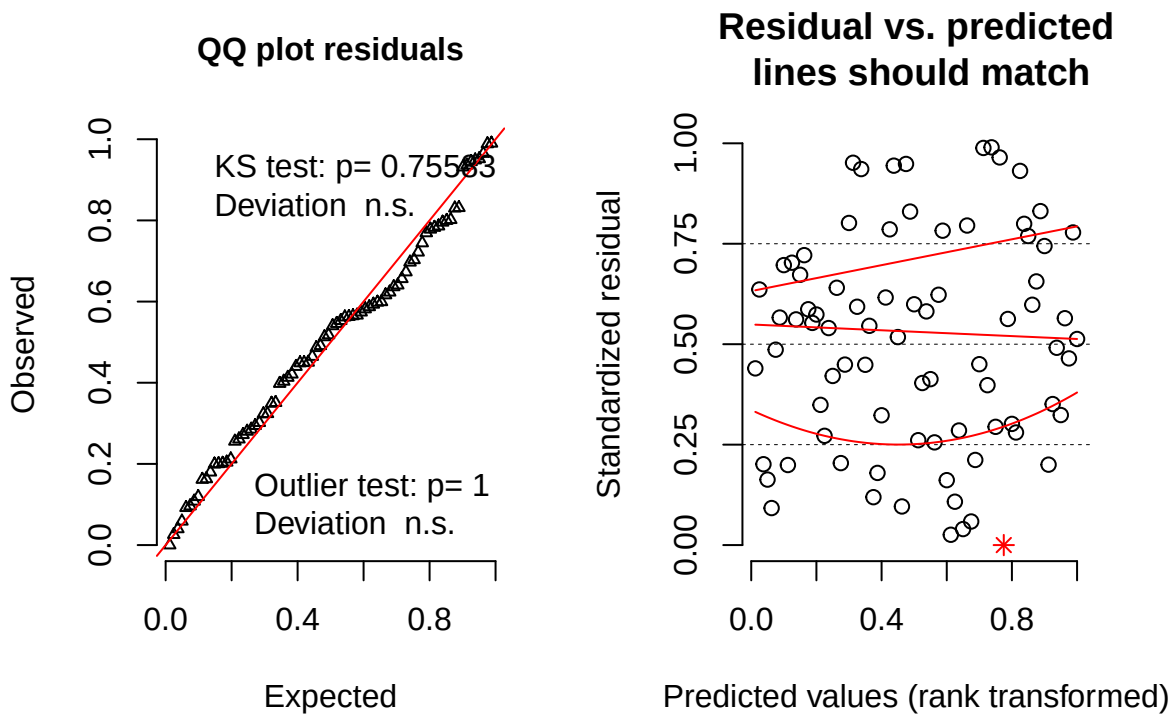



```
##
## $SumoftotalforestclosedtoLCCs
```

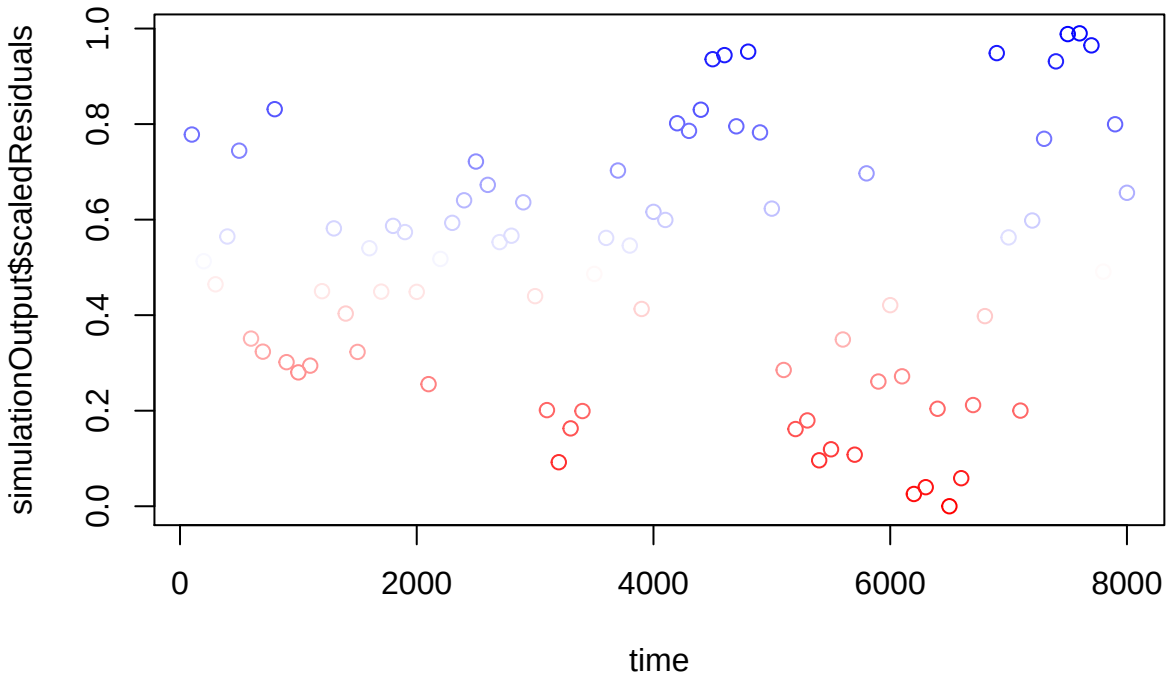



```
##
## $Arabledisturbedlandin
```

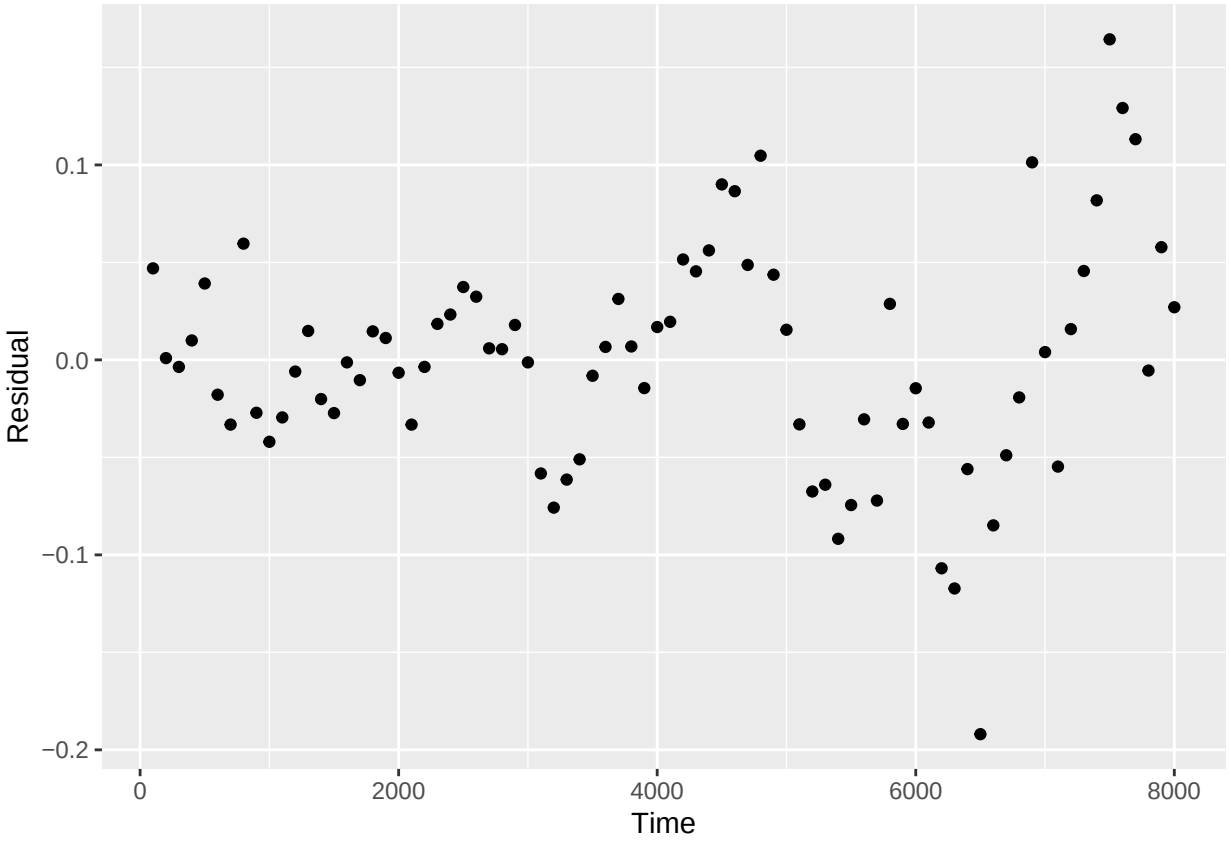

Predicted values of Charcoal
0.25
0.00
−0.25
−0.50
Charcoal
5
10
15
20
Arabledisturbedlandin




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



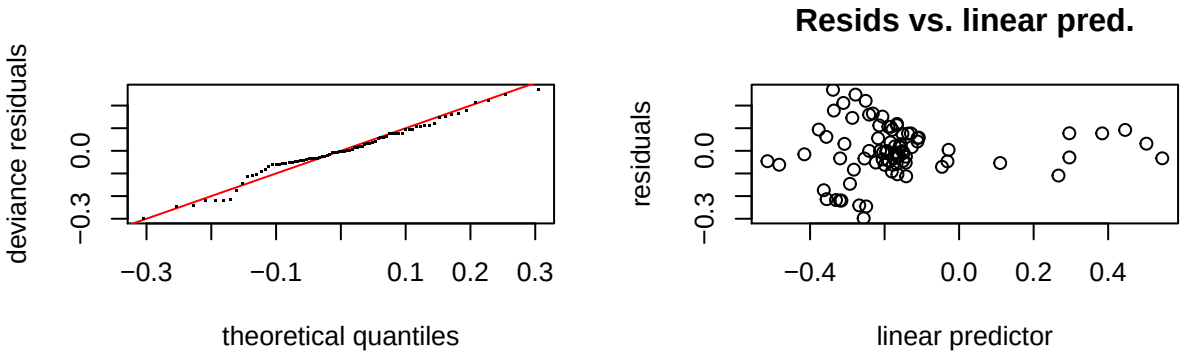

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.66546, p-value = 5.56e-12
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

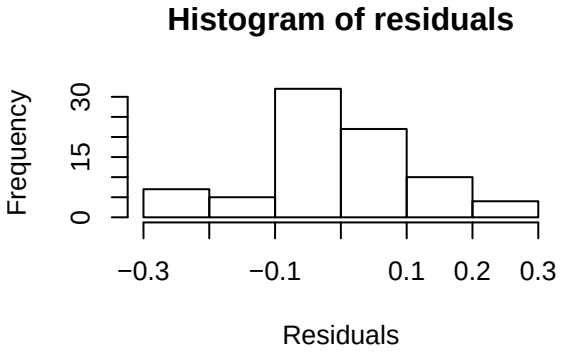


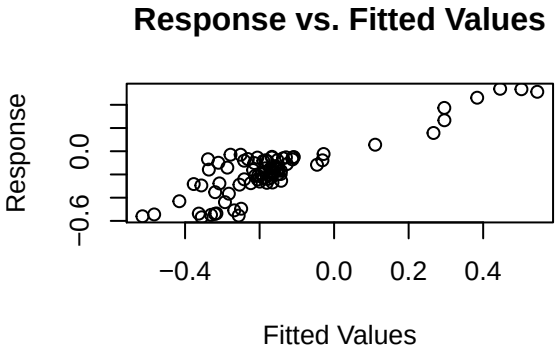
0 ka BP-8 ka BP climate plus total tree and arable cover, Atlantic ecoregion

```
late.climate.cover.atlantic <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET)  + + s(Sumoftotalfores
```

```
## [1] "Checking GAM"
```

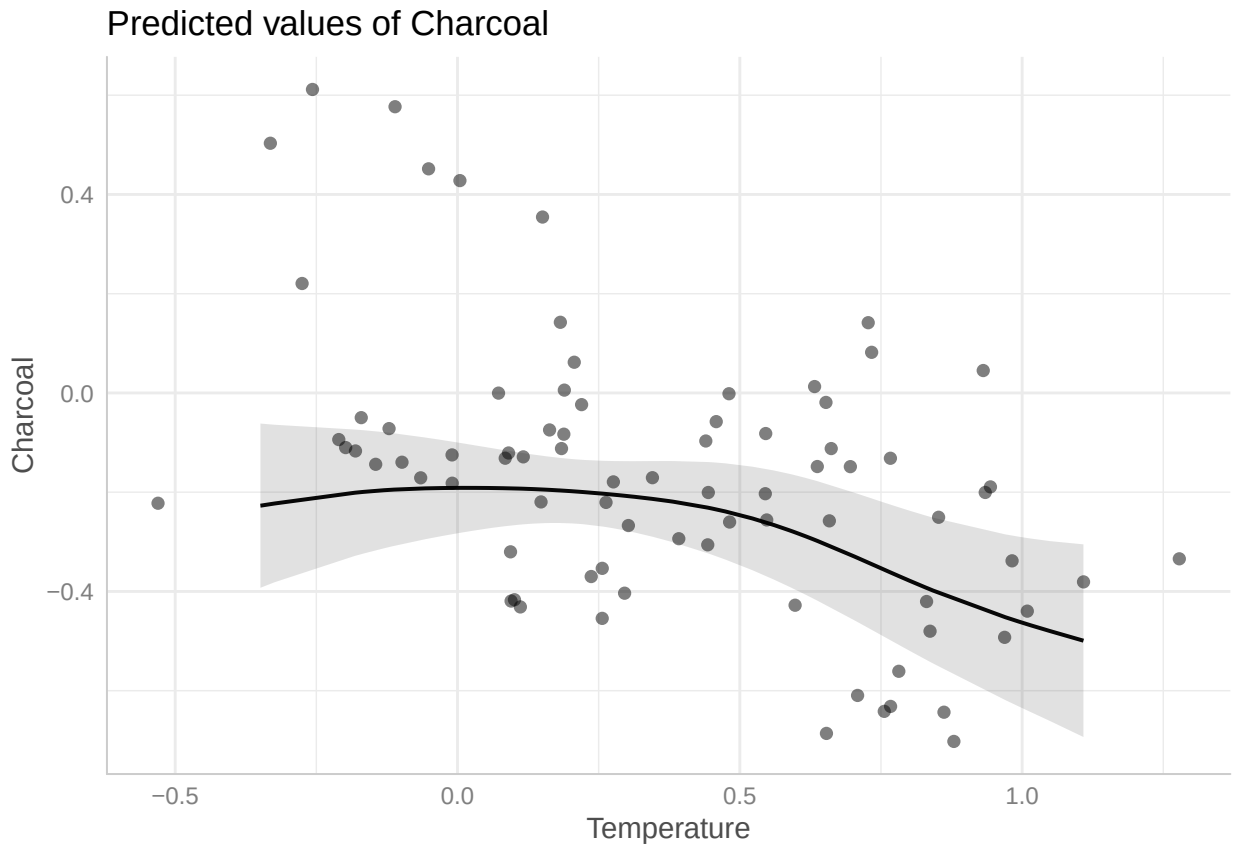




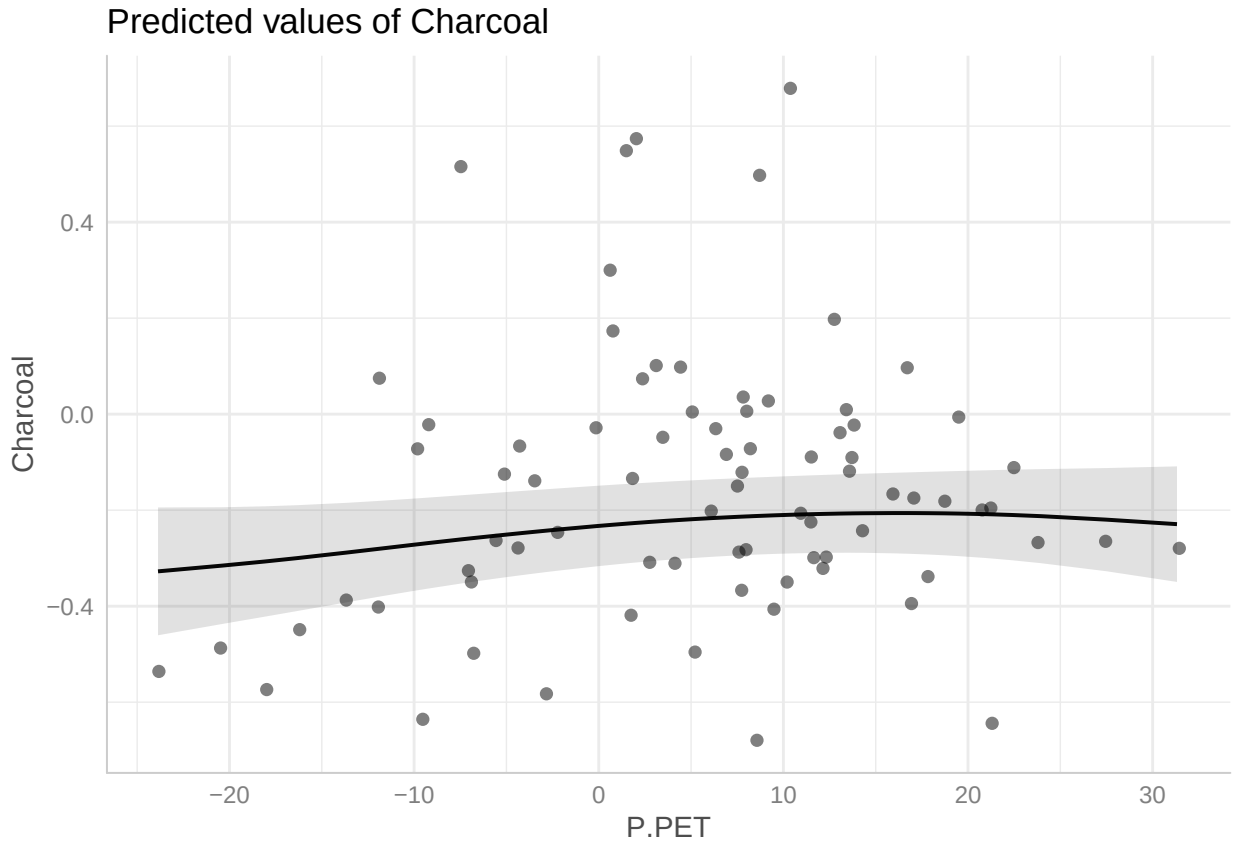



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 17 iterations.
## Gradient range [-9.453484e-06,5.542101e-06]
## (score -39.1279 & scale 0.01488095).
## Hessian positive definite, eigenvalue range [9.453359e-06,39.64709].
## Model rank =  37 / 37
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                    k'   edf k-index p-value
## s(Temperature)                  9.000 2.366    1.33    0.99
## s(P.PET)                        9.000 1.436    1.09    0.71
## s(SumoftotalforestclosedtoLCCs) 9.000 0.784    1.29    0.99
## s(Arabledisturbedlandin)        9.000 4.621    0.70  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
```

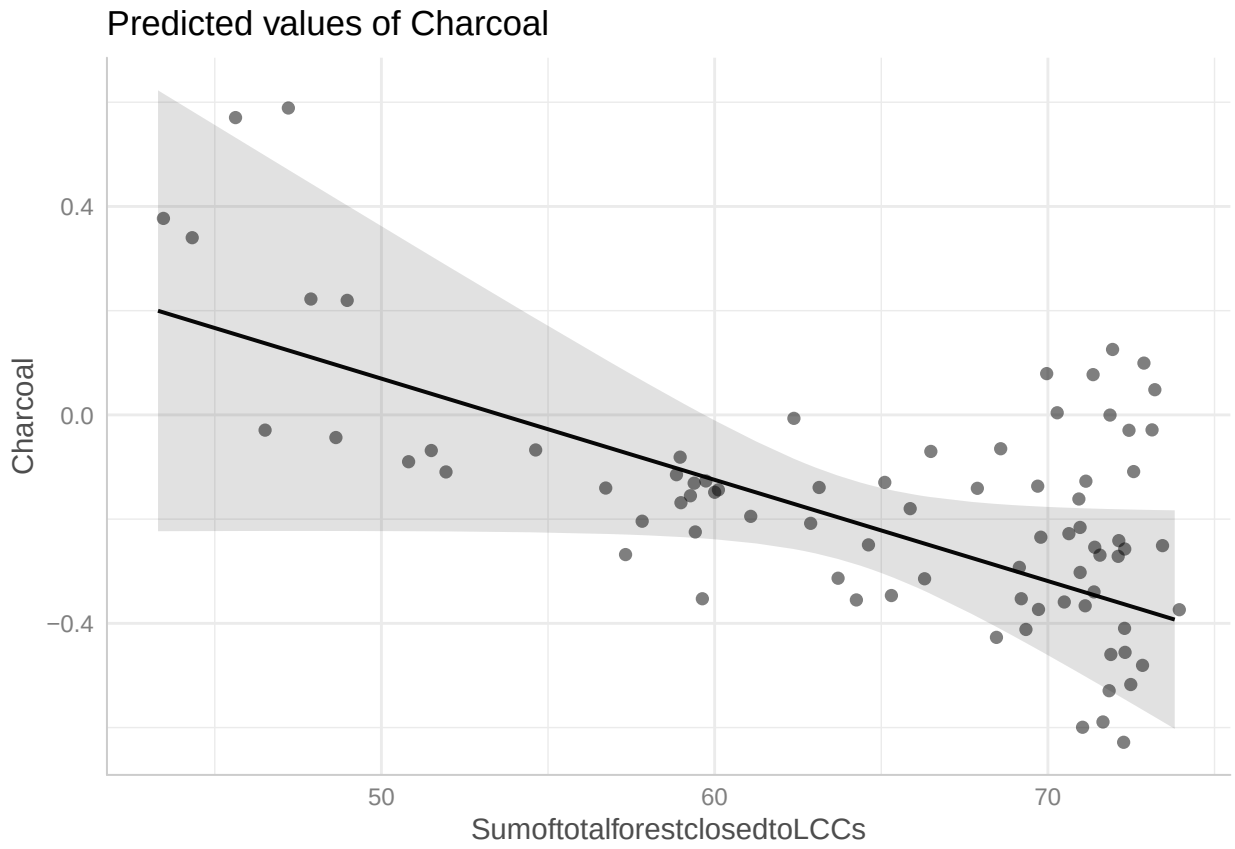
```
## Charcoal ~ s(Temperature) + s(P.PET) + +s(SumoftotalforestclosedtoLCCs) +
##     s(Arabledisturbedlandin)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.01364  -11.85   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df     F  p-value
## s(Temperature)                 2.3662      9 1.395 0.000888 ***
## s(P.PET)                       1.4358      9 0.469 0.044000 *
## s(SumoftotalforestclosedtoLCCs) 0.7841      9 0.404 0.018360 *
## s(Arabledisturbedlandin)       4.6207      9 5.708 6.39e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.737   Deviance explained = 76.7%
## -REML = -39.128  Scale est. = 0.014881  n = 80
## [1] "Plotting predictions"
## $Temperature
```



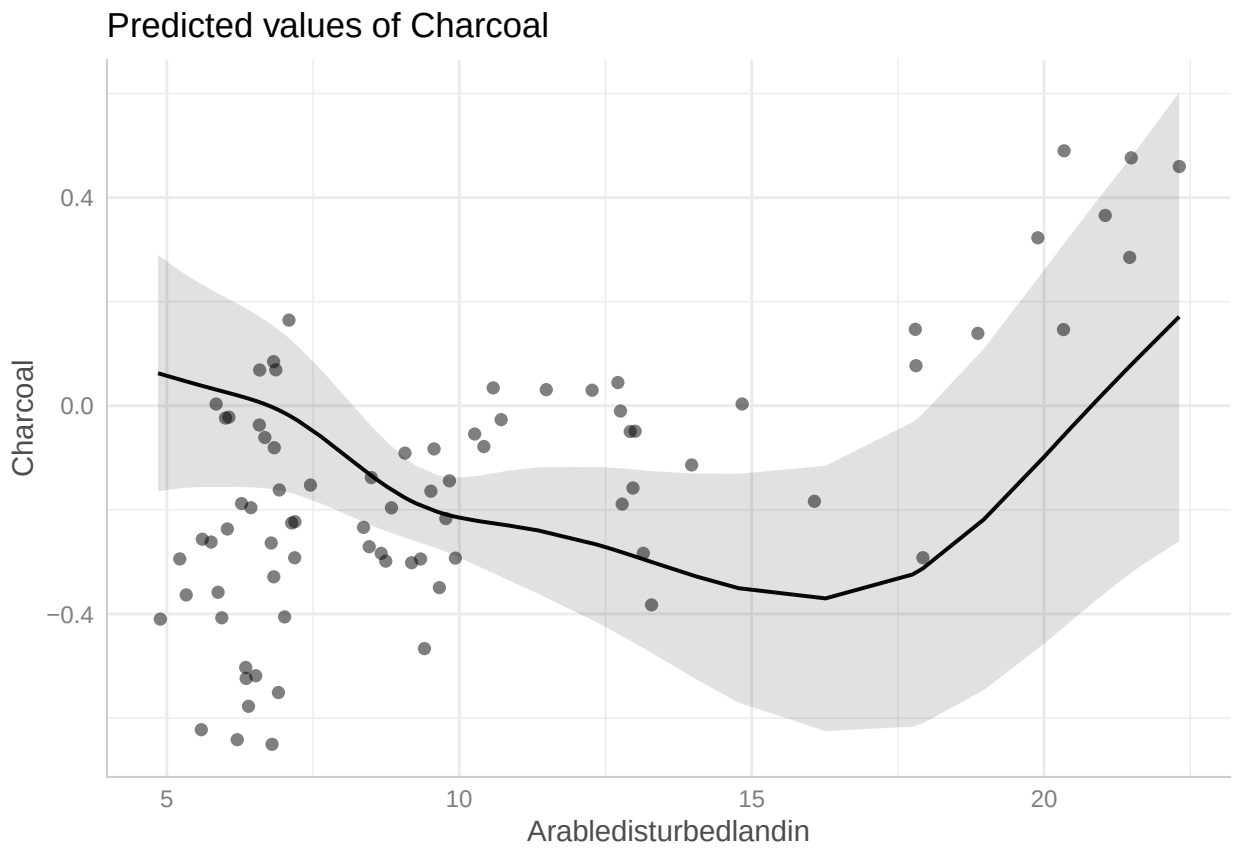

```
##
## $P.PET
```



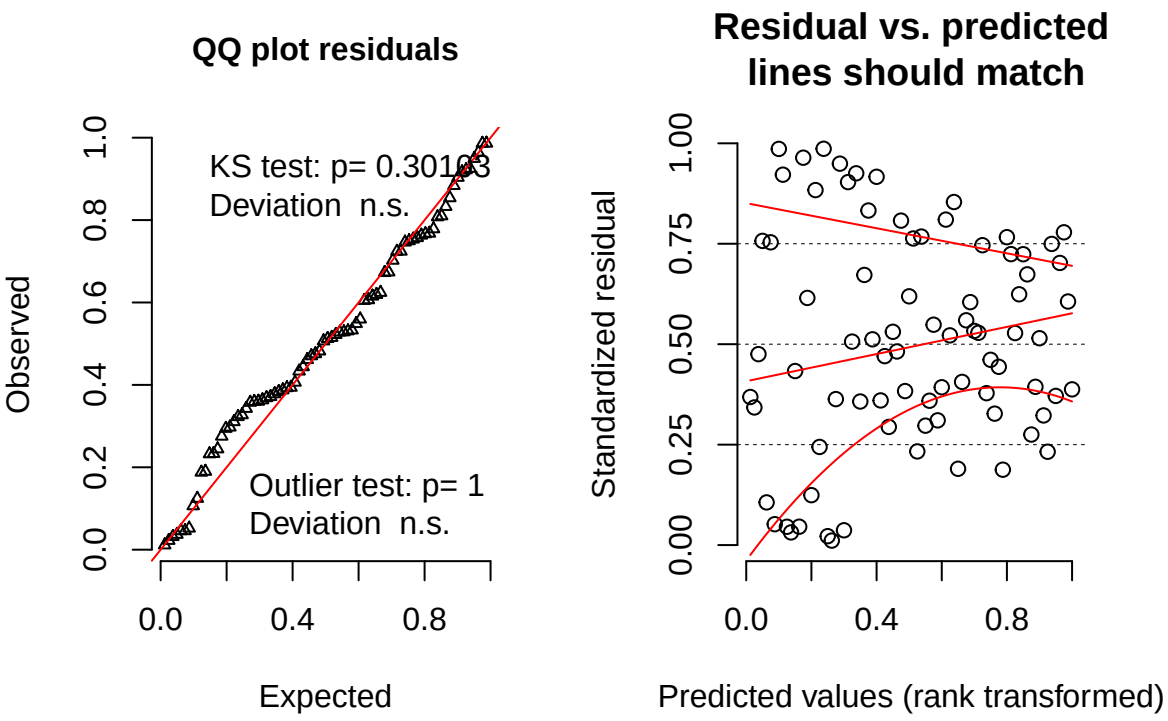

```
##
## $SumoftotalforestclosedtoLCCs
```



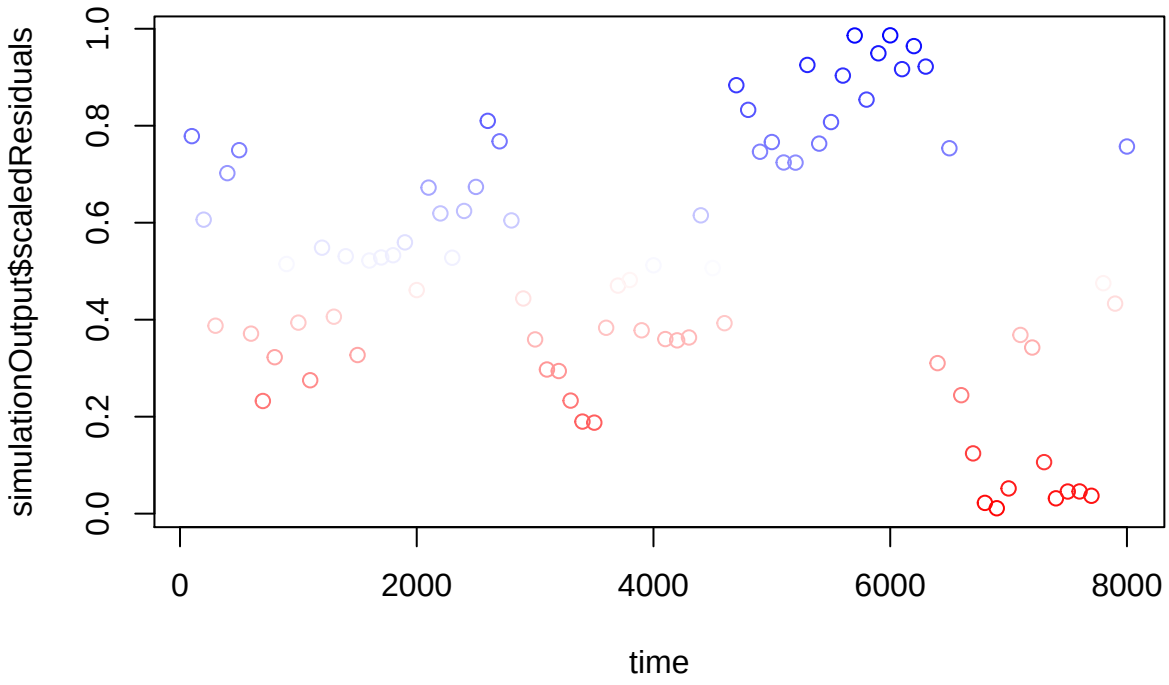

```
##
## $Arabledisturbedlandin
```


Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
5
10
15
20
Arabledisturbedlandin

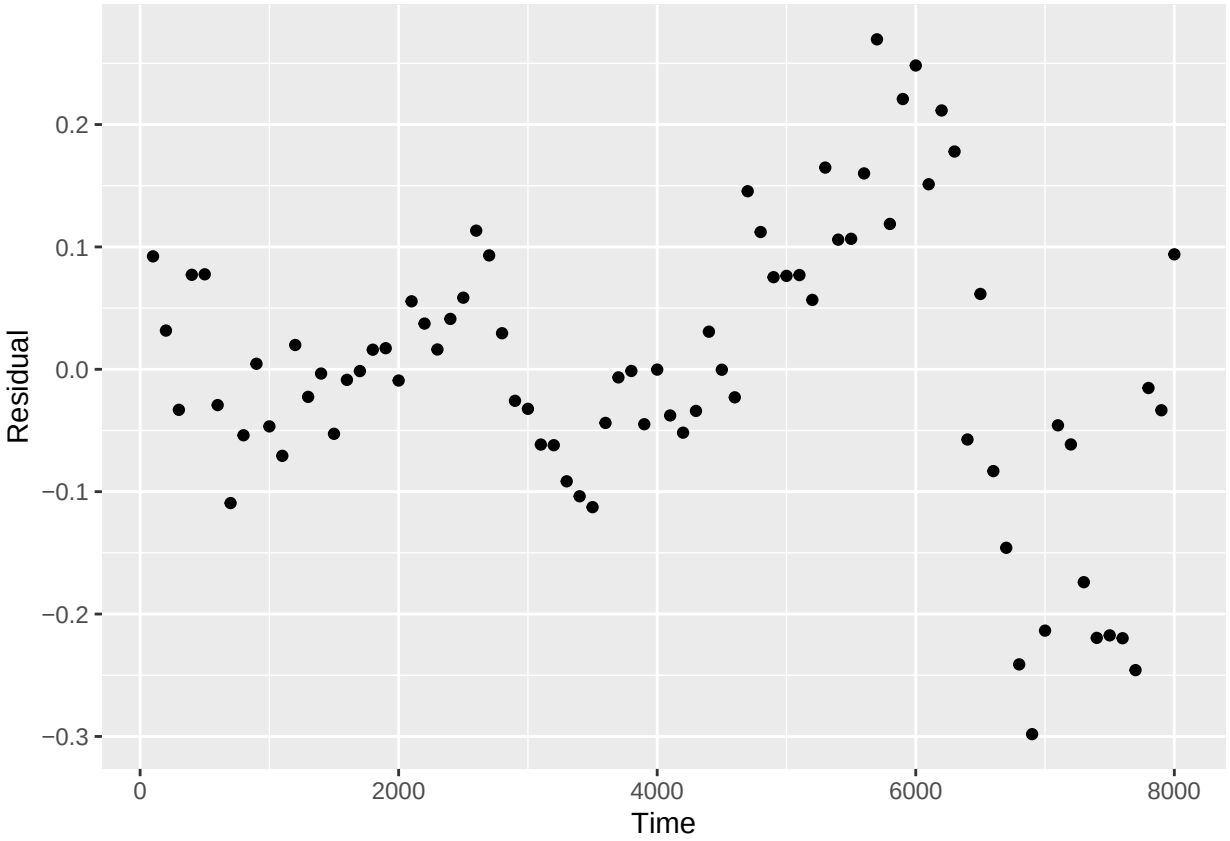
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



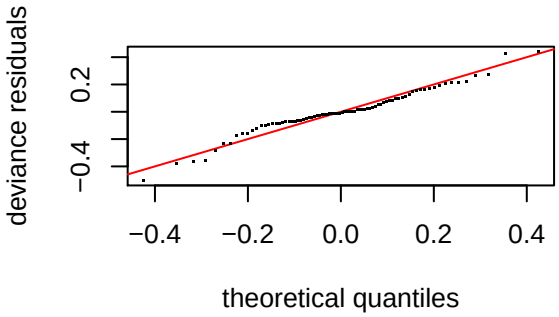

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.47025, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

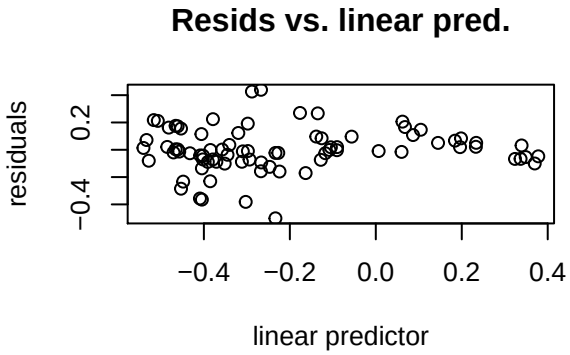


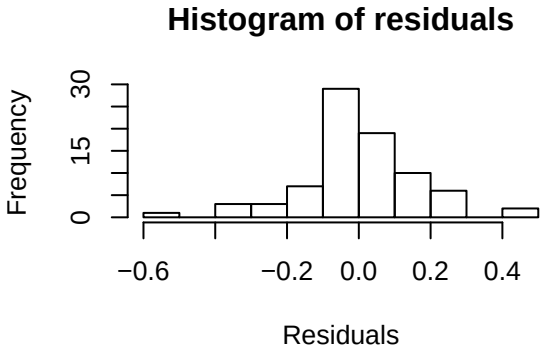
0 ka BP-8 ka BP climate plus total tree and arable cover, Boreo-Nemoral ecoregion

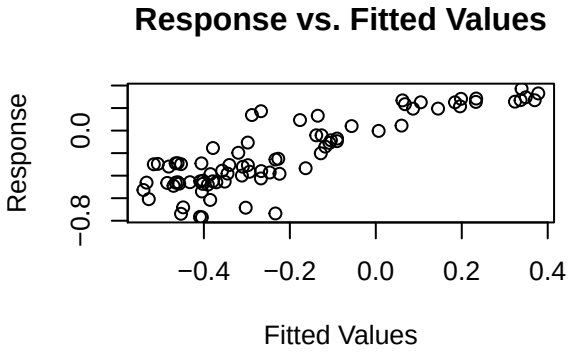
```
late.climate.cover.boreonemoral <- charcoal.gam(Charcoal ~ s(Temperature)  + s(P.PET)  + + s(Sumoftotali
```

```
## [1] "Checking GAM"
```



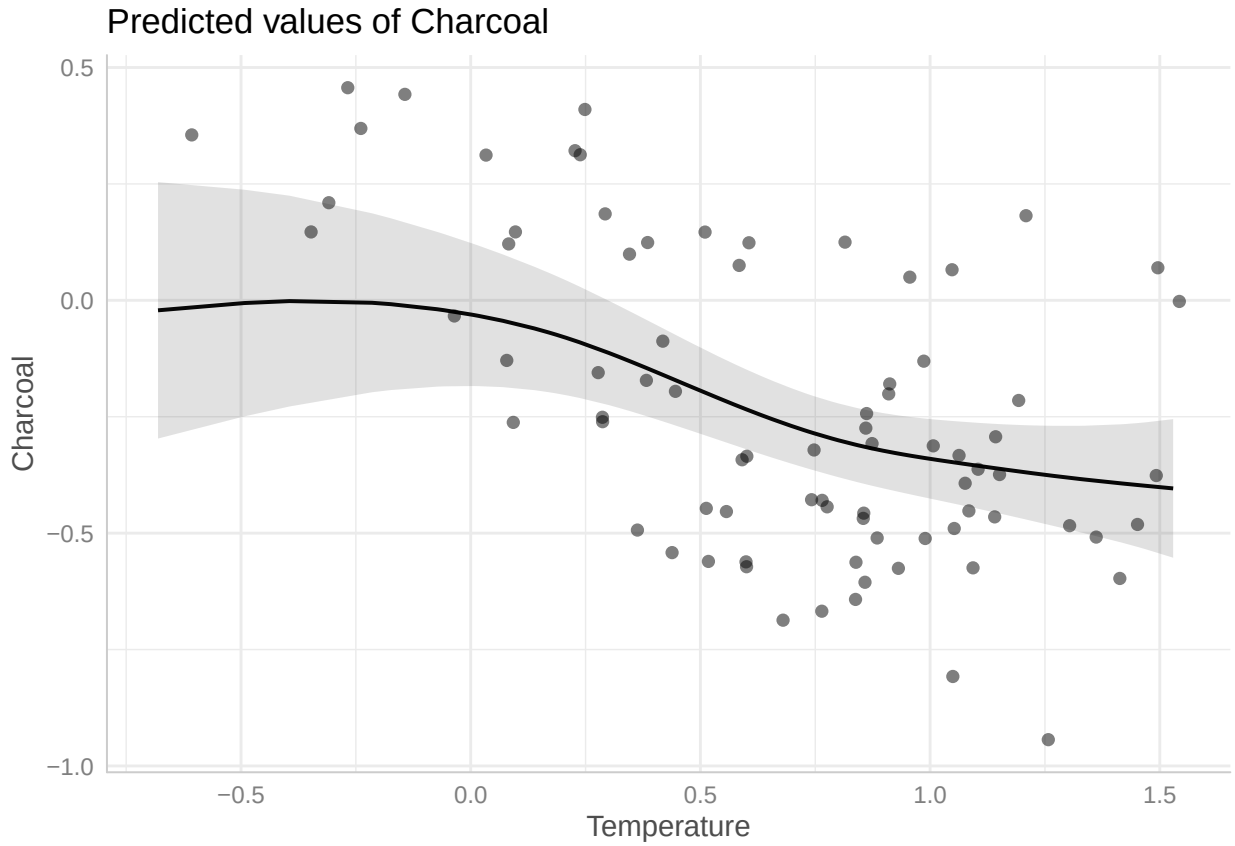




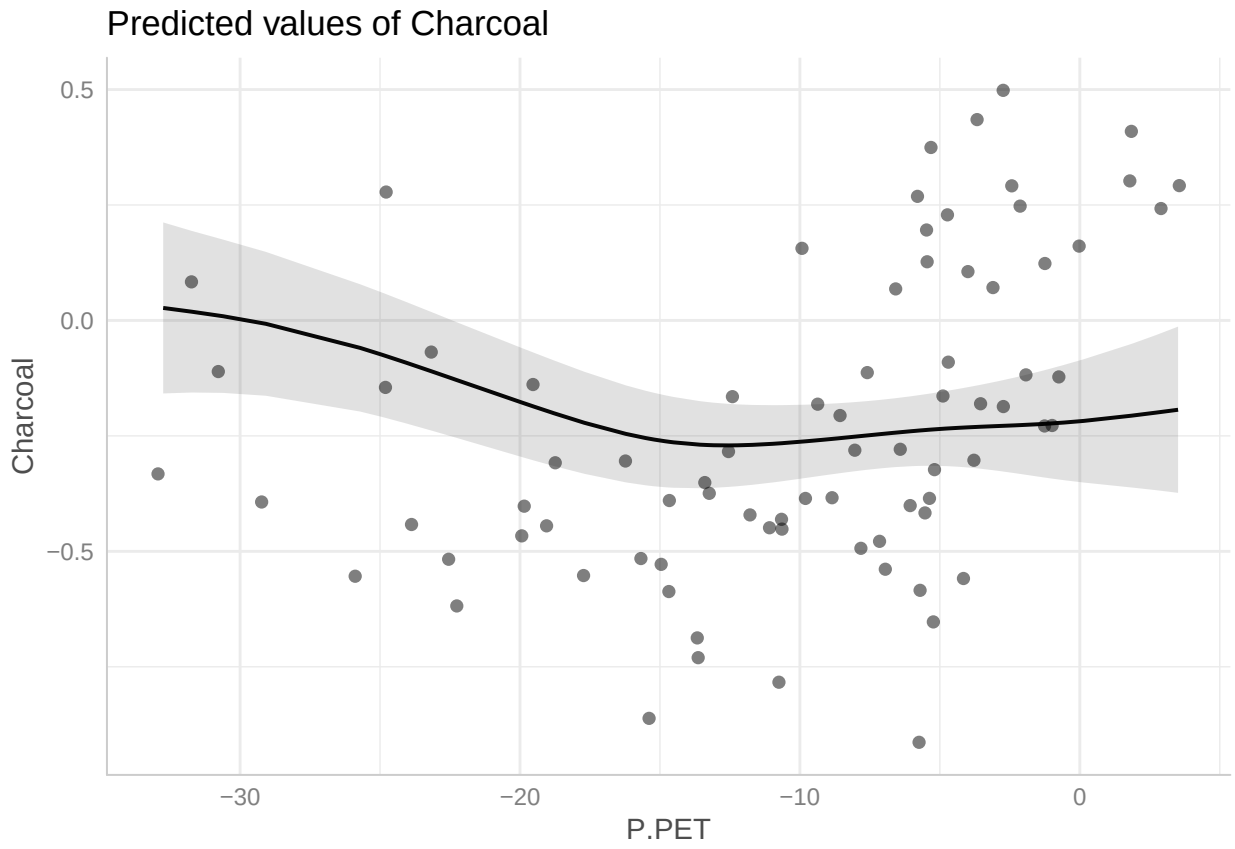



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-6.582047e-06,1.318079e-05]
## (score -16.27728 & scale 0.0289127).
## Hessian positive definite, eigenvalue range [4.742891e-07,39.6105].
## Model rank =  37 / 37
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                    k'   edf k-index p-value
## s(Temperature)                  9.000 2.351    0.98    0.39
## s(P.PET)                        9.000 2.477    1.11    0.77
## s(SumoftotalforestclosedtoLCCs) 9.000 0.853    0.90    0.17
## s(Arabledisturbedlandin)        9.000 2.269    1.06    0.66
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Temperature) + s(P.PET) + +s(SumoftotalforestclosedtoLCCs) +
##     s(Arabledisturbedlandin)
```

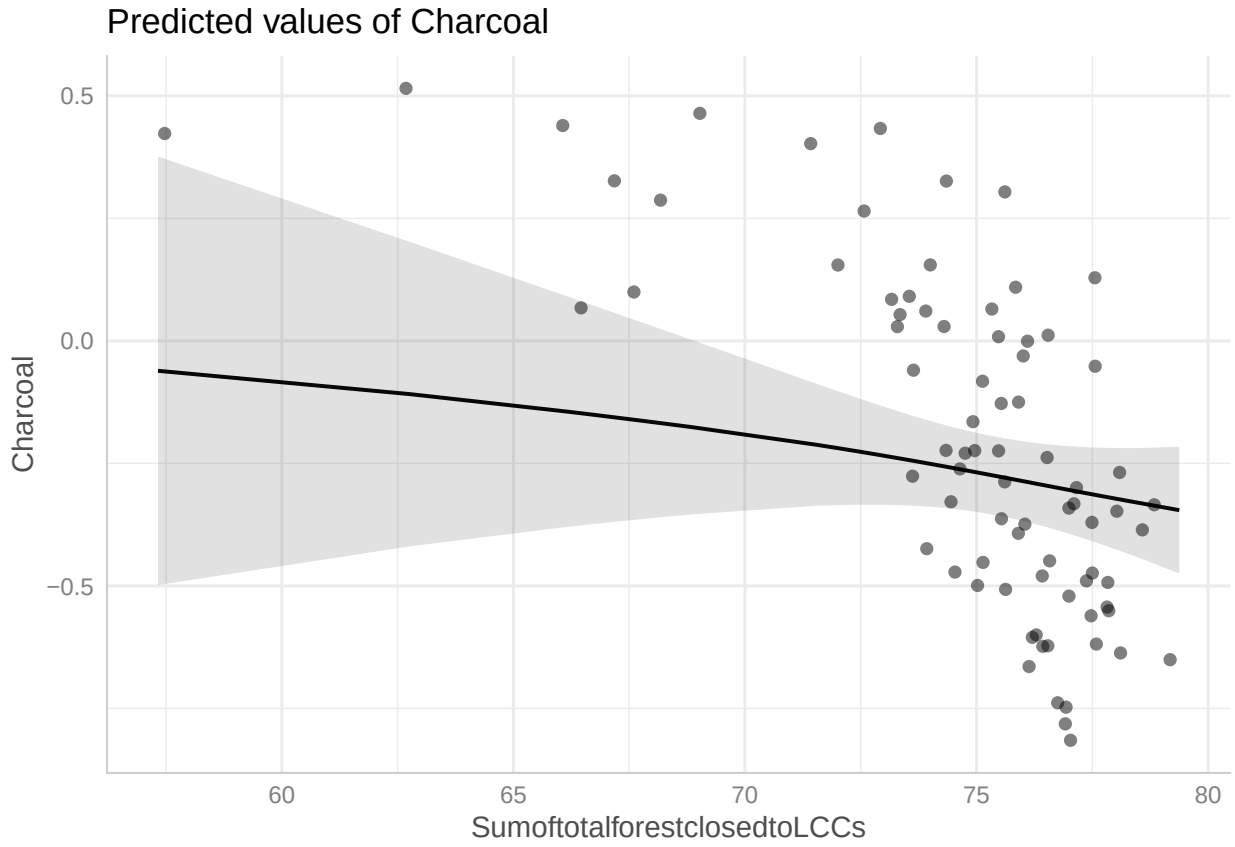
```
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.01901  -11.07   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df     F  p-value
## s(Temperature)                 2.3514      9 1.624 0.000362 ***
## s(P.PET)                       2.4771      9 1.506 0.001094 **
## s(SumoftotalforestclosedtoLCCs) 0.8534      9 0.217 0.059901 .
## s(Arabledisturbedlandin)       2.2694      9 1.905  1.7e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.708   Deviance explained = 73.8%
## -REML = -16.277  Scale est. = 0.028913  n = 80
## [1] "Plotting predictions"
## $Temperature
```



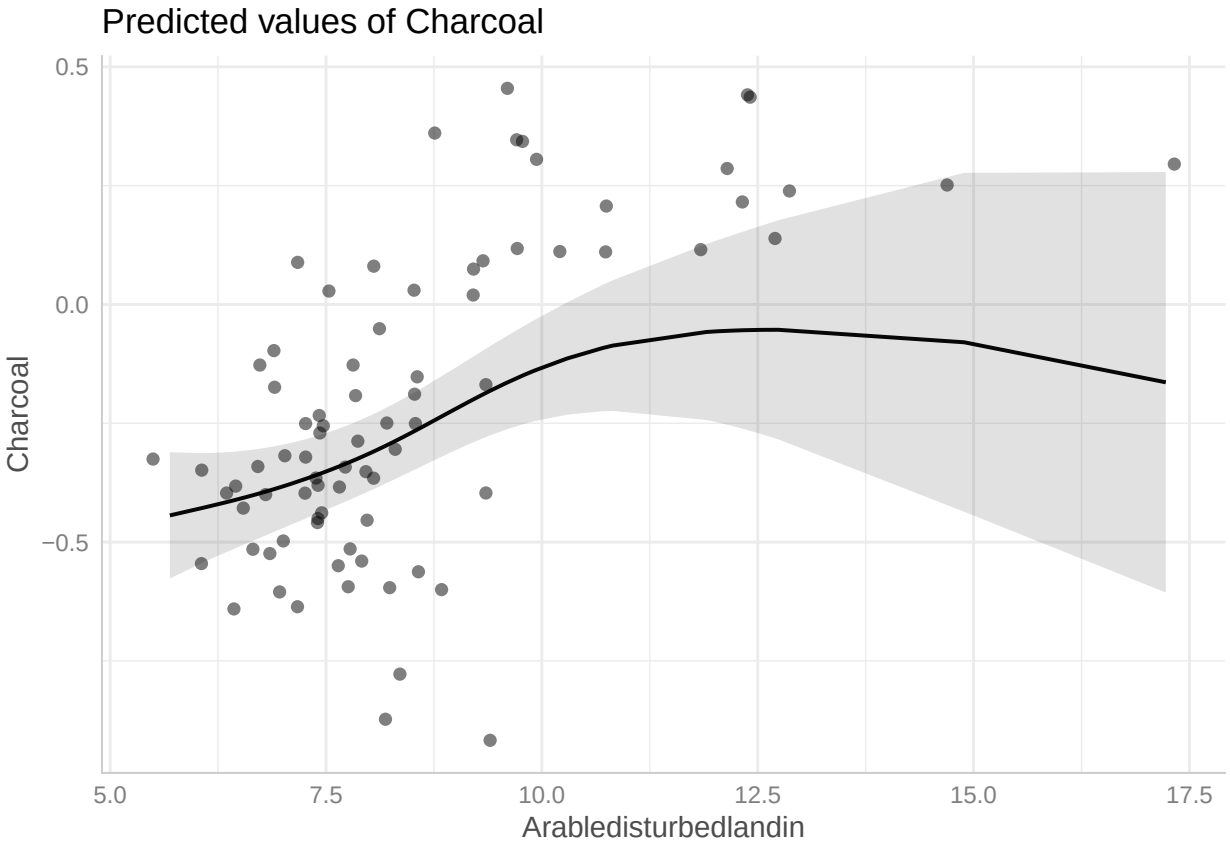

```
##
## $P.PET
```



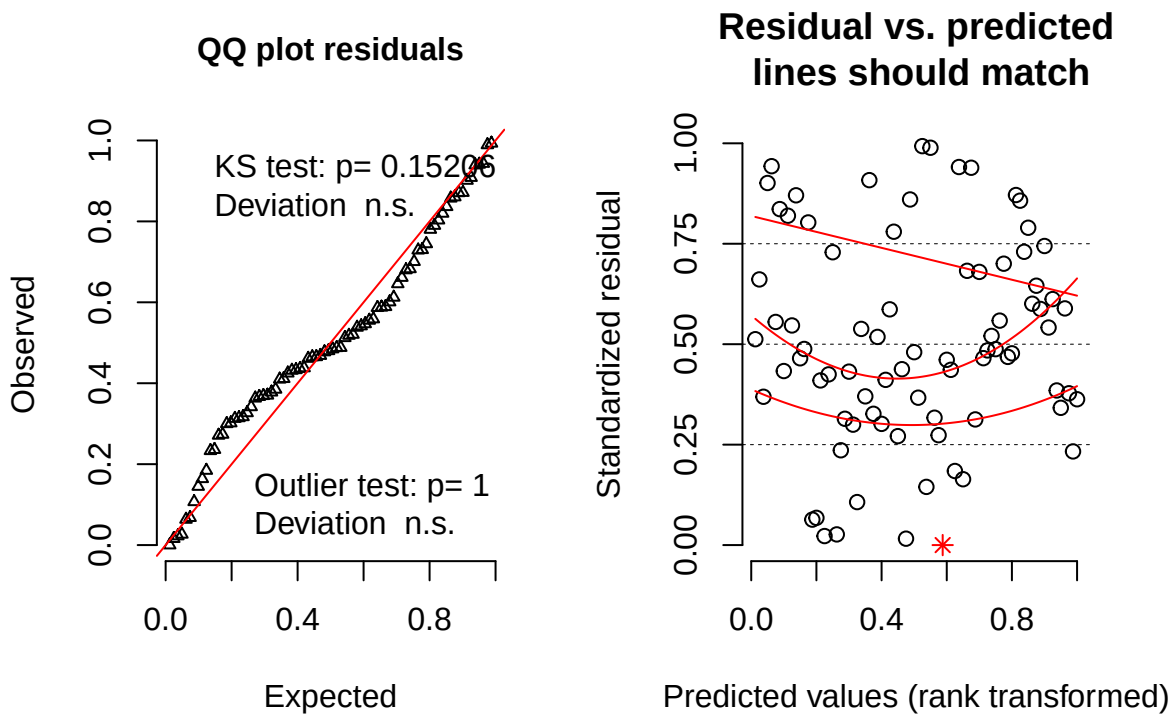

```
##
## $SumoftotalforestclosedtoLCCs
```



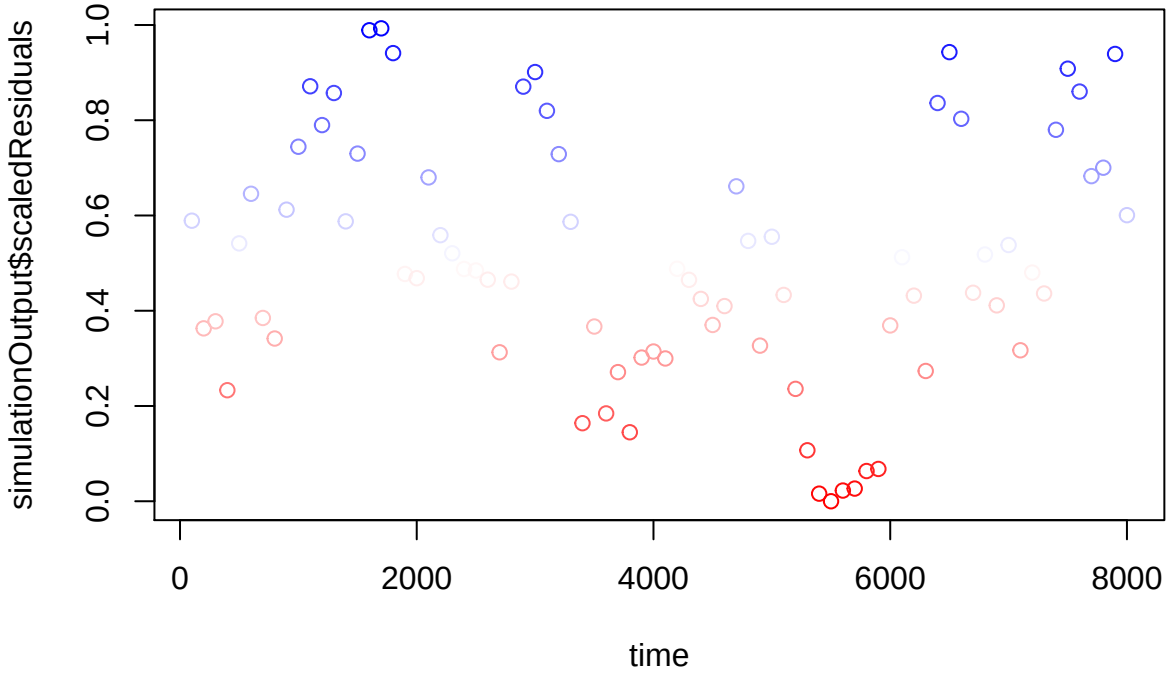

```
##
## $Arabledisturbedlandin
```


Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
5.0
7.5
10.0
12.5
15.0
17.5
Arabledisturbedlandin

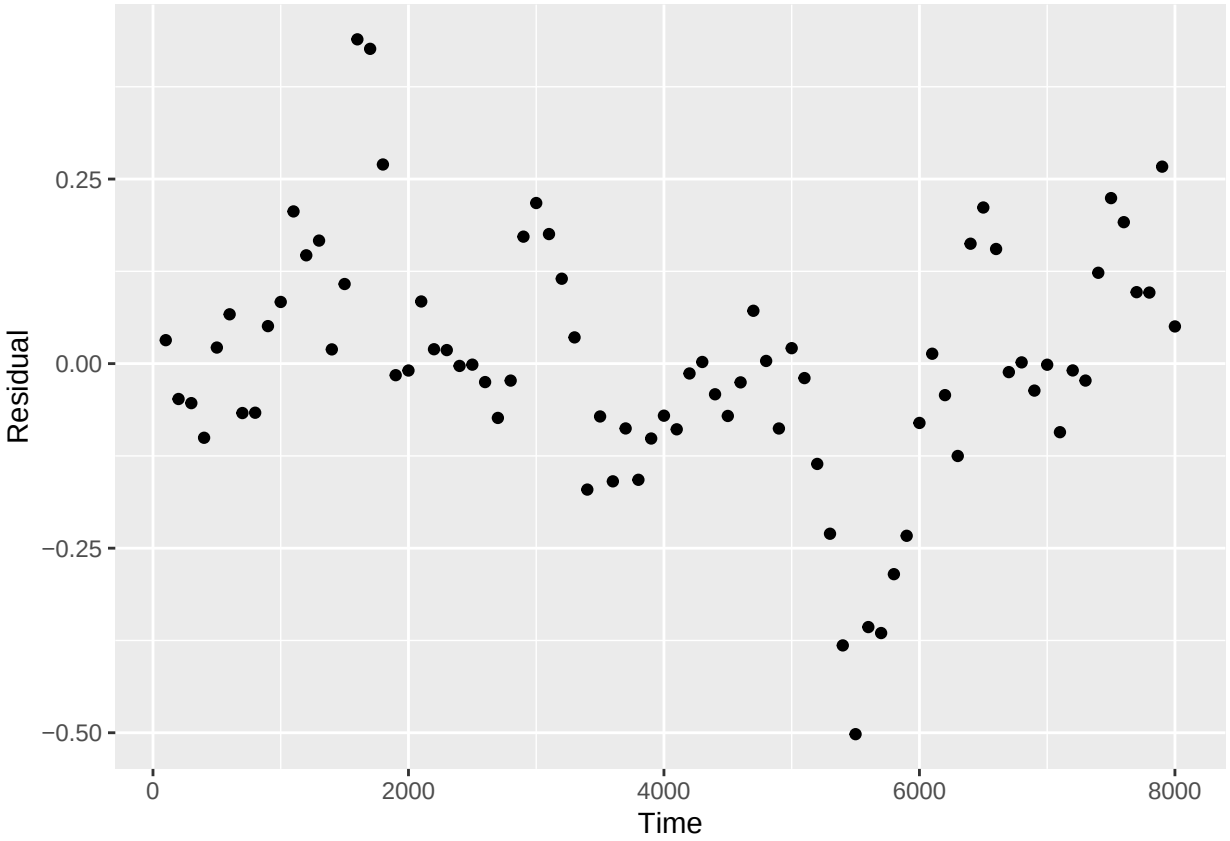
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

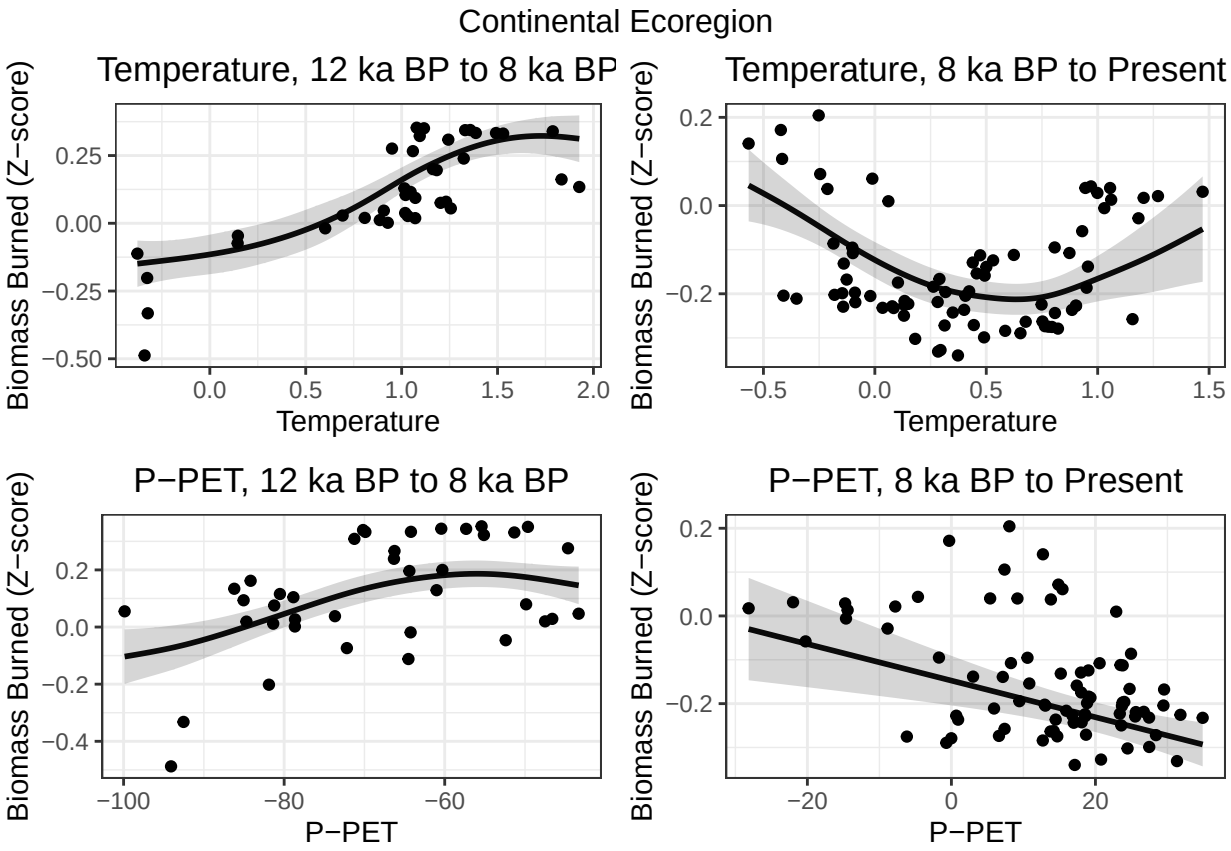



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.52524, p-value = 1.832e-15
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

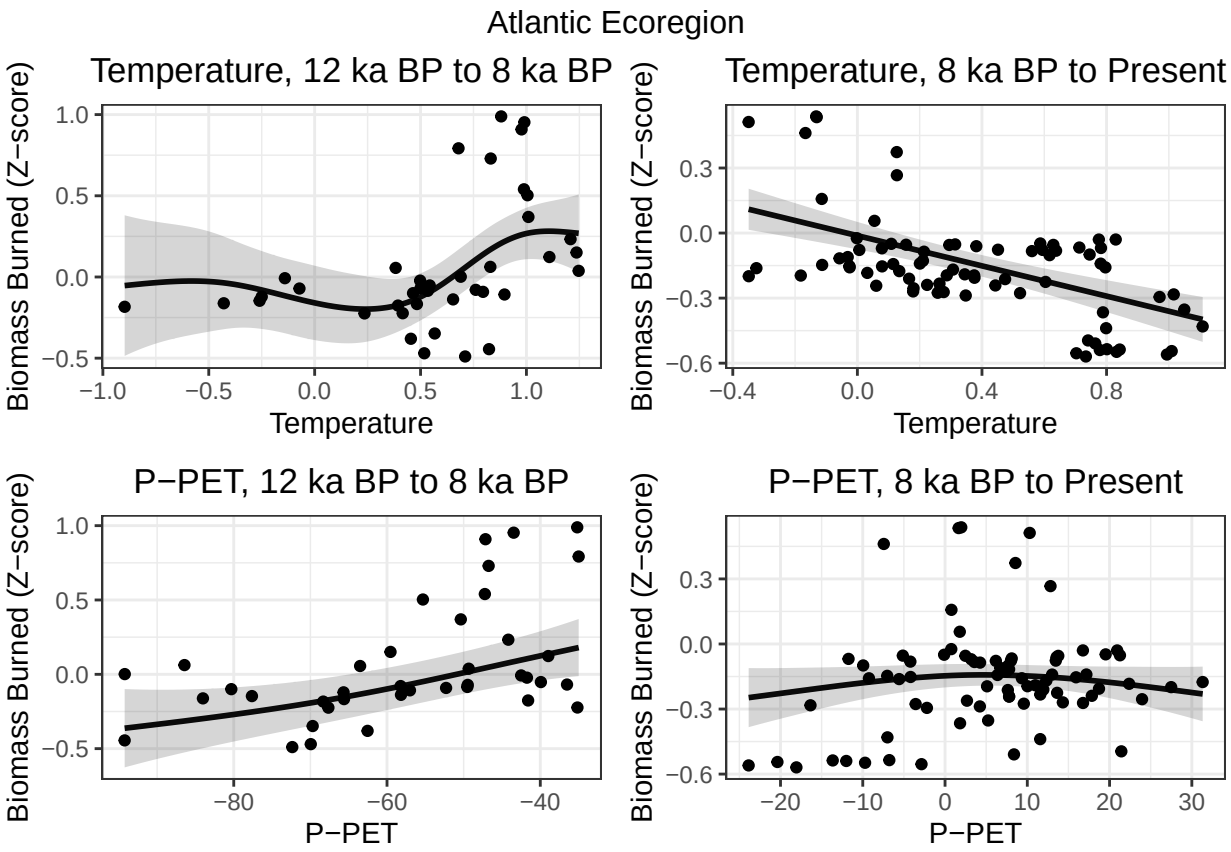

Residual
0.25
0.00
−0.25
−0.50
0
2000
4000
6000
8000
Time

Plots

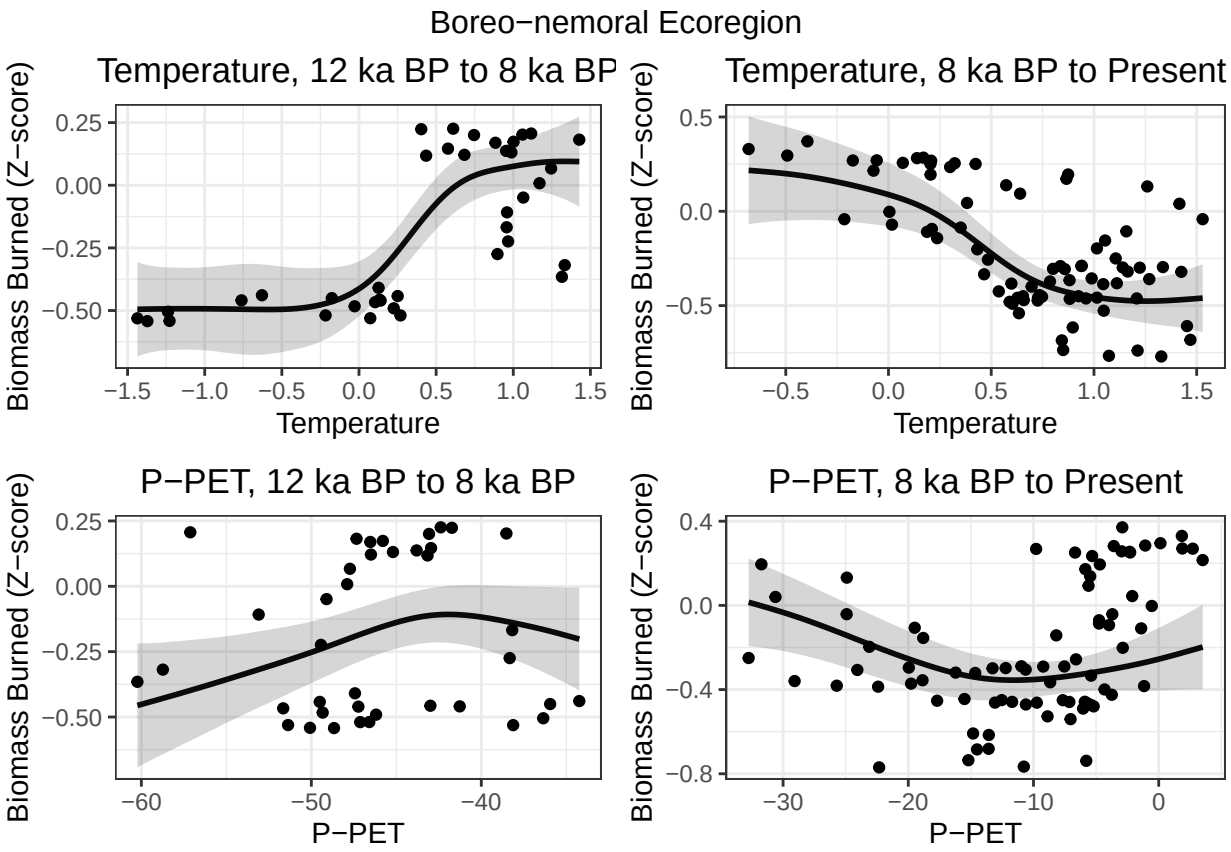
Continental ecoregion, pre- and post-8 ka BP, climate only



Atlantic ecoregion, pre- and post-8 ka BP, climate only



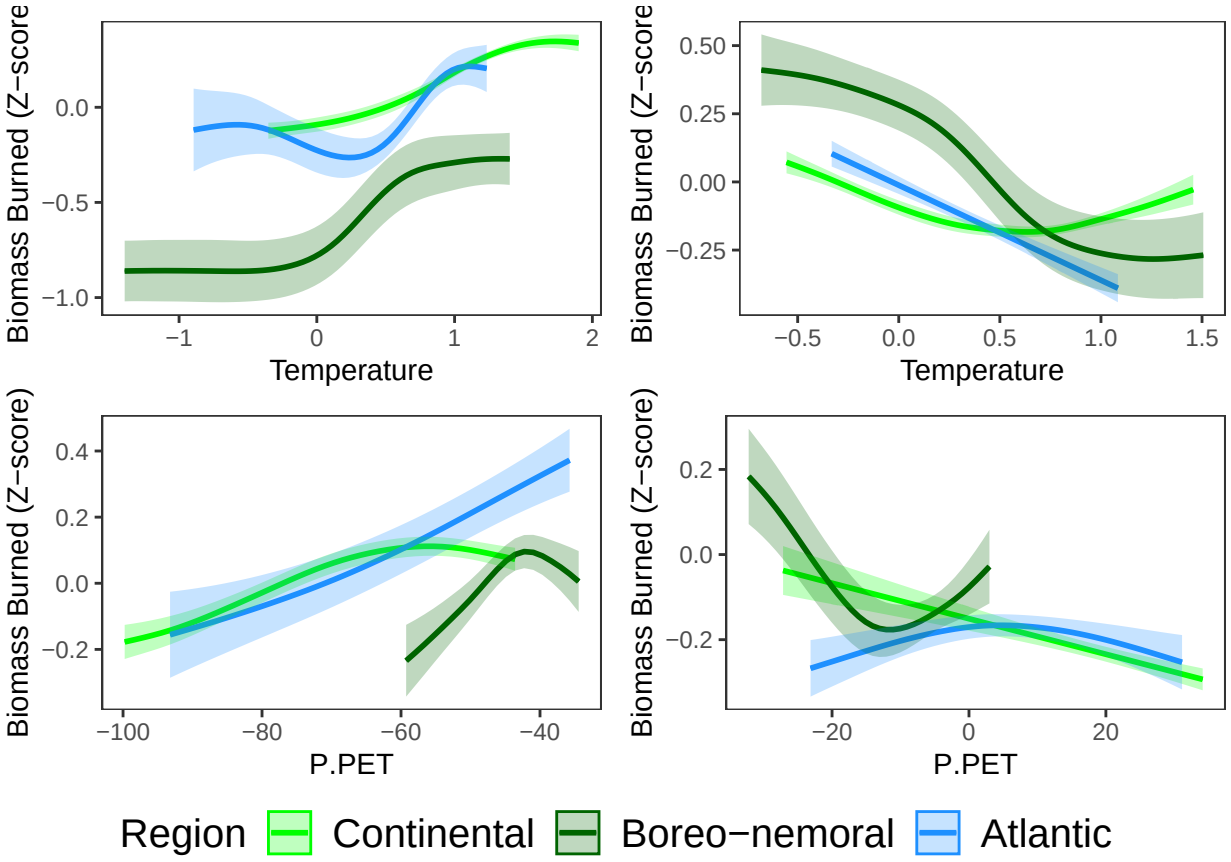
Boreo-nemoral ecoregion, pre- and post-8 ka BP, climate only



Summary Table - Deviance Explained

region	climate.12k.to.8ky	climate.8ky.to.0ky	climate.plus.cover.8ky.to.0ky
Continental	0.8744627	0.4920065	0.7958207
Atlantic	0.5268266	0.3776453	0.7674590
Boreo-nemoral	0.7510058	0.5995821	0.7375969
Mean of Regions	0.7174317	0.4897446	0.7669589

Summary Plot - All climate only GAMs, pre- and post-8 ka BP




```
## pdf
##   2
```

Summary for climate GAMs

GAMs made before 8 ka BP with climate alone are both consistent and sensible and explain, on average, 70% of the deviance. After 8 ka BP, GAMs made with climate only explain much less of the deviance, on average 45%, and produce results that are inconsistent across ecoregions and have unexpected trends (fire increases at lower temperatures). However, including two land cover types in the GAMs increases the deviance explain to 75%.

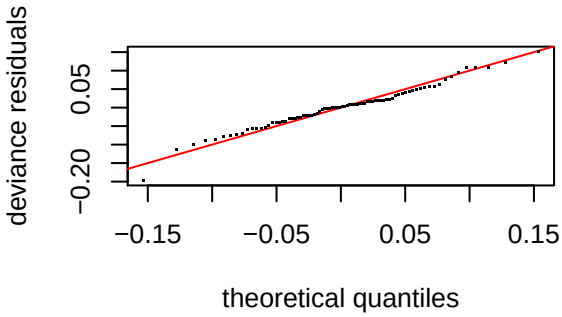
GAMs After 8ka BP with full land cover analysis

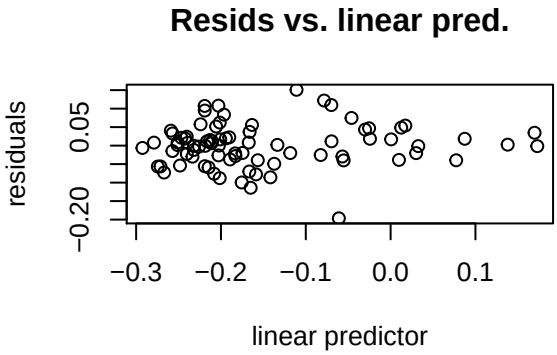
Total tree cover

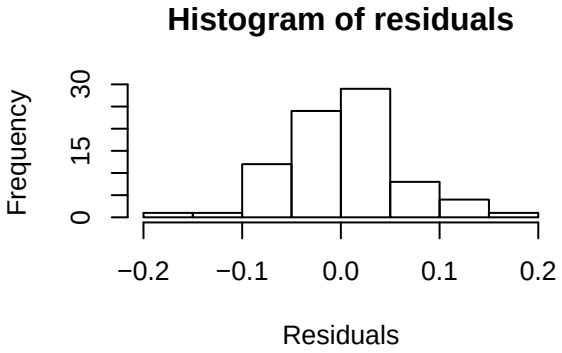
Total tree cover, Continental ecoregion

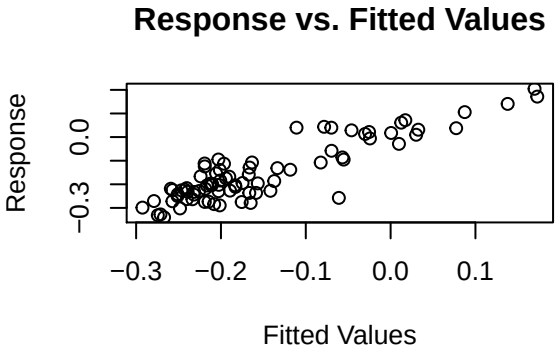
```
totaltree.continental <- charcoal.gam(Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature)  + s(
```

```
## [1] "Checking GAM"
```



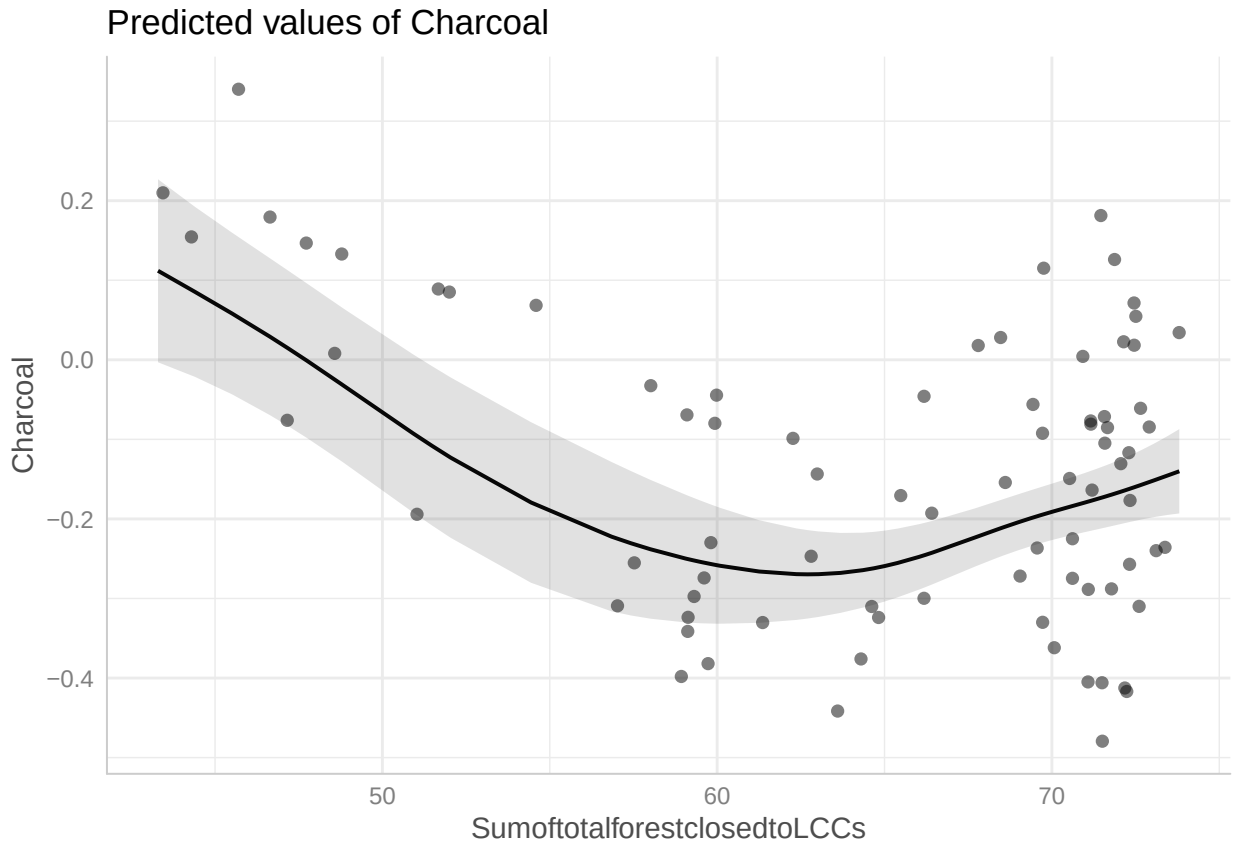




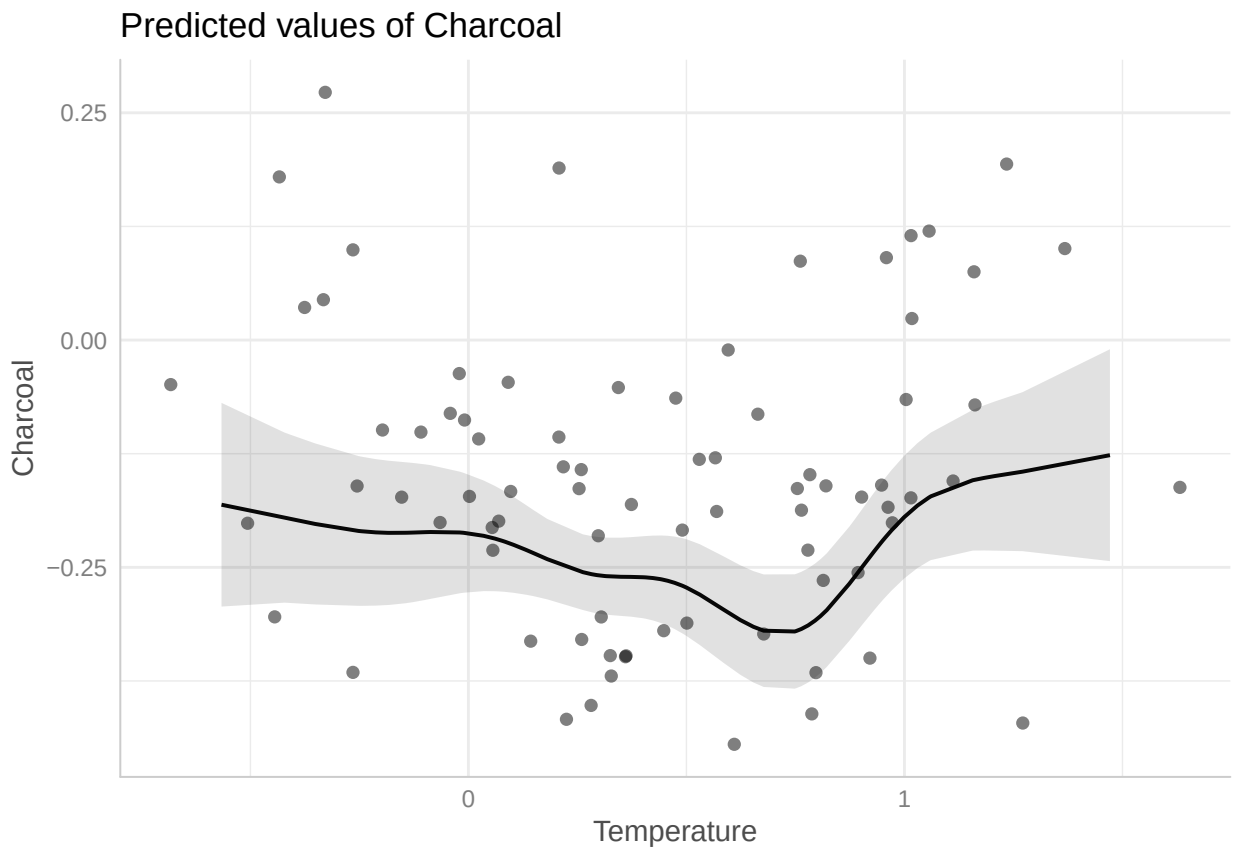



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 9 iterations.
## Gradient range [-1.504697e-05,6.536313e-06]
## (score -89.80714 & scale 0.003770801).
## Hessian positive definite, eigenvalue range [1.50464e-05,39.78544].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                  k'  edf k-index p-value
## s(SumoftotalforestclosedtoLCCs) 9.00 3.60    0.85    0.10
## s(Temperature)                  9.00 5.80    1.07    0.69
## s(P.PET)                        9.00 1.29    1.03    0.56
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature) +
##     s(P.PET)
##
```

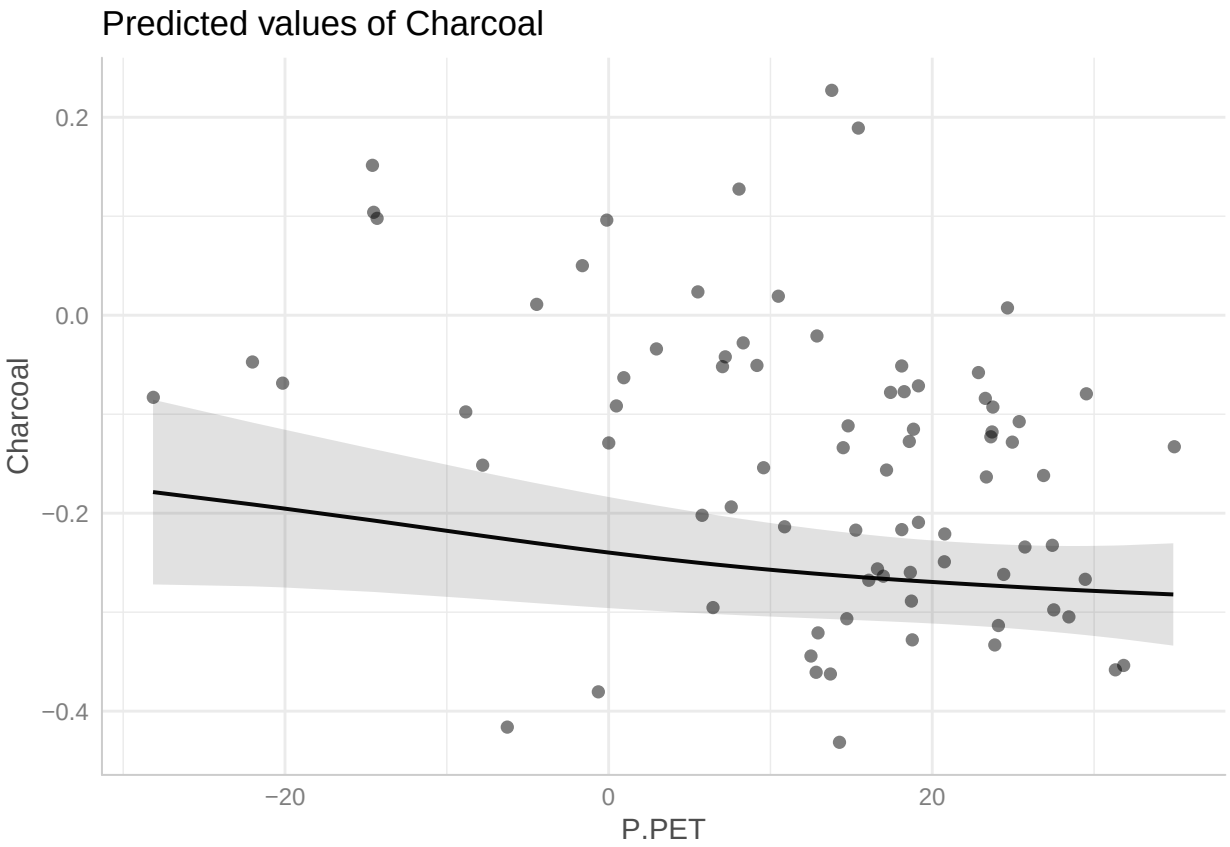
```
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.006865  -21.76   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df      F  p-value
## s(SumoftotalforestclosedtoLCCs) 3.597      9 10.053  < 2e-16 ***
## s(Temperature)                  5.797      9  3.432 2.59e-05 ***
## s(P.PET)                        1.289      9  0.538   0.0269 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.772   Deviance explained = 80.3%
## -REML = -89.807  Scale est. = 0.0037708  n = 80
## [1] "Plotting predictions"
## $SumoftotalforestclosedtoLCCs
```

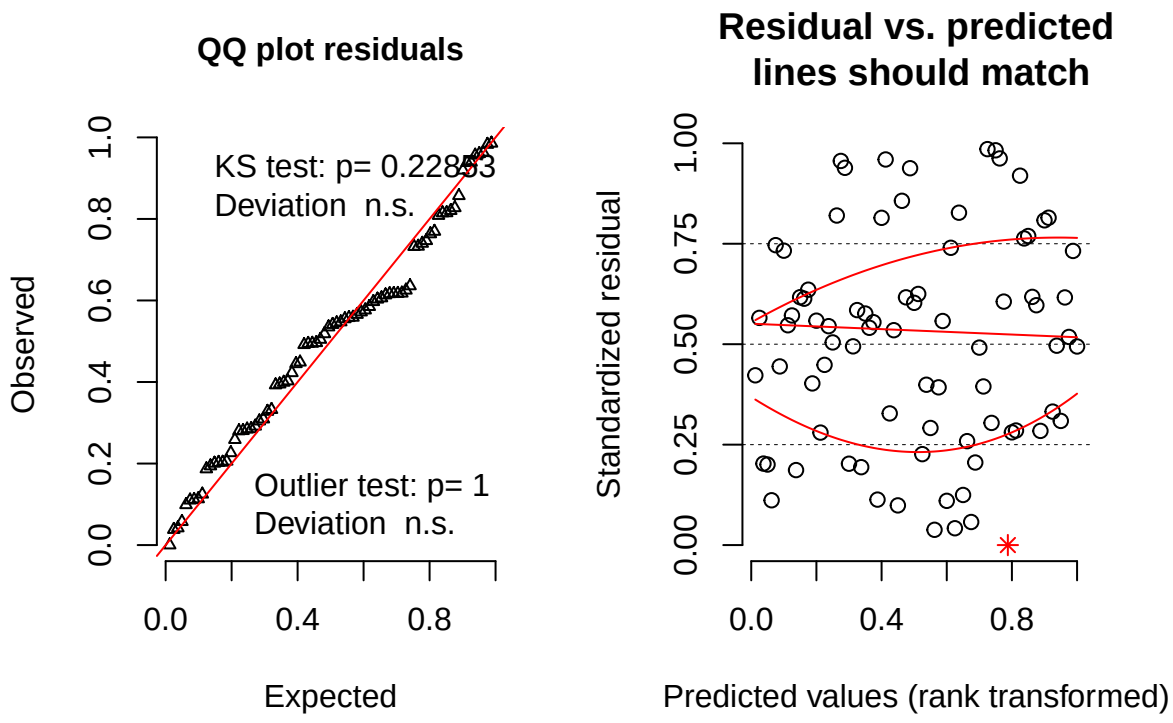



```
##
## $Temperature
```

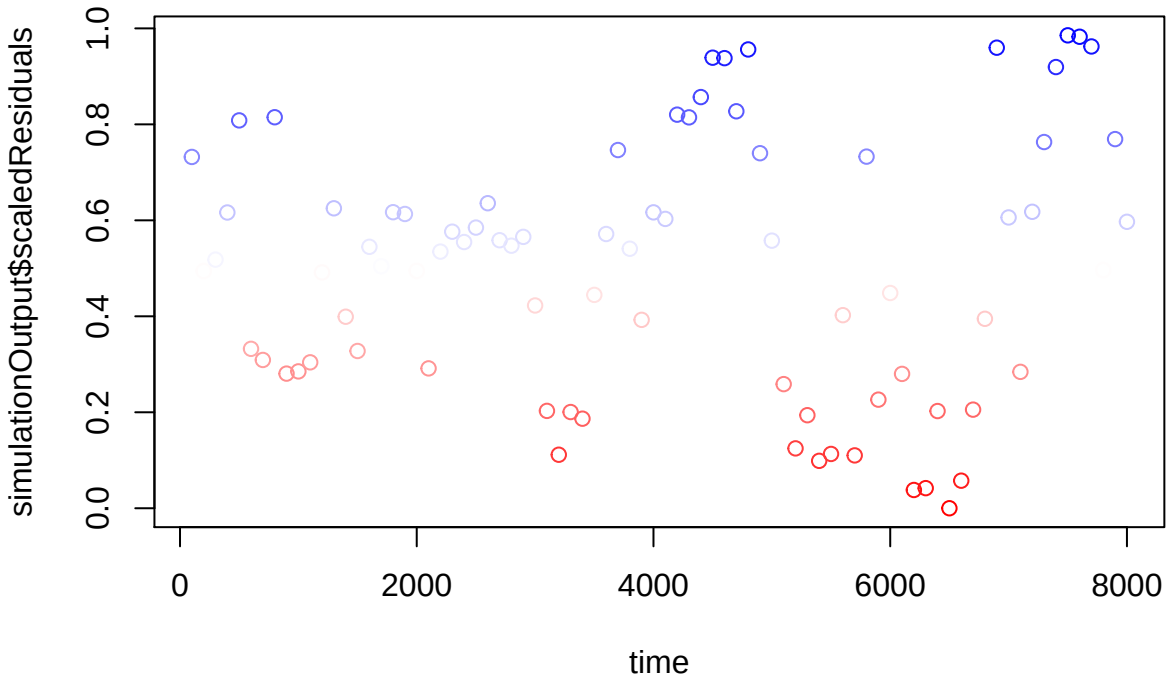

Predicted values of Charcoal
0.25
0.00
−0.25
Charcoal
0
1
Temperature

```
##
## $P.PET
```

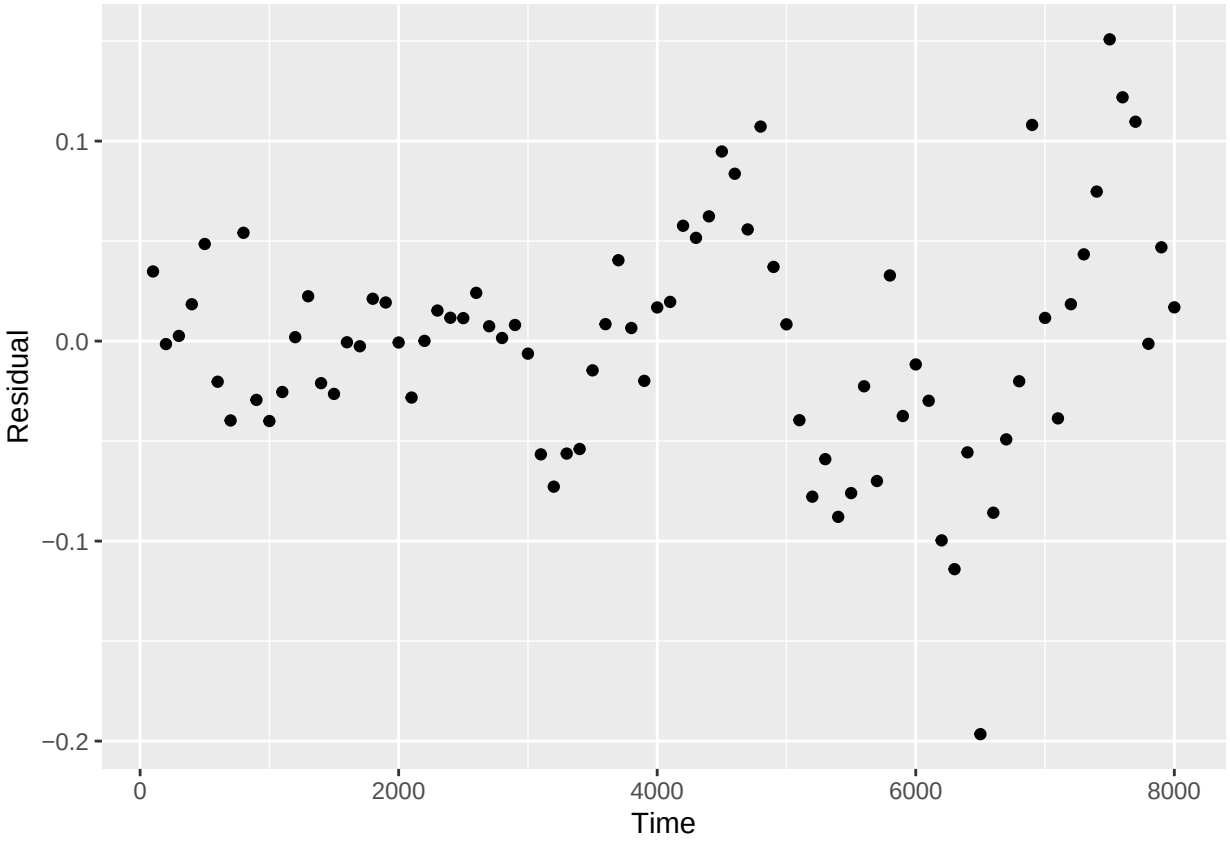

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



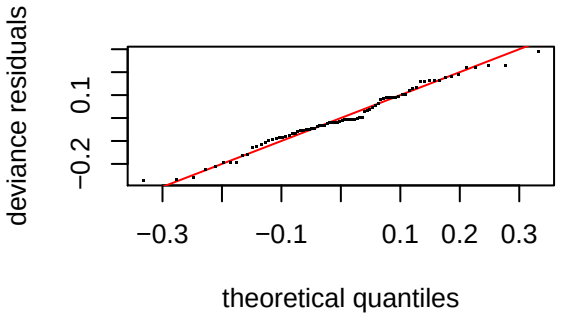

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.6982, p-value = 2.673e-11
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

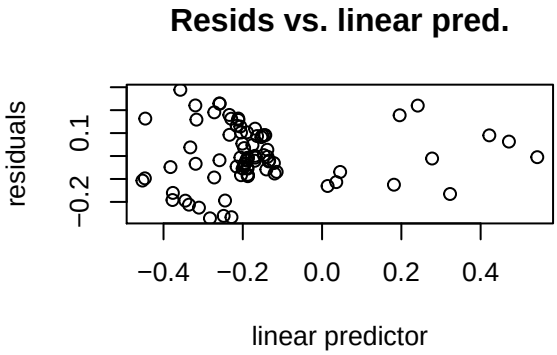


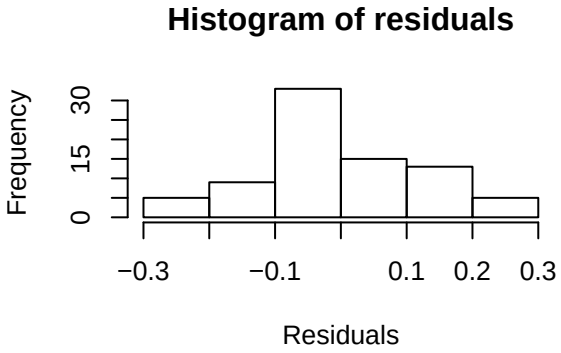
Total tree cover, Atlantic ecoregion

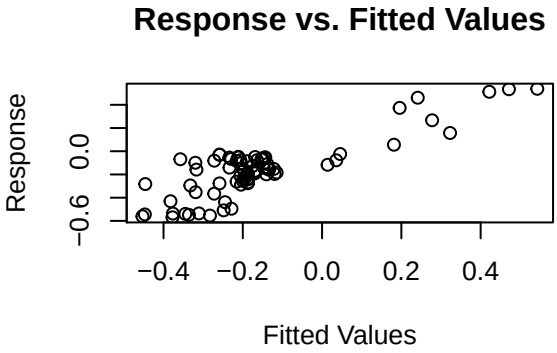
```
totaltree.atlantic <- charcoal.gam(Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature)  + s(P.P
```

```
## [1] "Checking GAM"
```



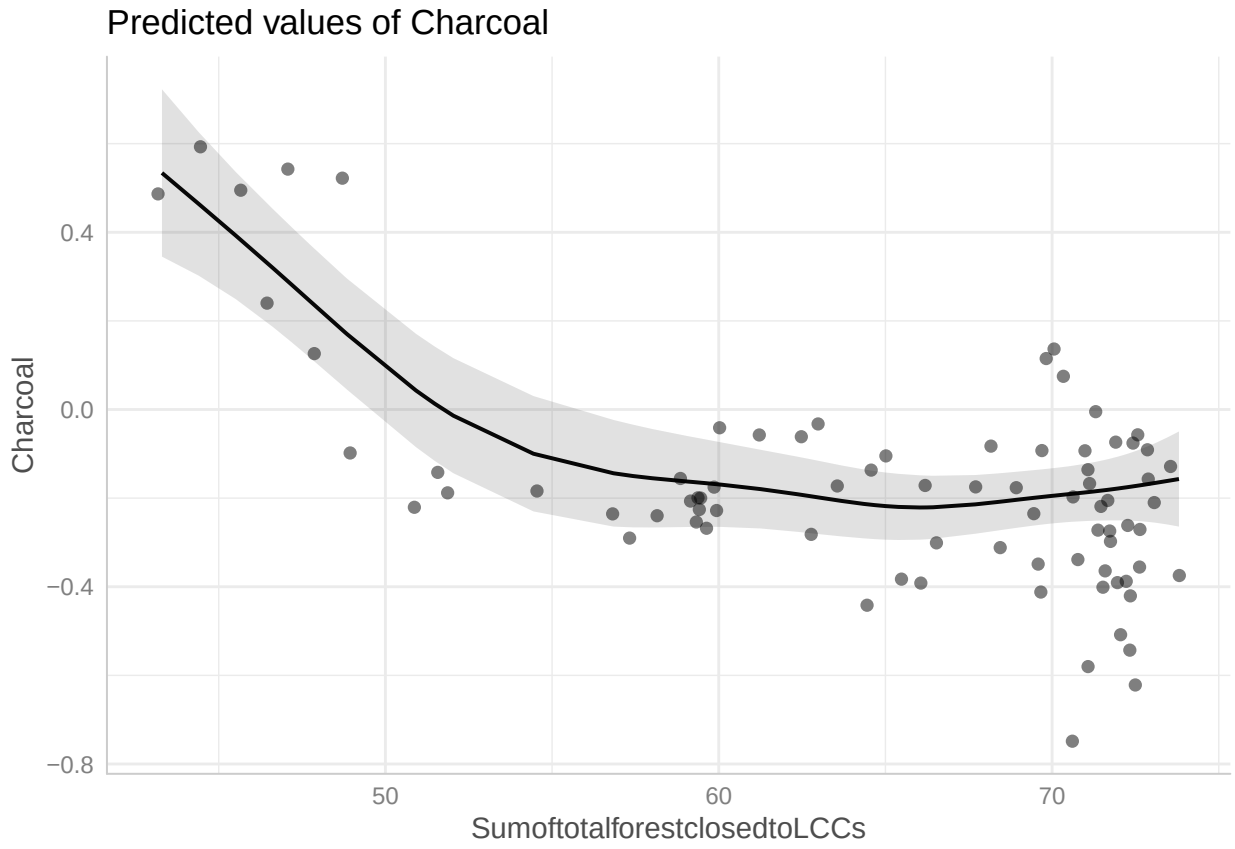




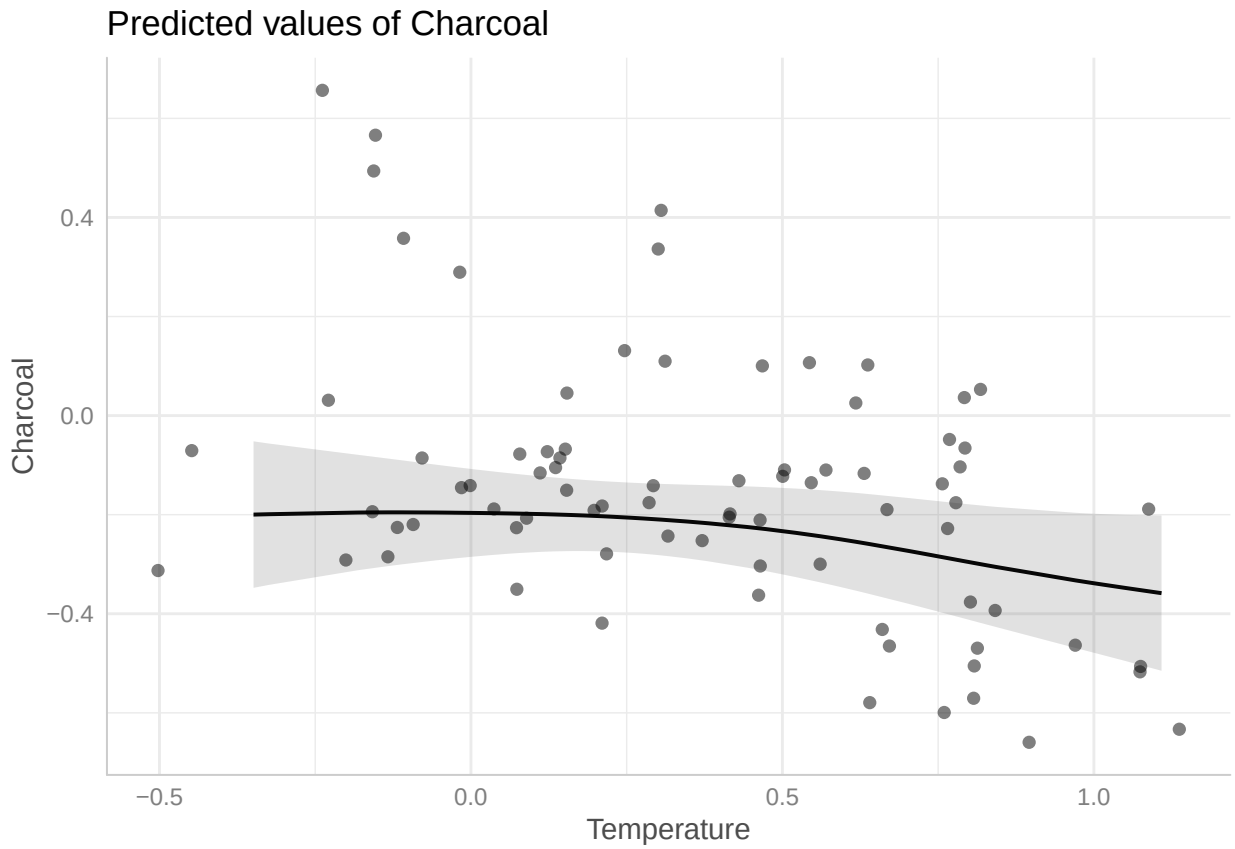



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-4.628882e-06,5.950208e-06]
## (score -35.74327 & scale 0.01766711).
## Hessian positive definite, eigenvalue range [0.0258906,39.58458].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                  k'  edf k-index p-value
## s(SumoftotalforestclosedtoLCCs) 9.00 3.74    1.25    0.99
## s(Temperature)                  9.00 1.51    1.28    0.99
## s(P.PET)                        9.00 1.80    1.02    0.60
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature) +
##     s(P.PET)
##
```

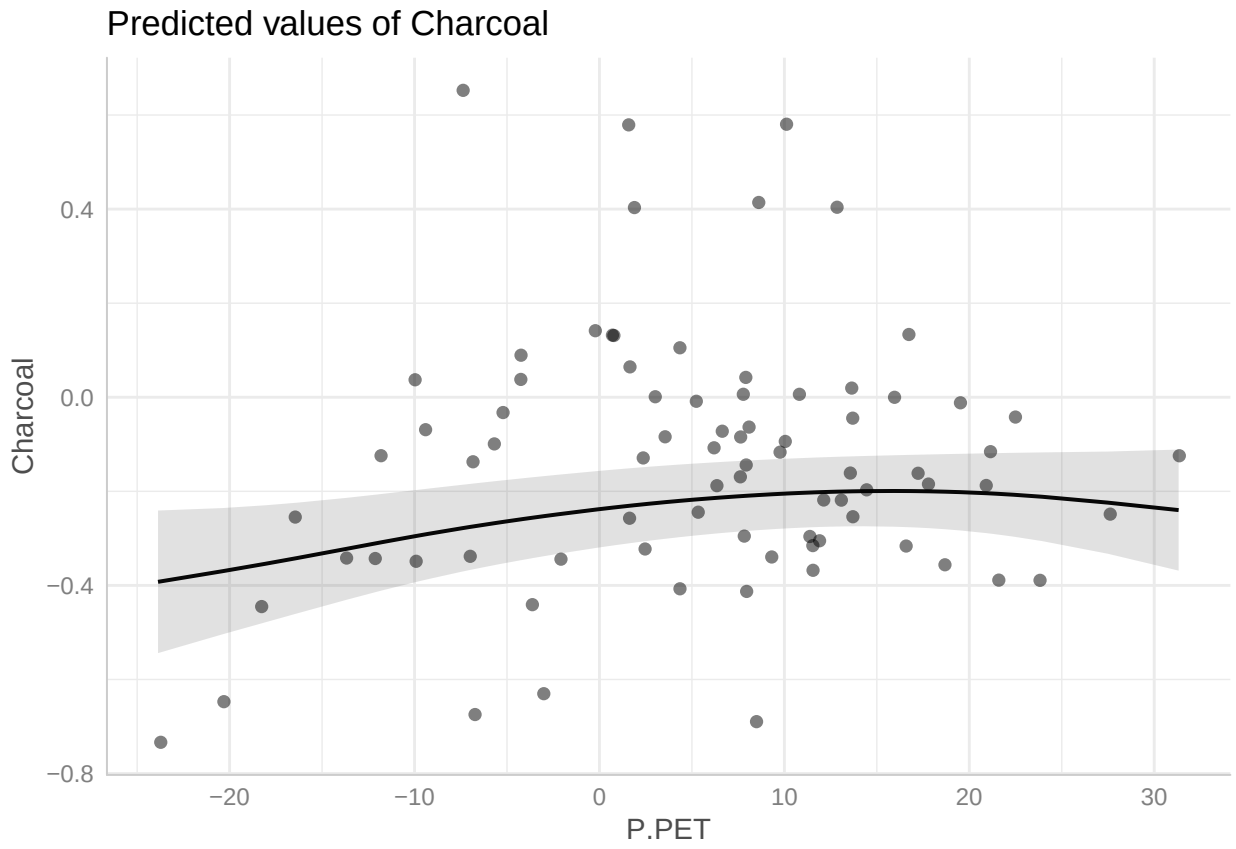
```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.01486  -10.88   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df     F  p-value
## s(SumoftotalforestclosedtoLCCs) 3.744      9 9.166 5.24e-16 ***
## s(Temperature)                  1.508      9 0.527   0.0290 *
## s(P.PET)                        1.797      9 0.835   0.0101 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.688   Deviance explained = 71.5%
## -REML = -35.743  Scale est. = 0.017667  n = 80
## [1] "Plotting predictions"
## $SumoftotalforestclosedtoLCCs
```

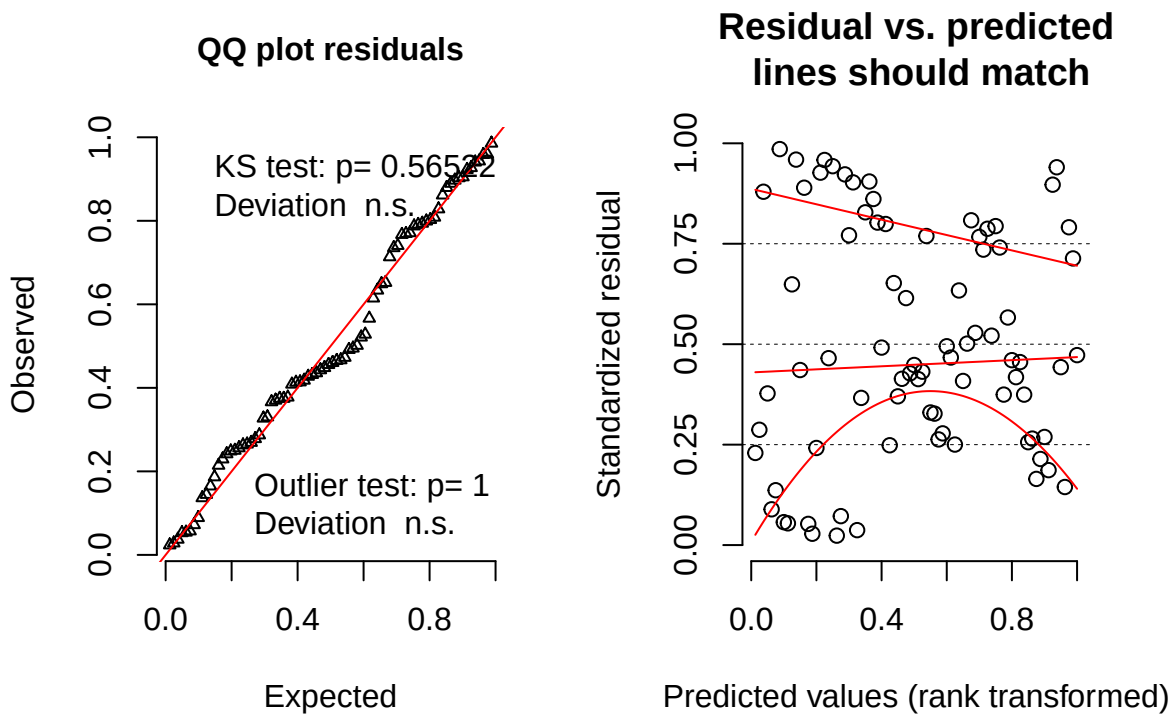



```
##
## $Temperature
```

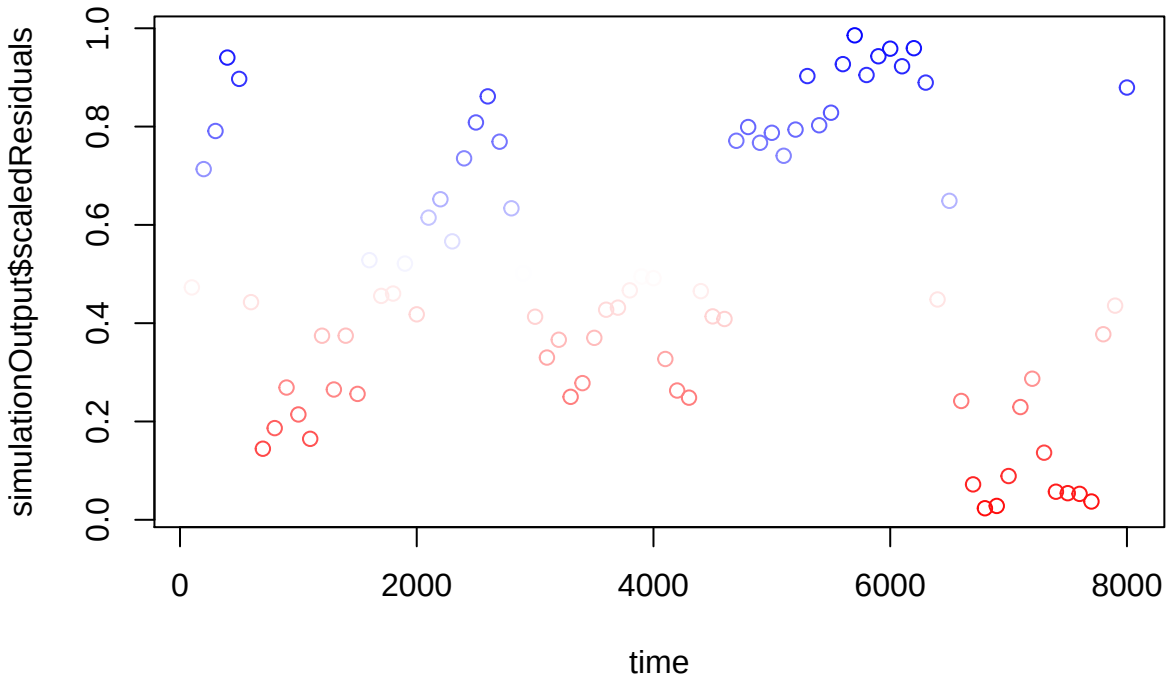

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

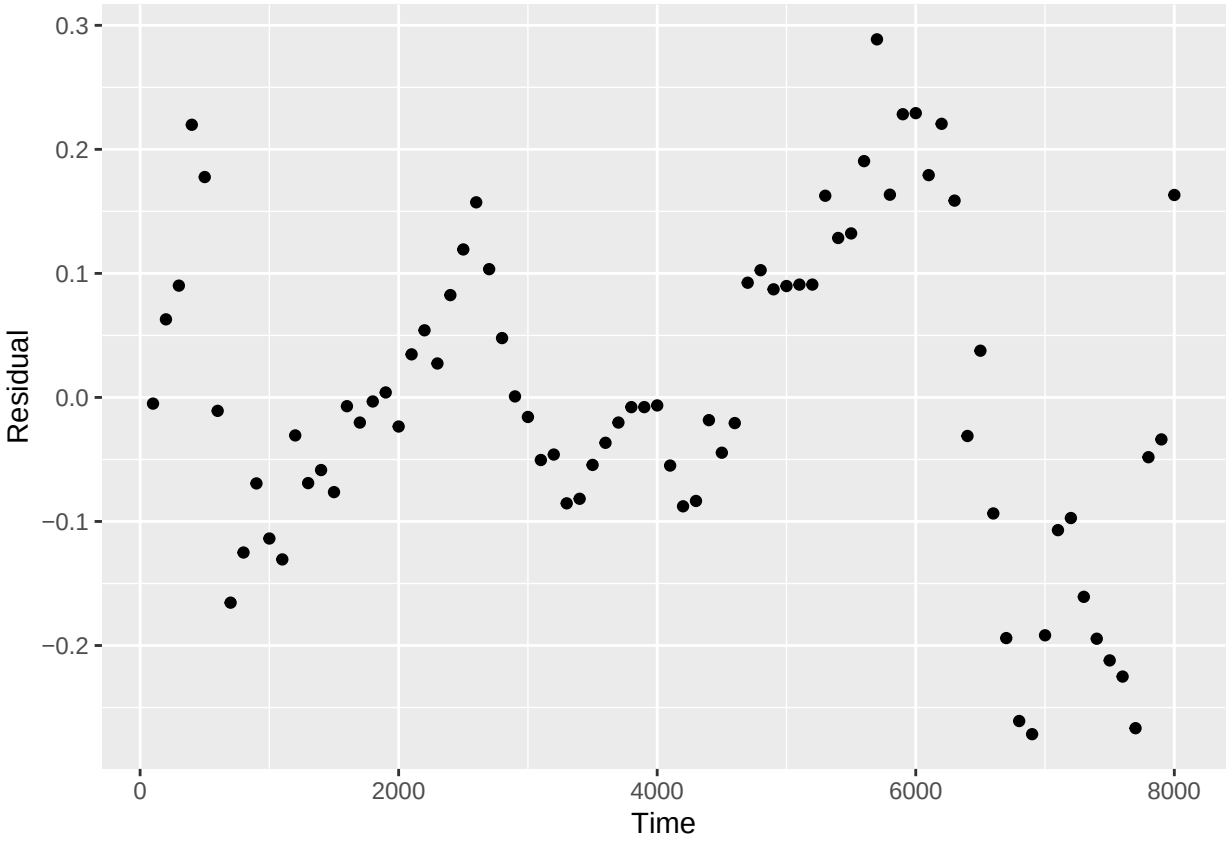

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.8
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



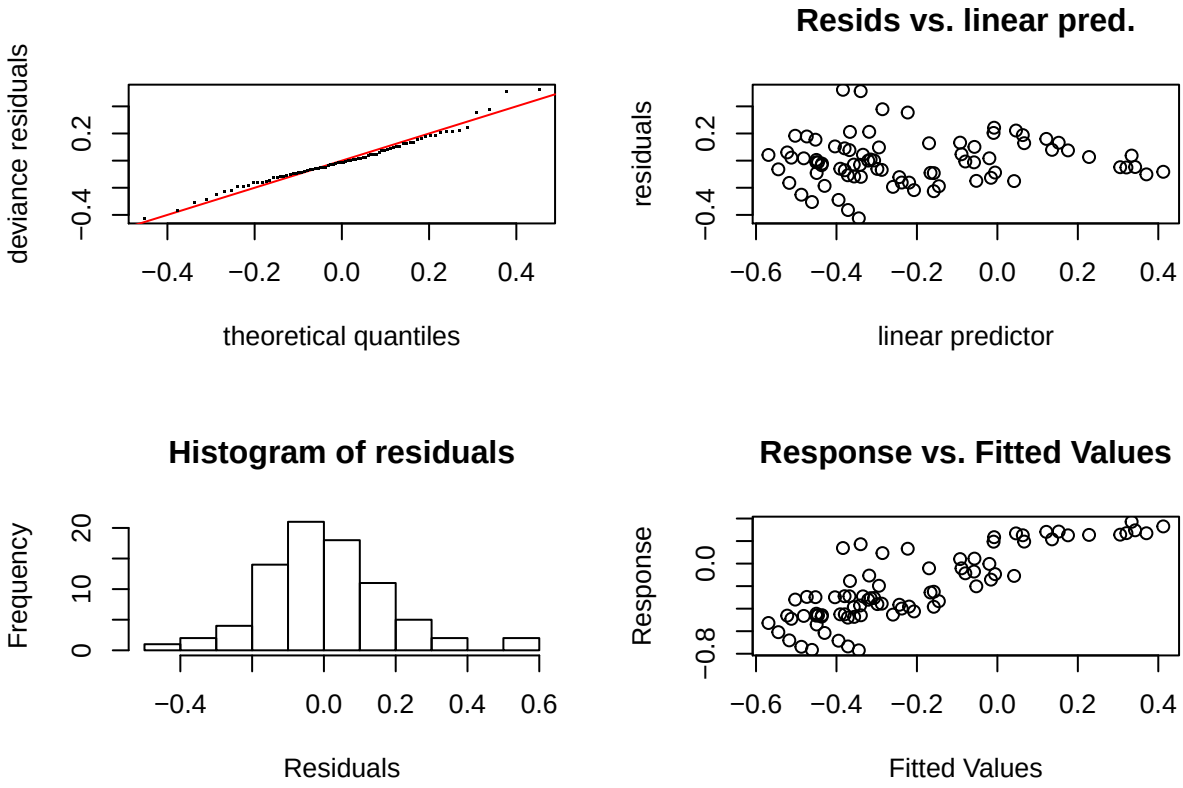

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.28649, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Total tree cover, Boreo-Nemoral ecoregion

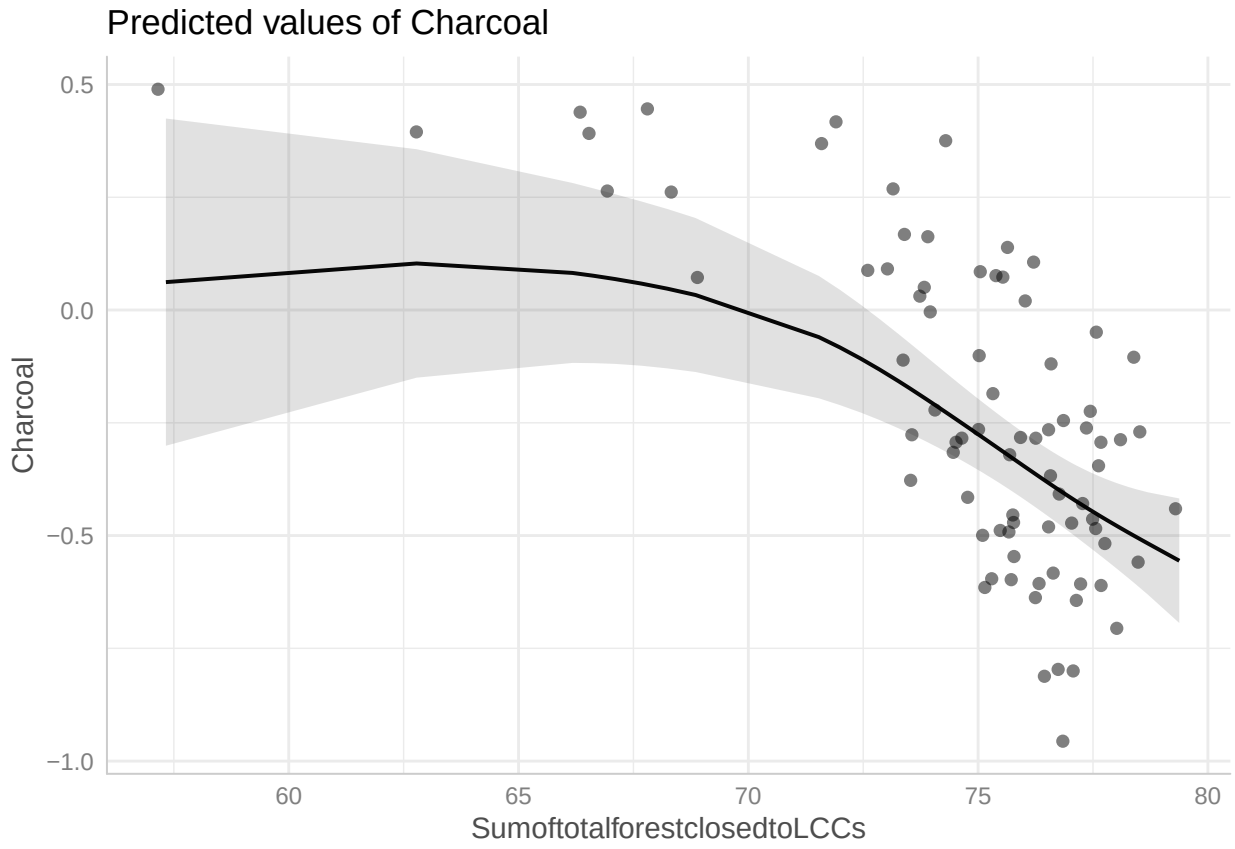
```
totaltree.boreonemoral <- charcoal.gam(Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature)  + s
```

```
## [1] "Checking GAM"
```

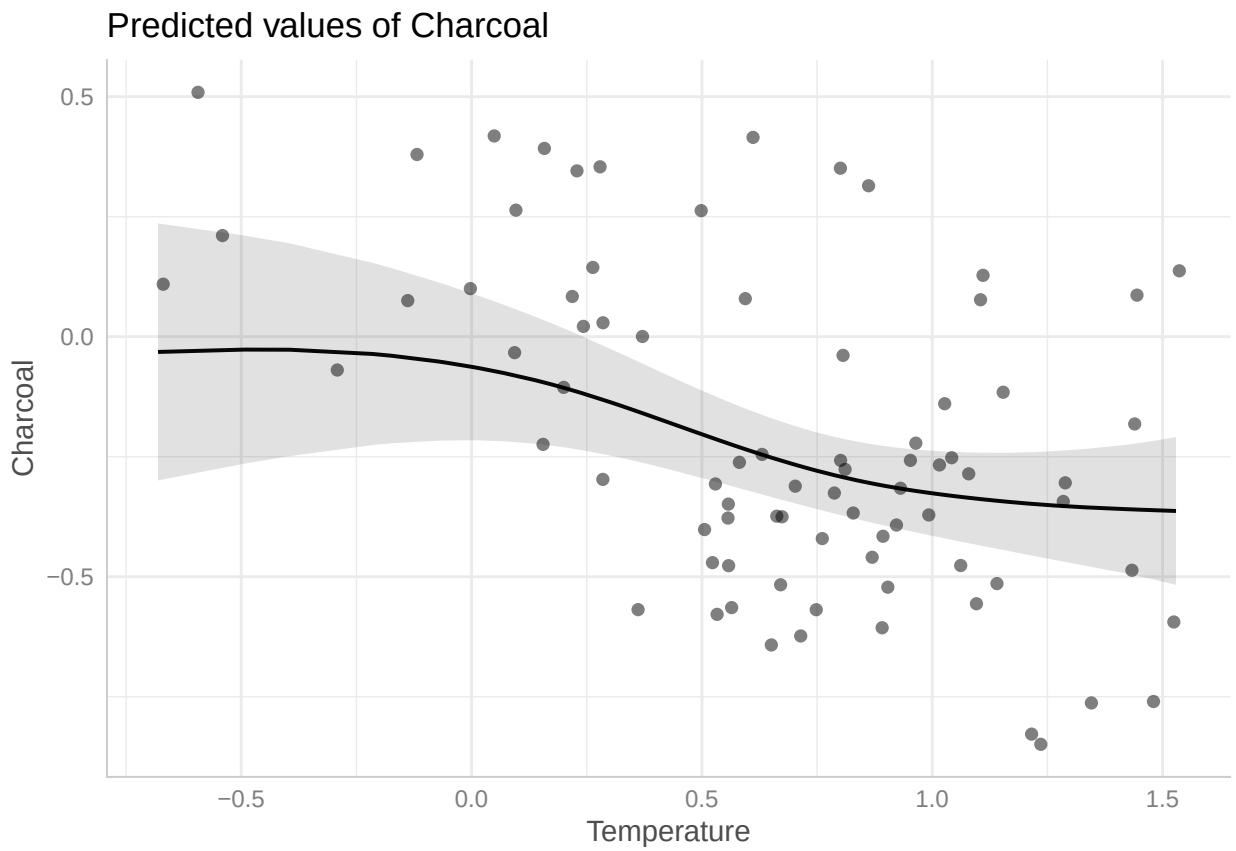



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-2.082303e-05,3.009454e-05]
## (score -12.50301 & scale 0.03283606).
## Hessian positive definite, eigenvalue range [1.496118e-06,39.58805].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                                   k'  edf k-index p-value
## s(SumoftotalforestclosedtoLCCs) 9.00 2.55    0.94    0.20
## s(Temperature)                  9.00 2.02    1.00    0.41
## s(P.PET)                        9.00 2.35    1.08    0.71
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(SumoftotalforestclosedtoLCCs) + s(Temperature) +
##     s(P.PET)
##
```

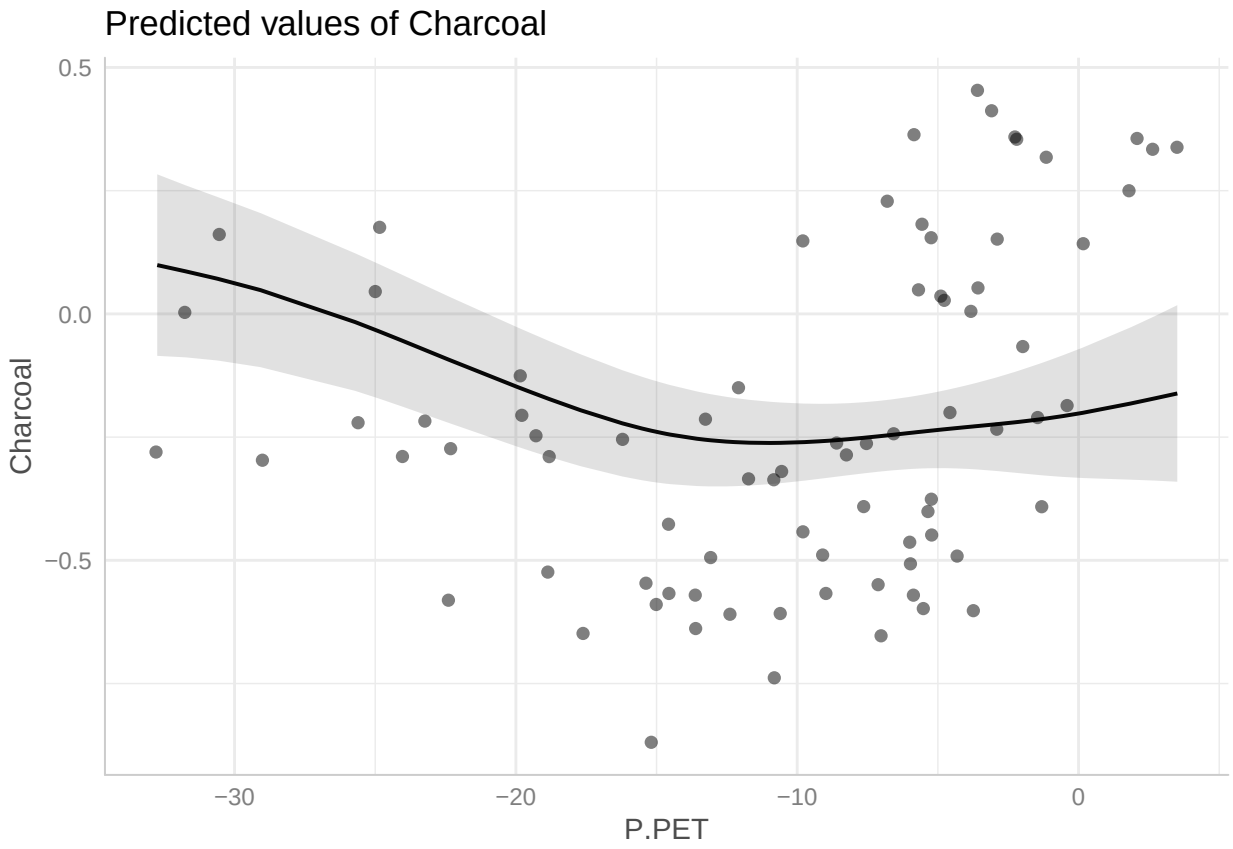
```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.02026  -10.38 5.78e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                   edf Ref.df     F  p-value
## s(SumoftotalforestclosedtoLCCs) 2.547      9 3.234 6.42e-07 ***
## s(Temperature)                  2.024      9 1.025 0.004113 **
## s(P.PET)                        2.346      9 1.909 0.000148 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.669   Deviance explained = 69.8%
## -REML = -12.503  Scale est. = 0.032836  n = 80
## [1] "Plotting predictions"
## $SumoftotalforestclosedtoLCCs
```



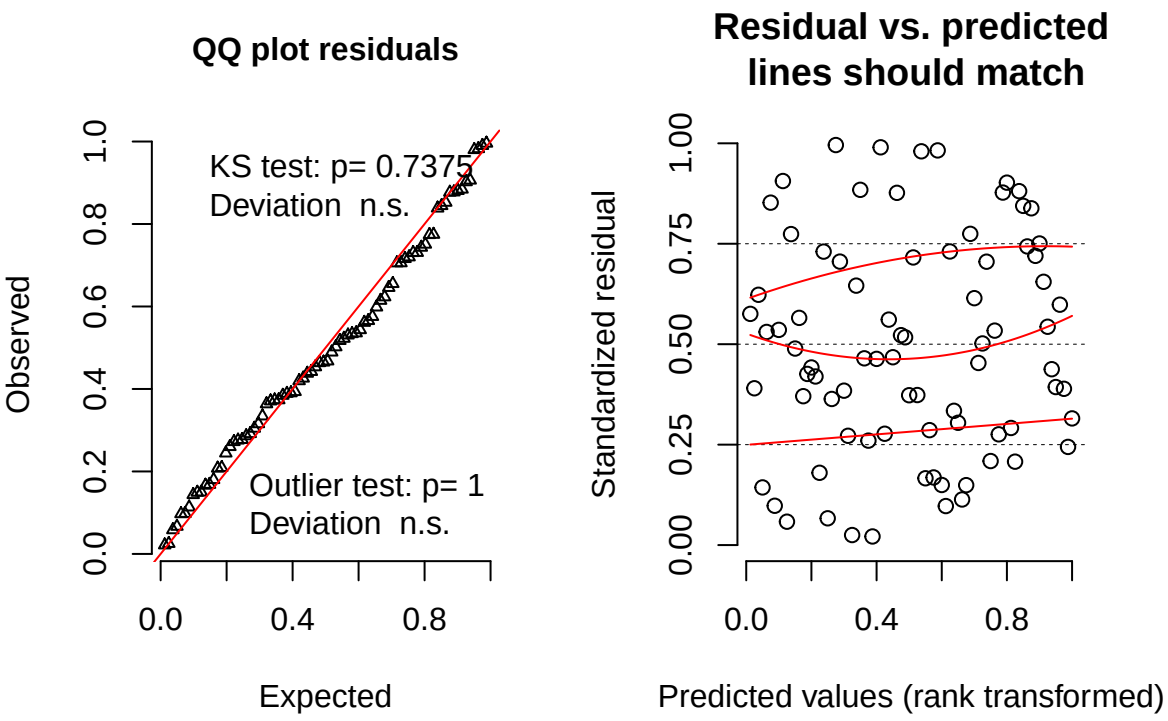

```
##
## $Temperature
```


Predicted values of Charcoal
Charcoal
Temperature
0.5
0.0
−0.5
−0.5
0.0
0.5
1.0
1.5

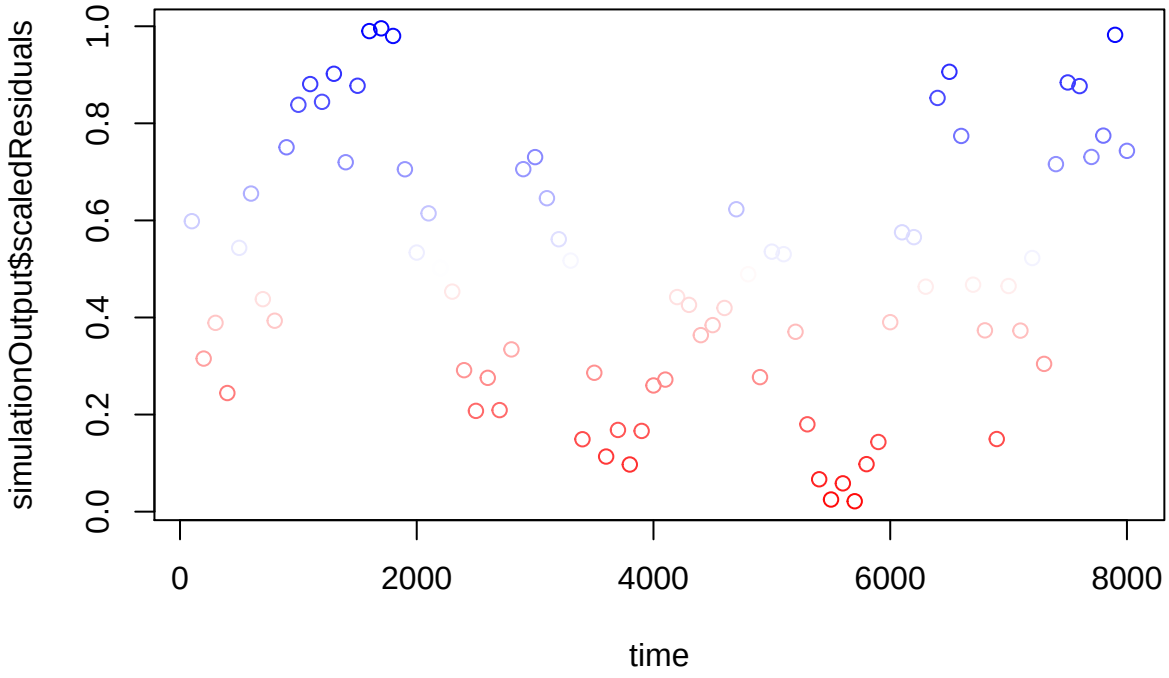
```
##
## $P.PET
```


Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
−30
−20
−10
0
P.PET

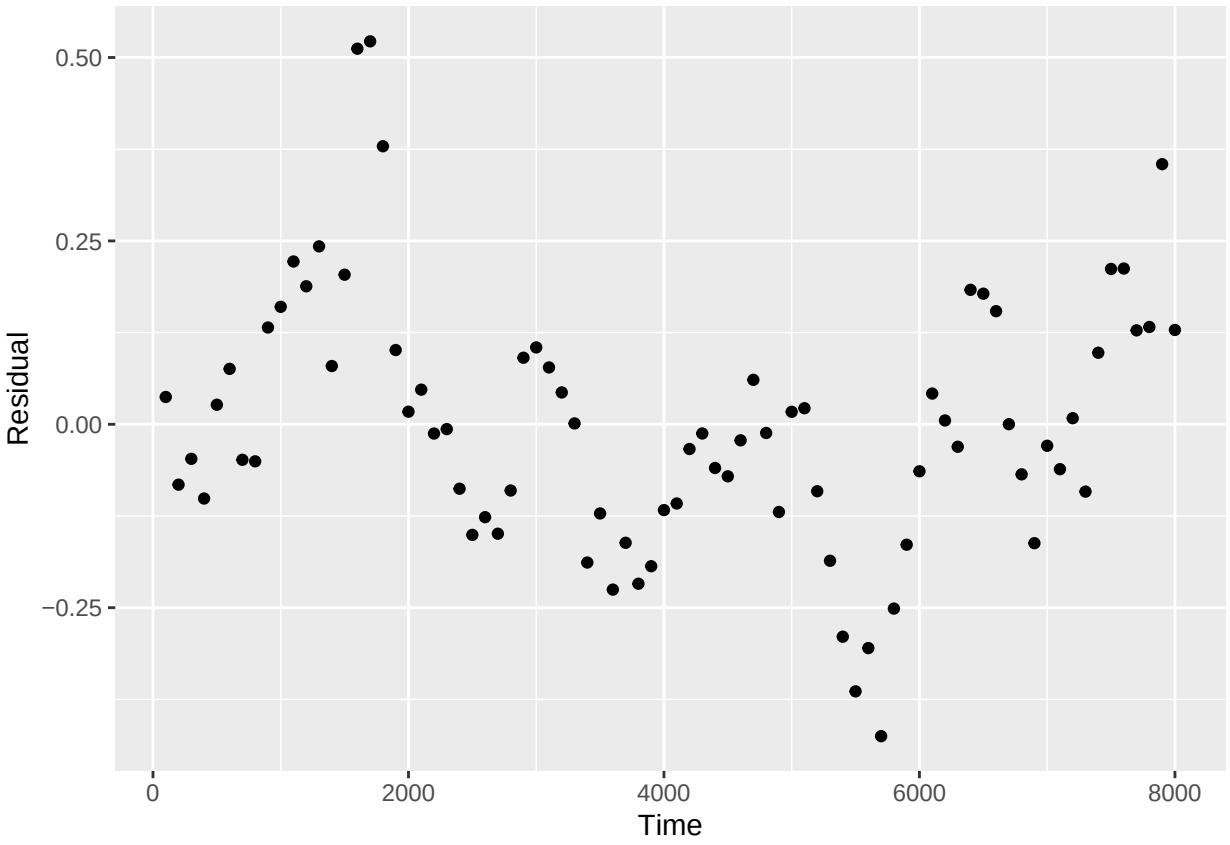
DHARMa scaled residual plots




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

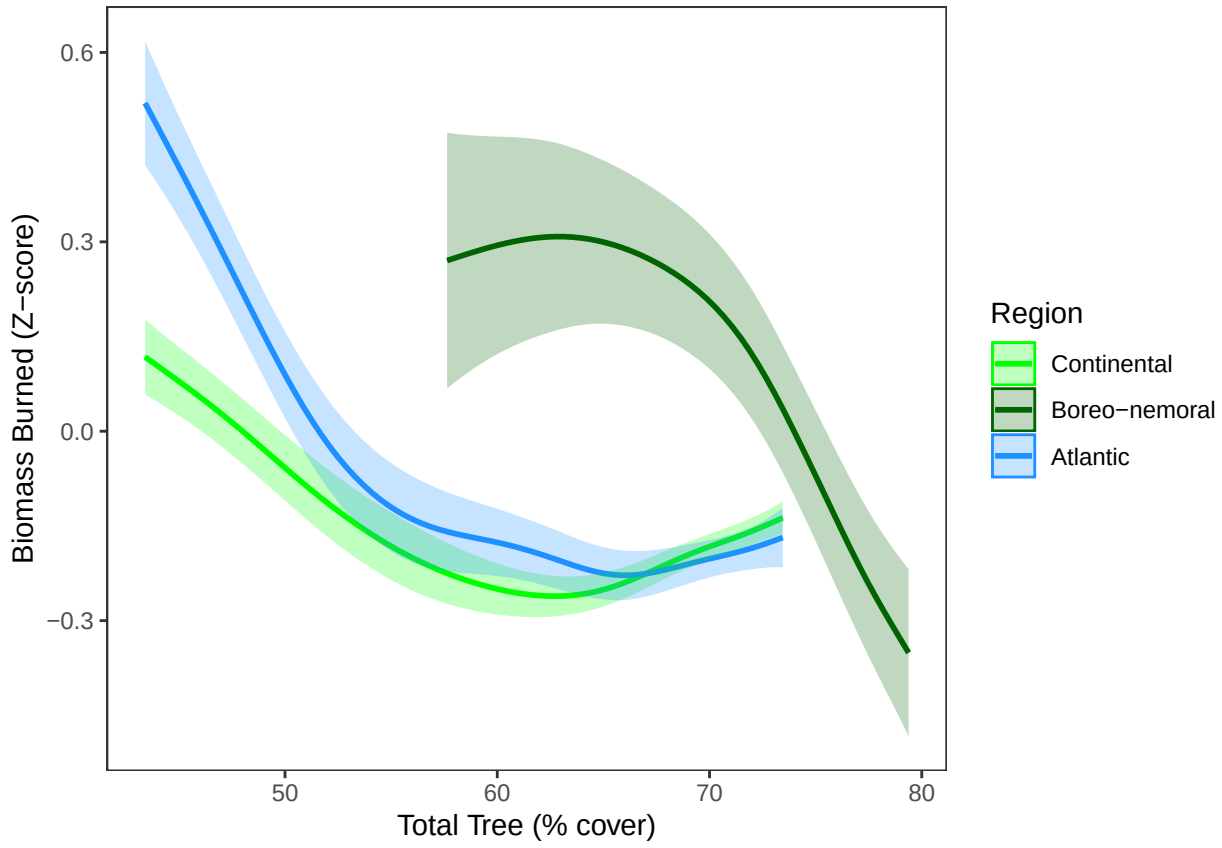



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.39587, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

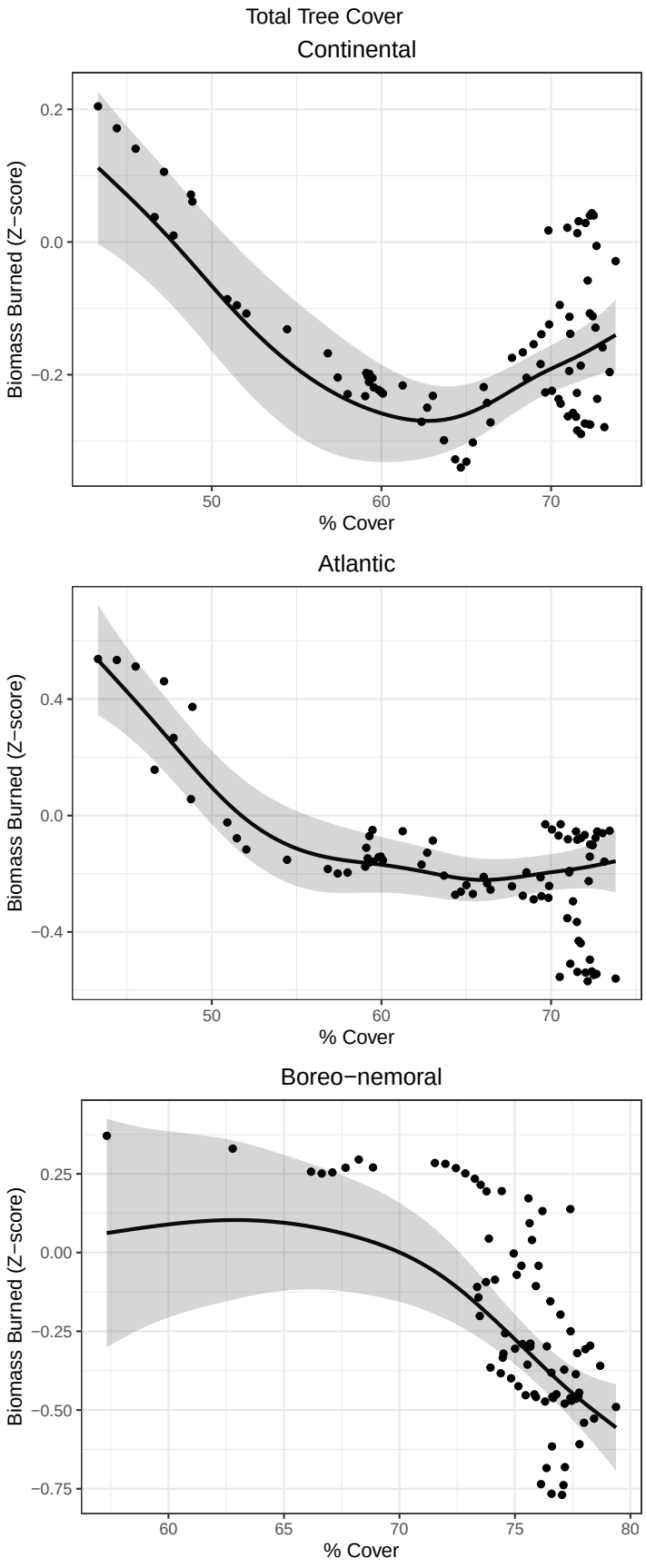


Total tree cover plot

Here we show the marginal response of biomass burned to total tree cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.


Biomass Burned (Z−score)
0.6
0.3
0.0
−0.3
50
60
70
80
Total Tree (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```

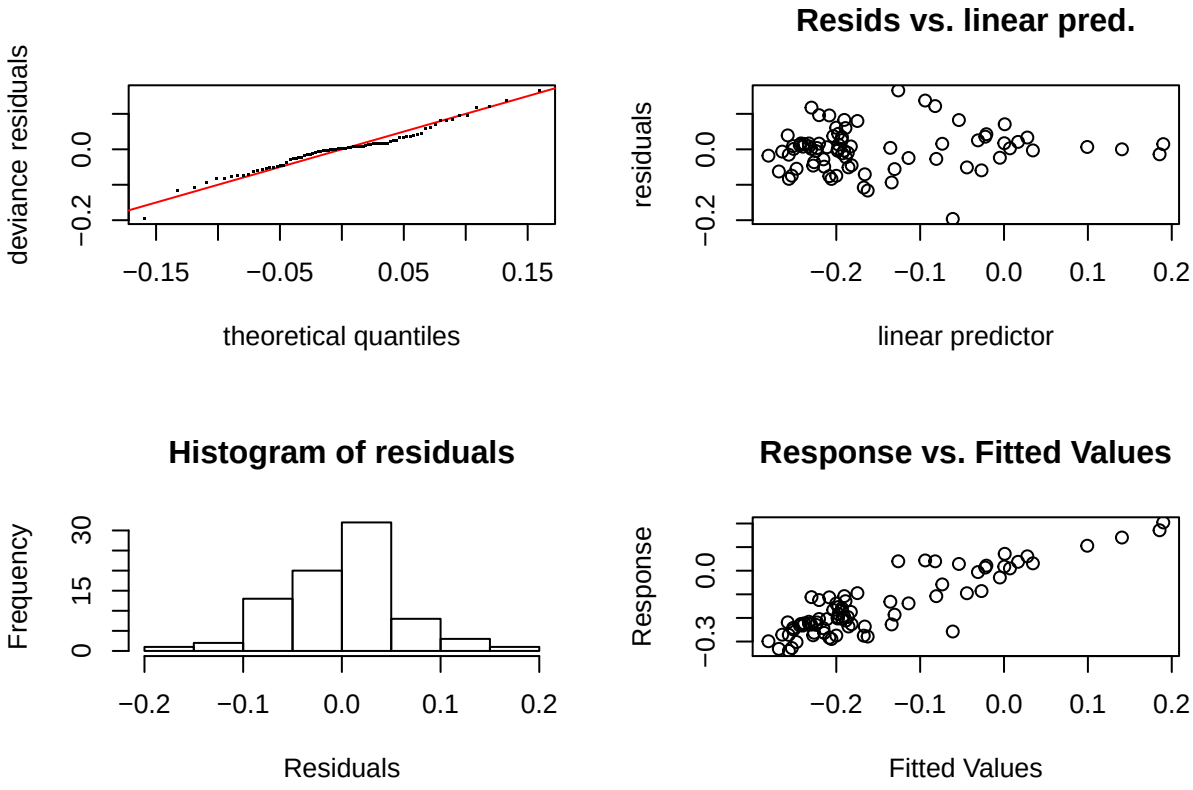

Total Tree Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
50
60
70
% Cover
Atlantic
Biomass Burned (Z−score)
0.4
0.0
−0.4
50
60
70
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.25
0.00
−0.25
−0.50
−0.75
60
65
70
75
80
% Cover

Broadleaf tree cover

Broadleaf tree cover, Continental ecoregion

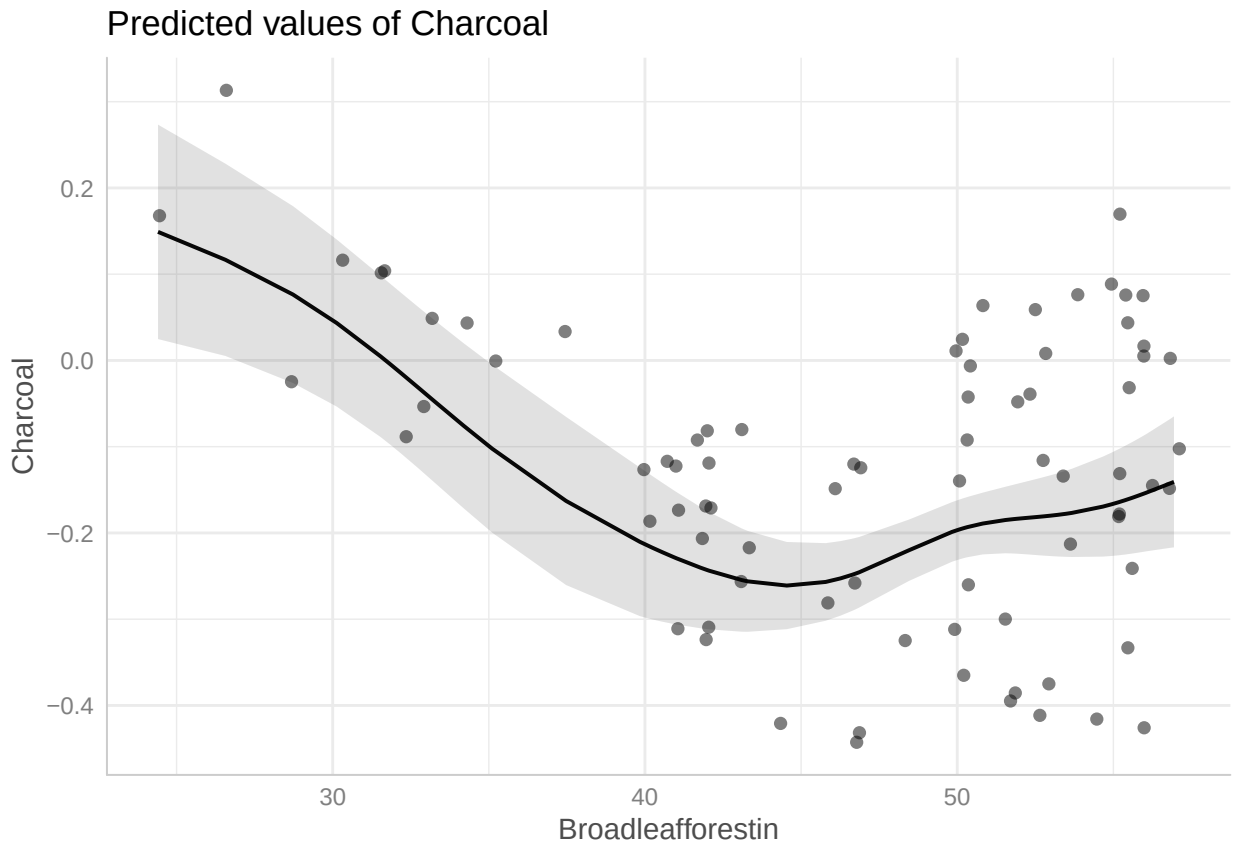
```
broad.continental <- charcoal.gam(Charcoal ~ s(Broadleafforestin) + s(Temperature)  + s(P.PET), data = A
```

```
## [1] "Checking GAM"
```

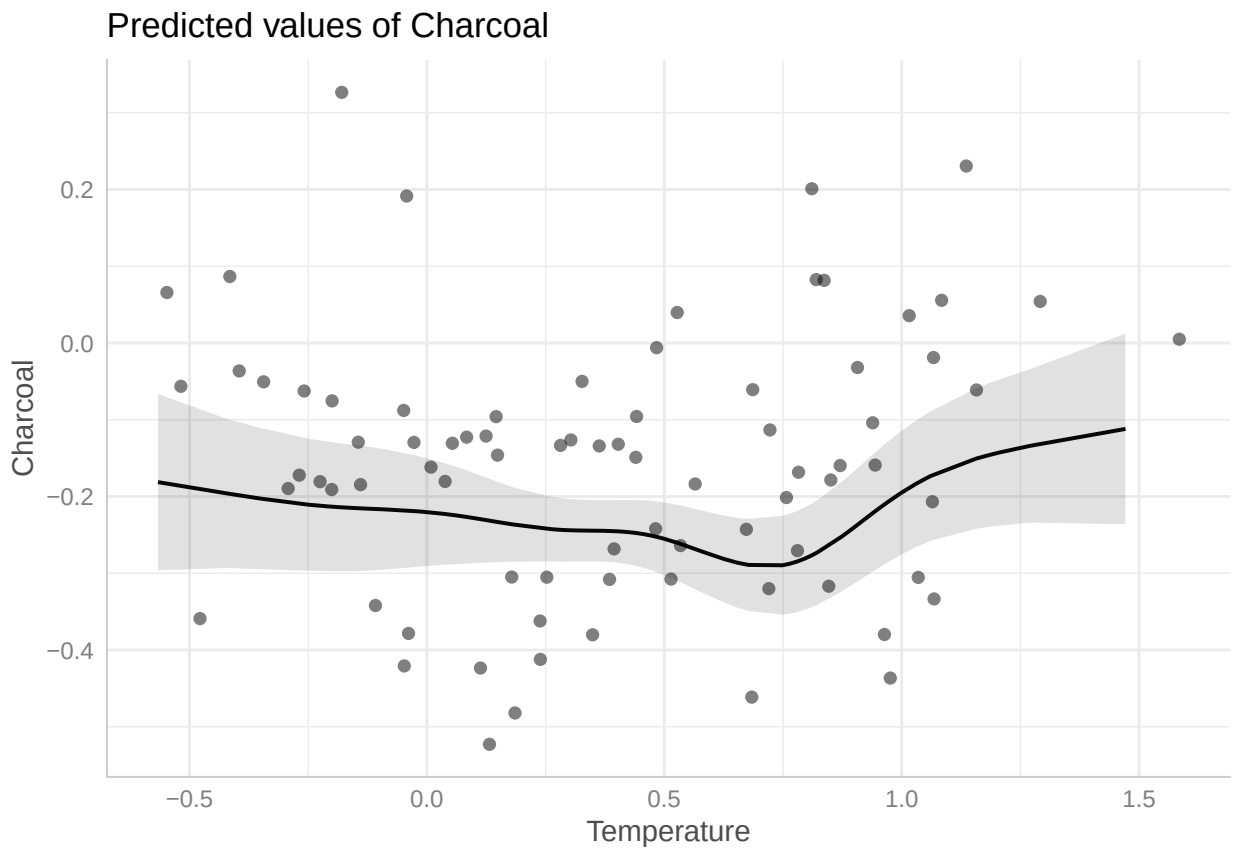



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-2.18593e-05,9.138687e-06]
## (score -87.9711 & scale 0.004071206).
## Hessian positive definite, eigenvalue range [4.691582e-07,39.76897].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                       k'  edf k-index p-value
## s(Broadleafforestin) 9.00 4.14    1.21    0.96
## s(Temperature)       9.00 4.92    1.05    0.65
## s(P.PET)             9.00 1.25    1.00    0.43
## $mfrow
```

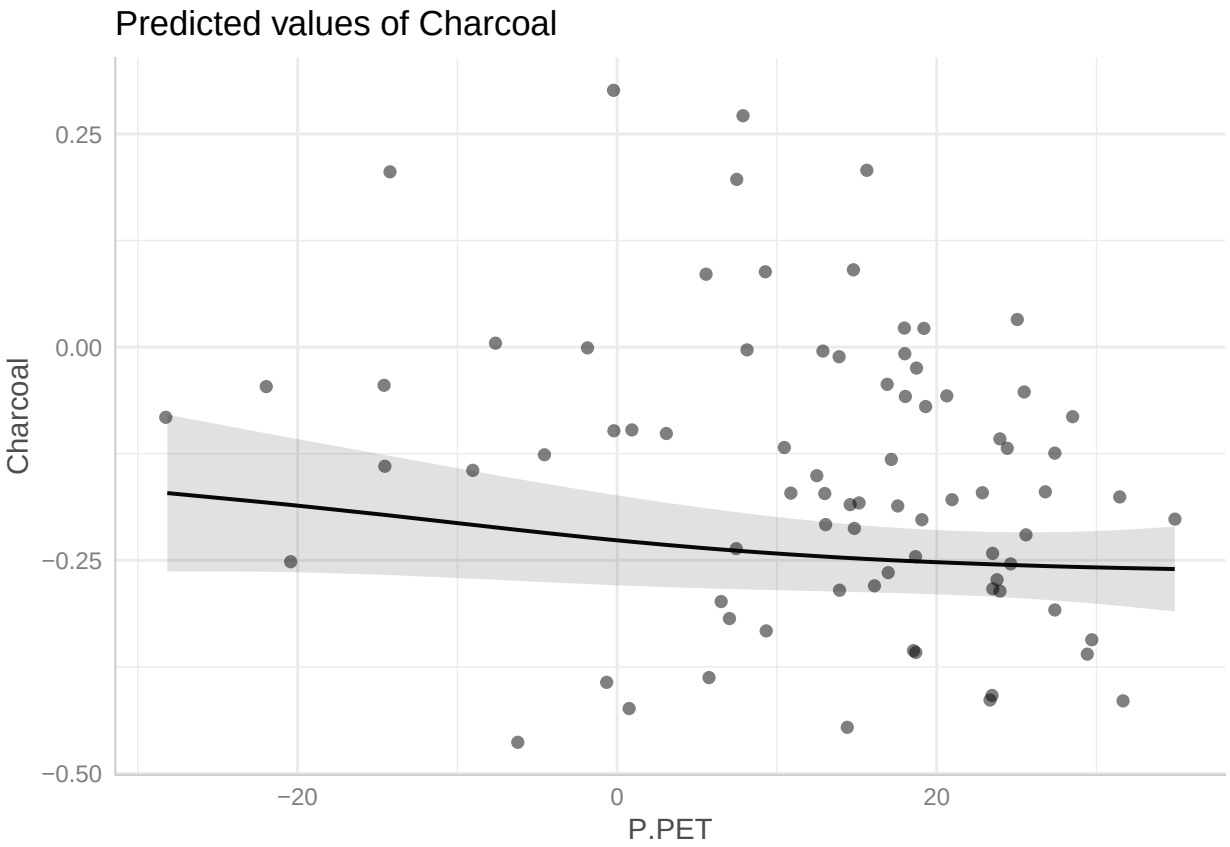
```
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Broadleafforestin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.007134  -20.95   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                         edf Ref.df     F  p-value
## s(Broadleafforestin) 4.142      9 9.222 6.54e-15 ***
## s(Temperature)       4.923      9 2.271 0.000542 ***
## s(P.PET)             1.248      9 0.416 0.049588 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.754   Deviance explained = 78.6%
## -REML = -87.971  Scale est. = 0.0040712  n = 80
## [1] "Plotting predictions"
## $Broadleafforestin
```

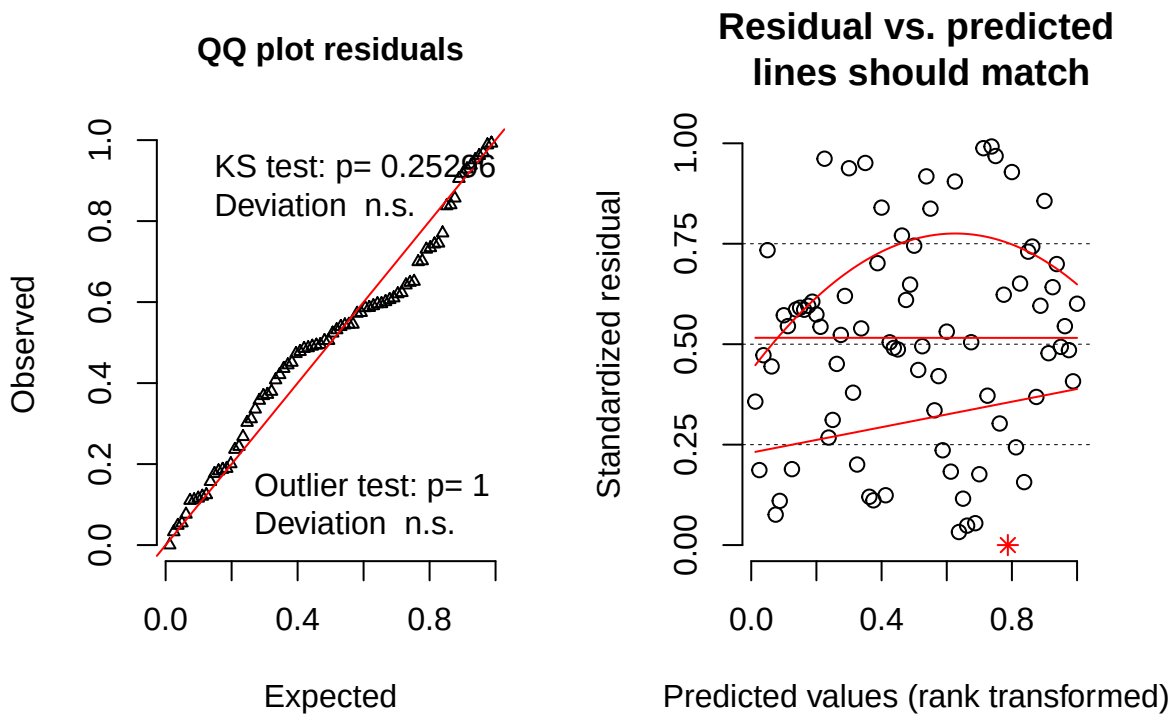



```
##
## $Temperature
```

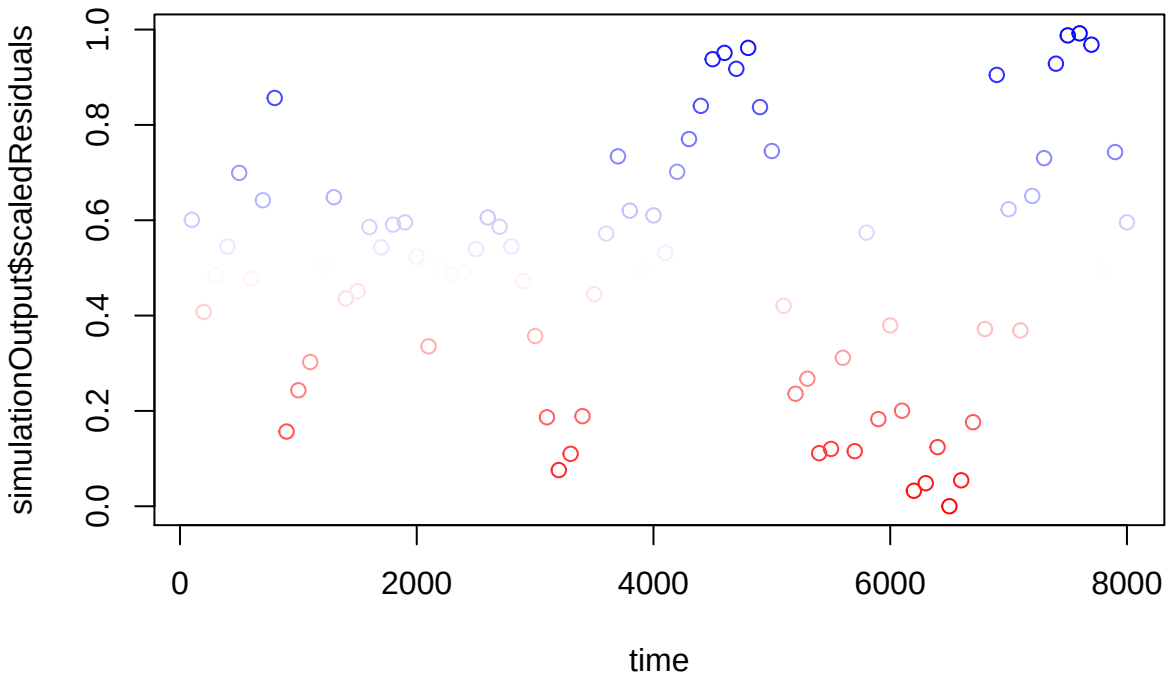

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−0.5
0.0
0.5
1.0
1.5
Temperature

```
##
## $P.PET
```

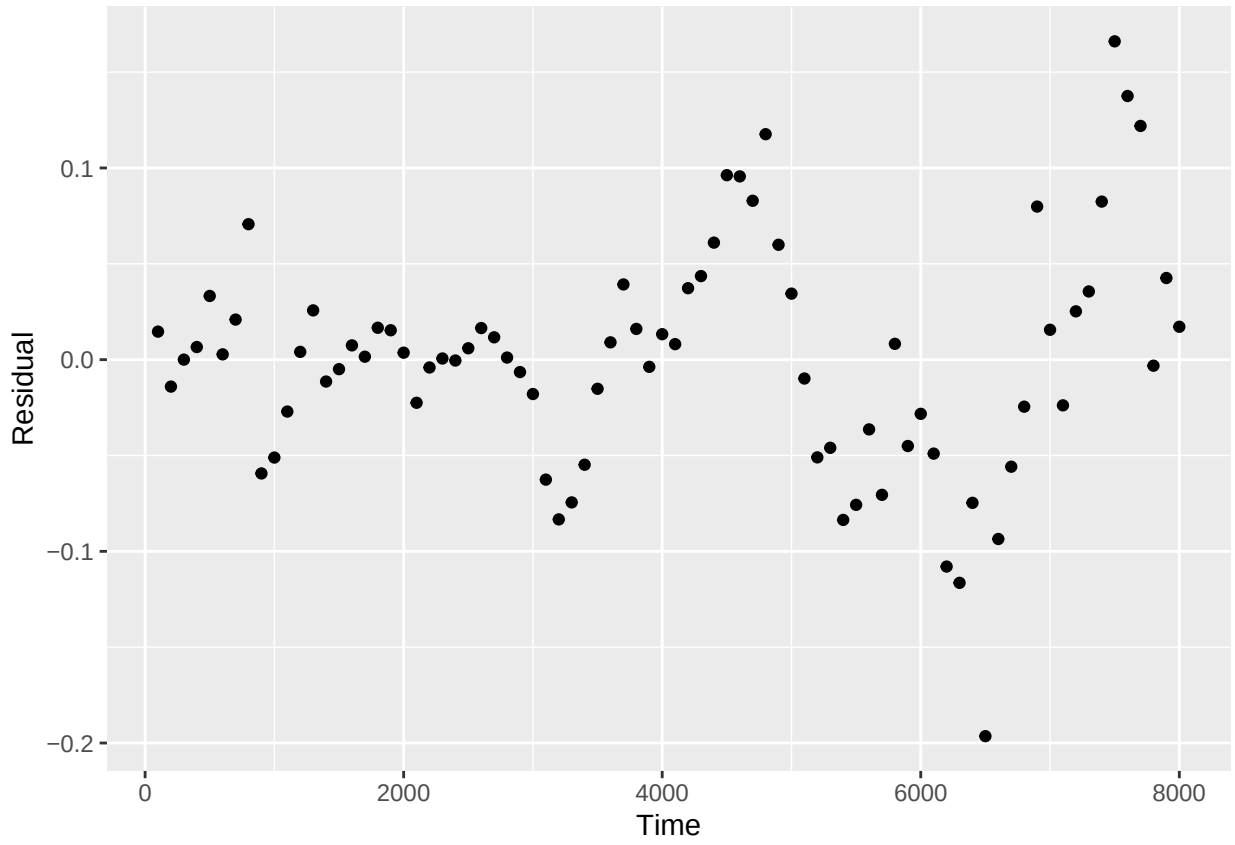

Predicted values of Charcoal
Charcoal
0.25
0.00
−0.25
−0.50
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



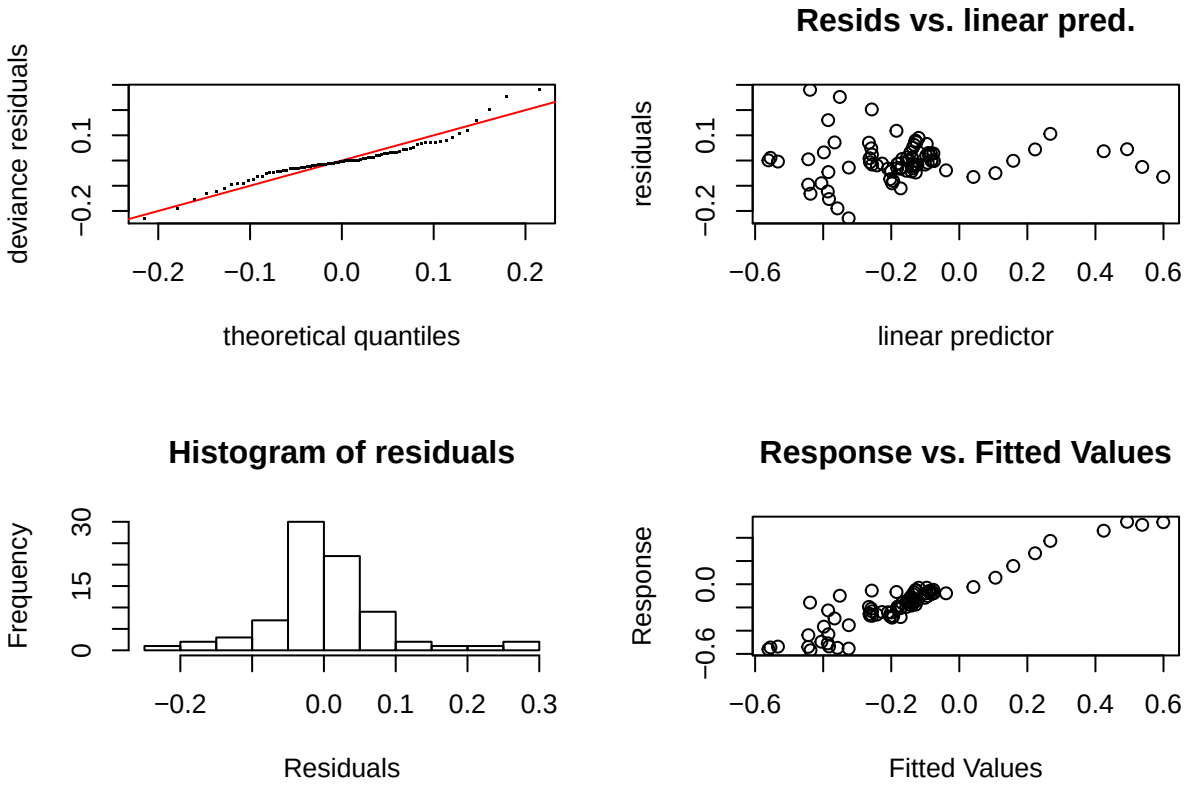

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.51413, p-value = 8.704e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Broadleaf tree cover, Atlantic ecoregion

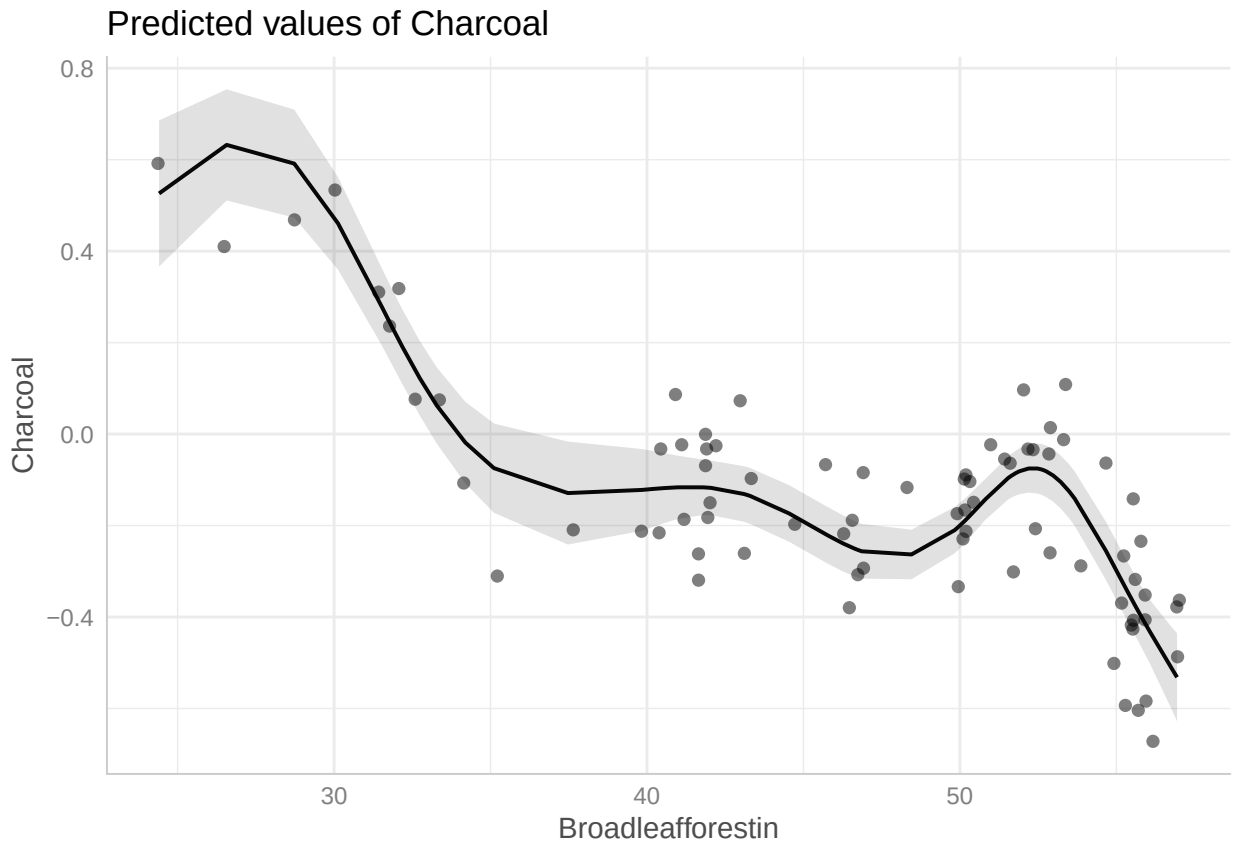
```
broad.atlantic <- charcoal.gam(Charcoal ~ s(Broadleafforestin) + s(Temperature)  + s(P.PET), data = All
```

```
## [1] "Checking GAM"
```

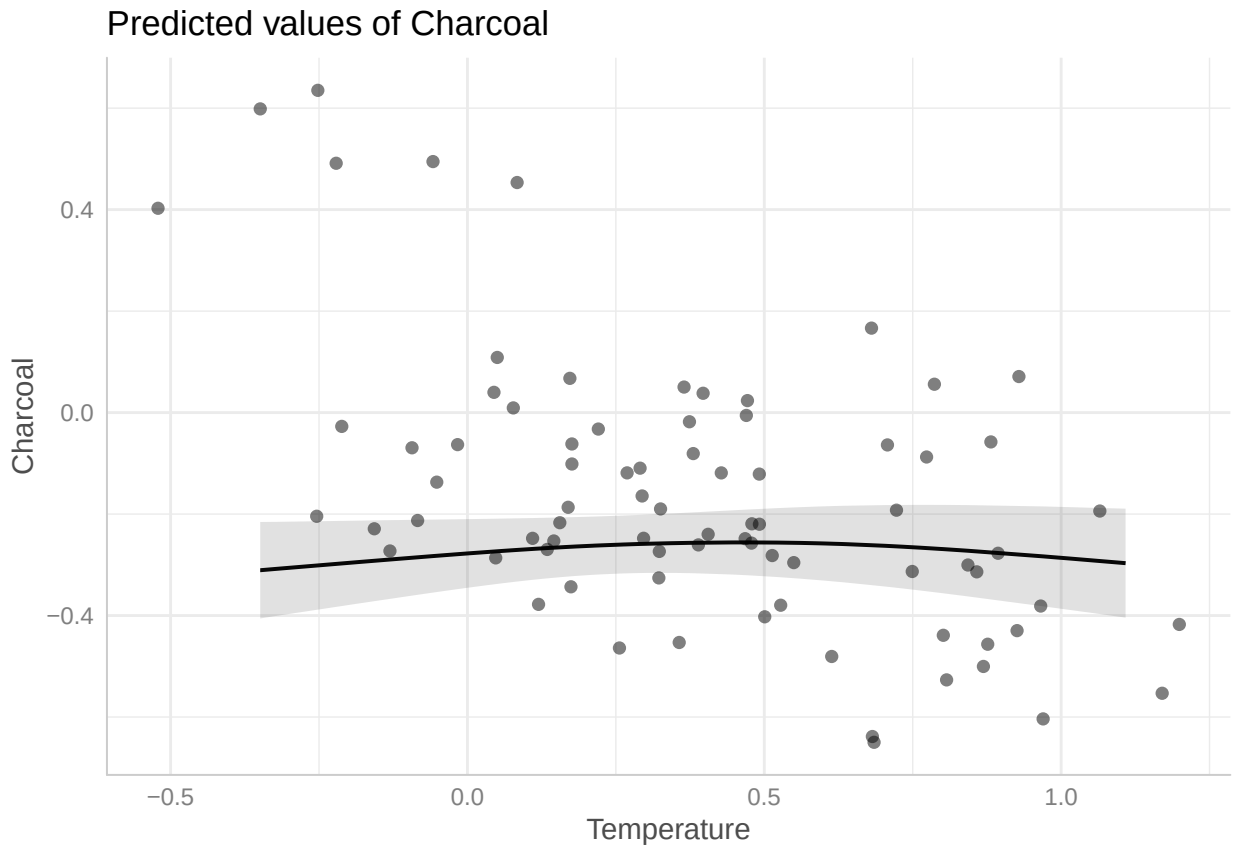



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-2.114109e-05,2.745618e-05]
## (score -61.12791 & scale 0.00741223).
## Hessian positive definite, eigenvalue range [4.647857e-07,39.8619].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                            k'      edf k-index p-value
## s(Broadleafforestin) 9.000000 7.813265    1.16    0.91
## s(Temperature)       9.000000 1.147403    1.24    0.99
## s(P.PET)             9.000000 0.000102    1.17    0.93
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Broadleafforestin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

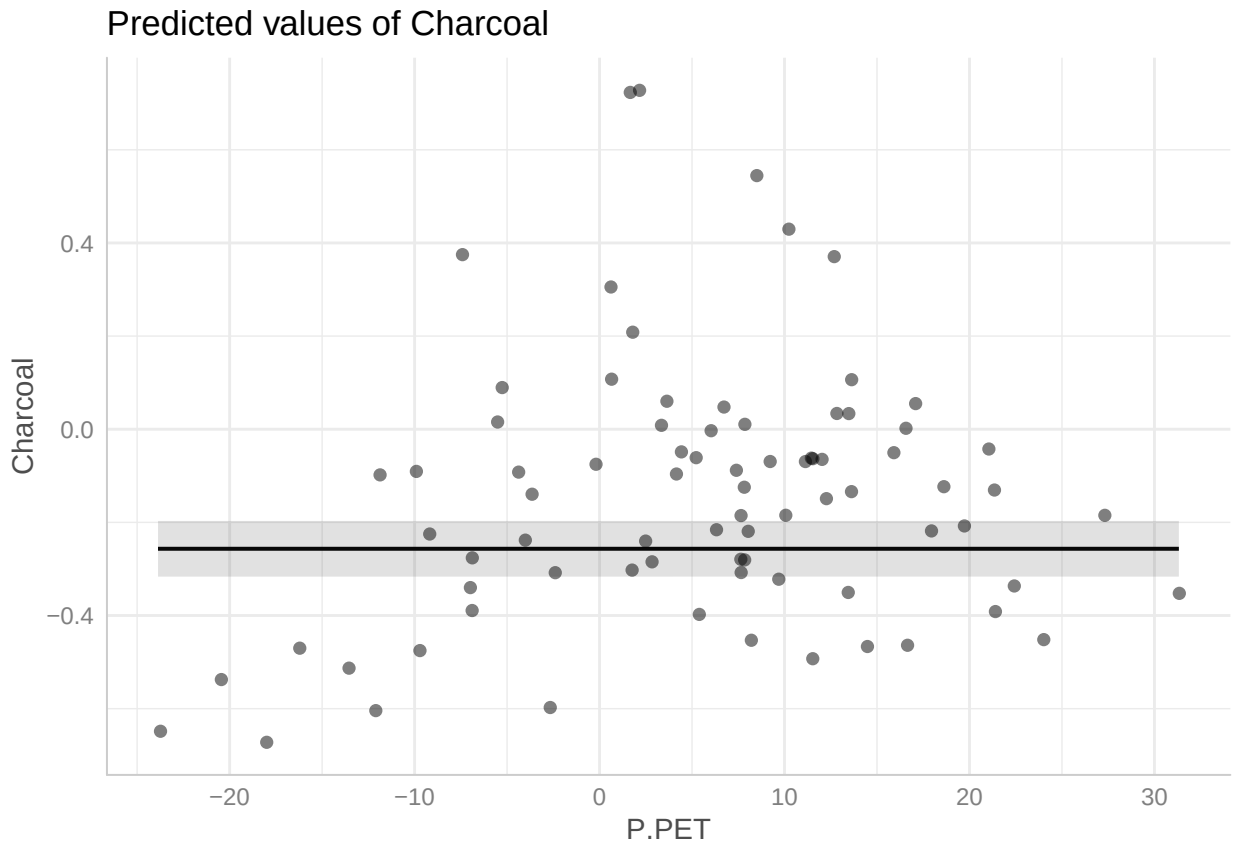
```
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.161603   0.009626  -16.79   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                             edf Ref.df      F p-value
## s(Broadleafforestin) 7.8132646      9 38.200  <2e-16 ***
## s(Temperature)       1.1474031      9  0.243   0.137
## s(P.PET)             0.0001023      9  0.000   0.509
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.869   Deviance explained = 88.4%
## -REML = -61.128  Scale est. = 0.0074122  n = 80
## [1] "Plotting predictions"
## $Broadleafforestin
```

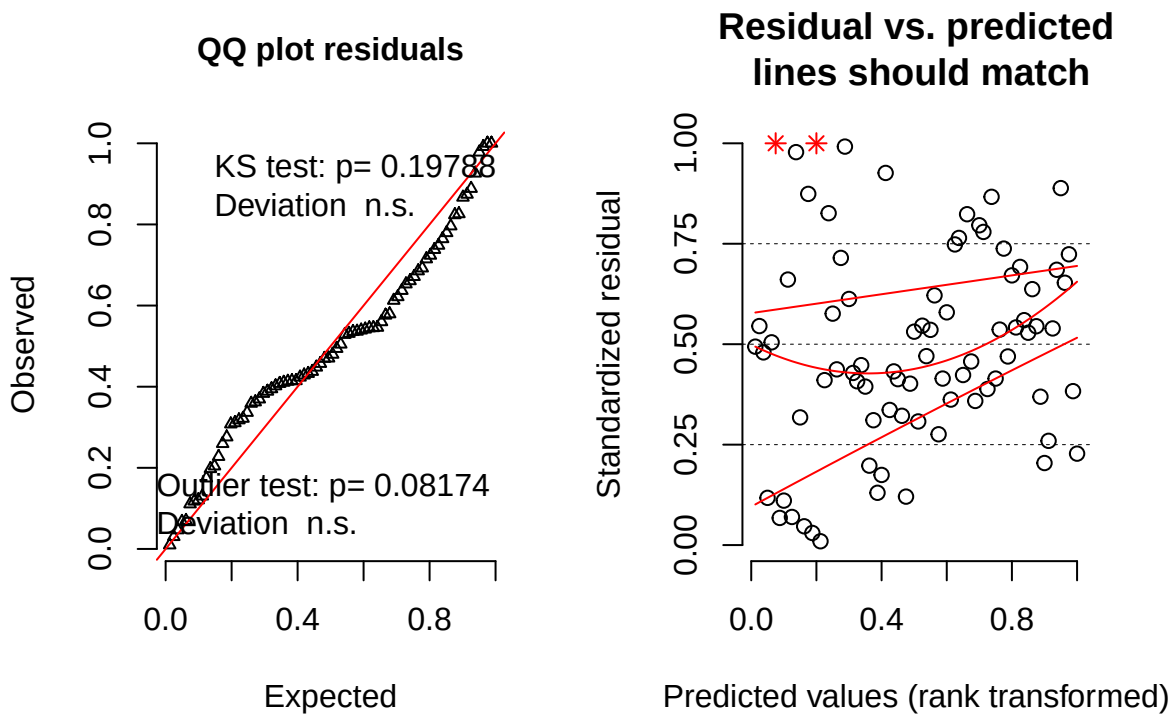



```
##
## $Temperature
```

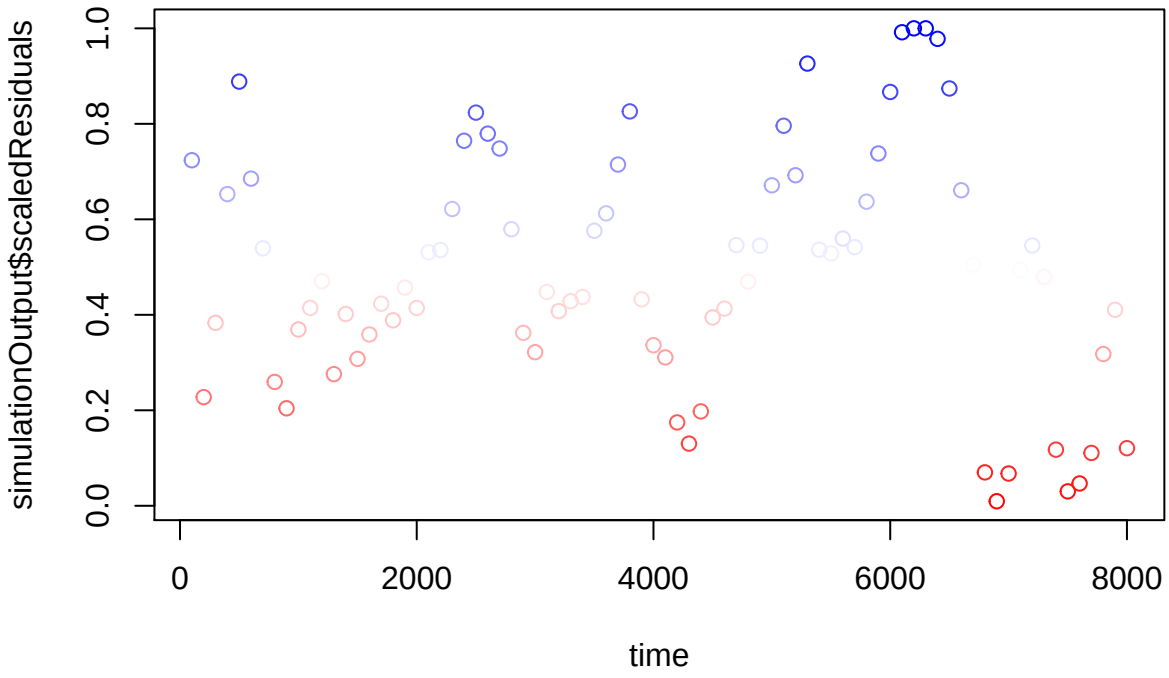

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

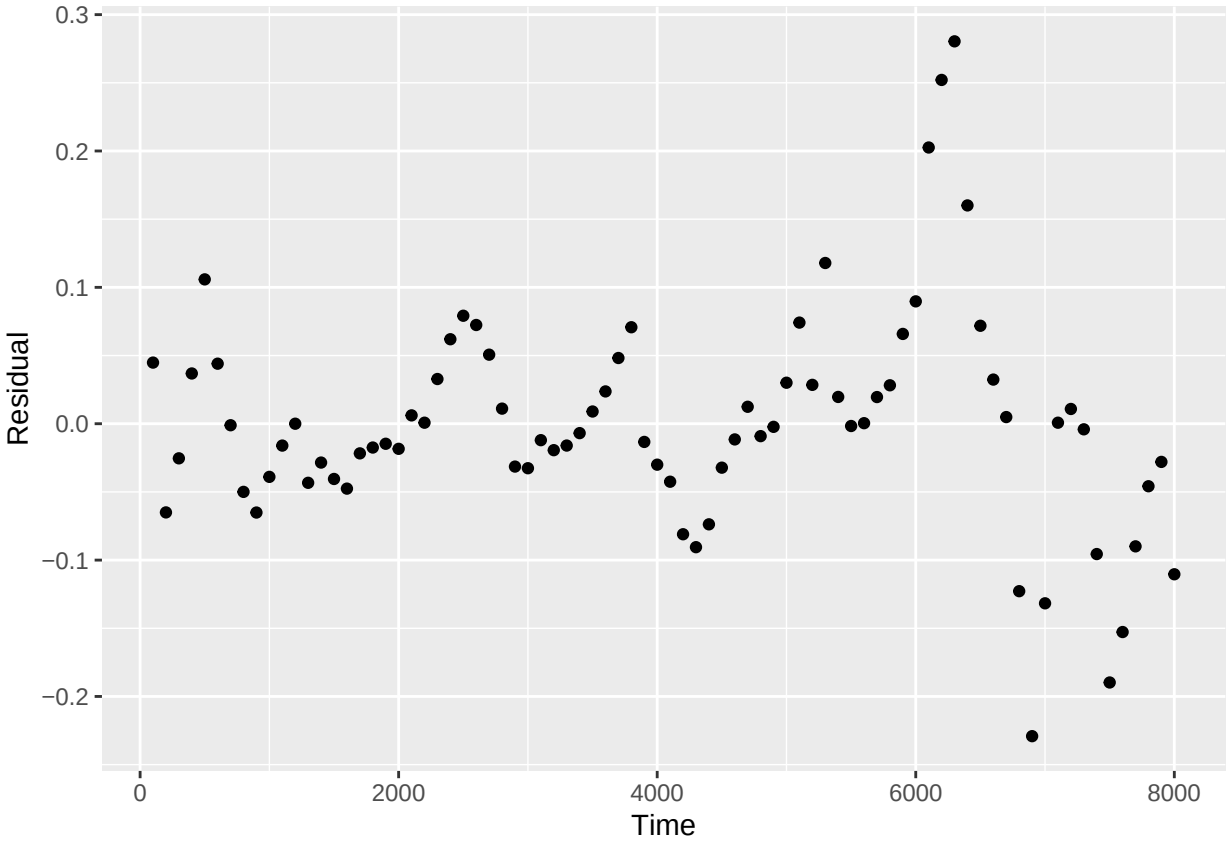

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



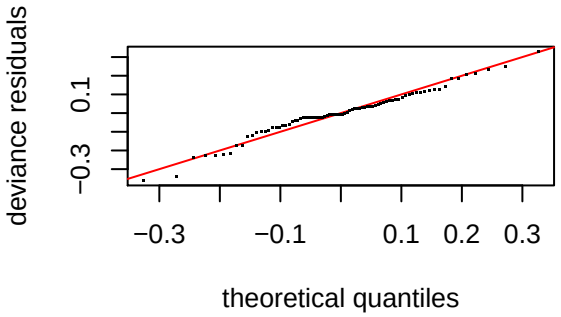

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.43924, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

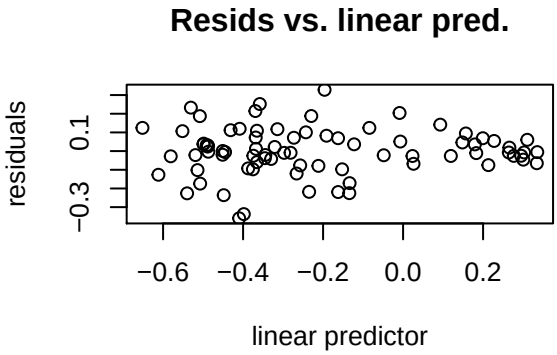


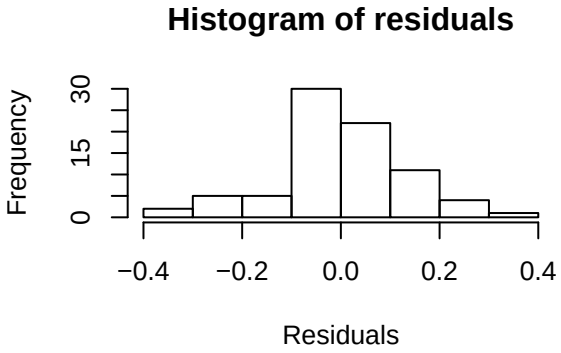
Broadleaf tree cover, Boreo-Nemoral ecoregion

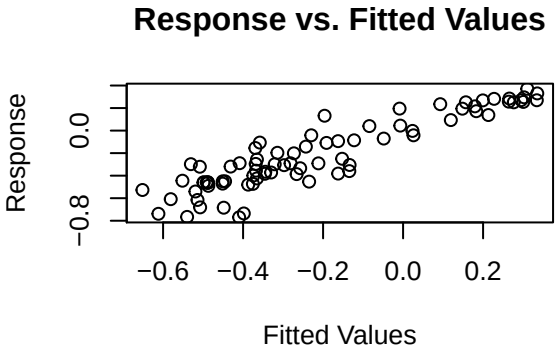
```
broad.boreonemoral <- charcoal.gam(Charcoal ~ s(Broadleafforestin) + s(Temperature)  + s(P.PET), data =
```

```
## [1] "Checking GAM"
```



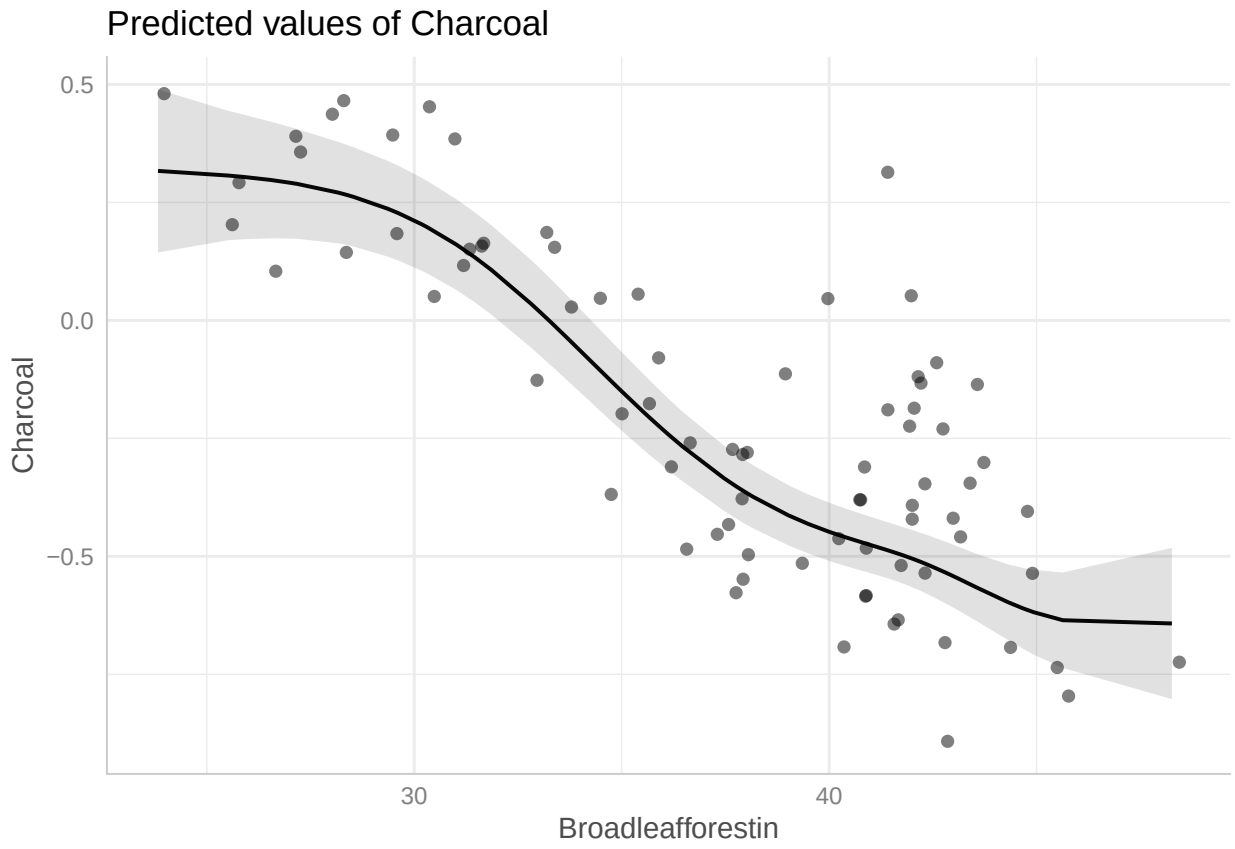




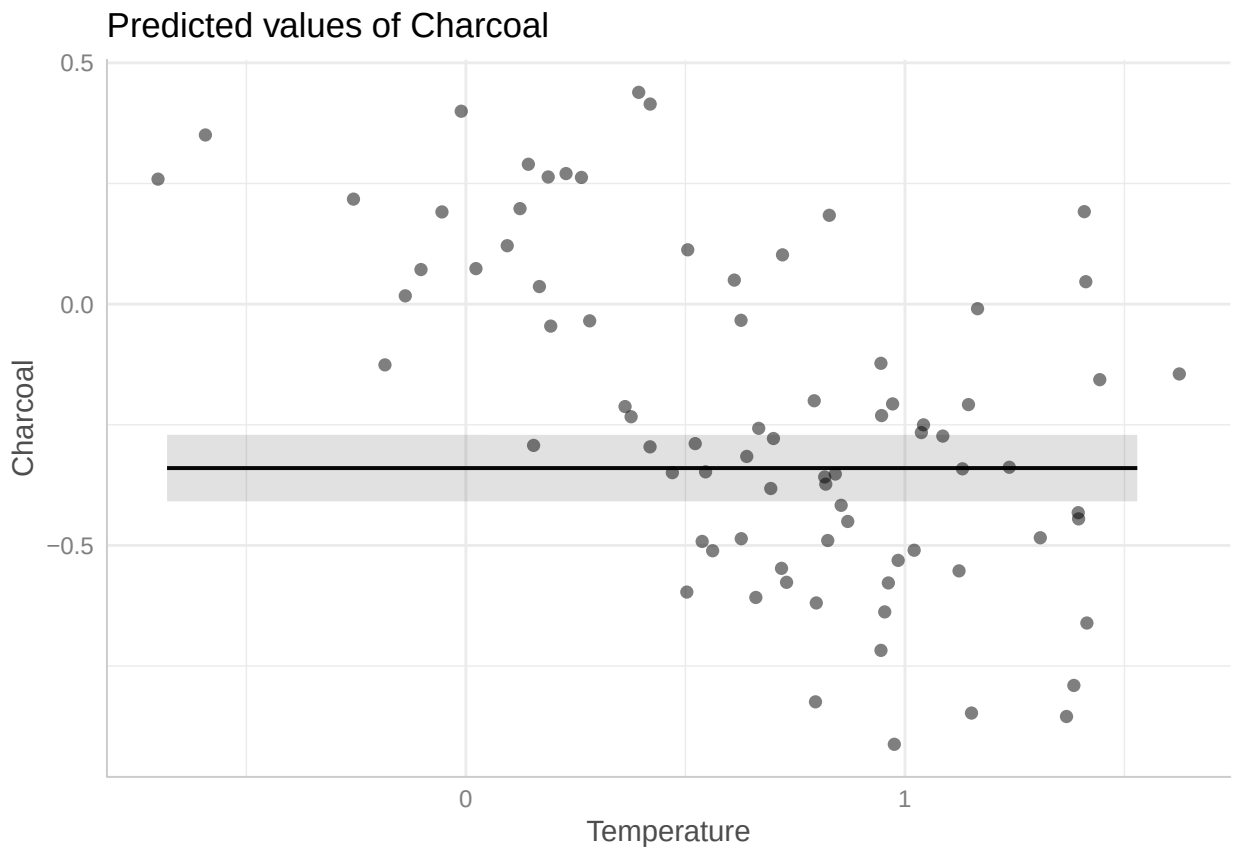



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-1.643455e-05,2.894894e-05]
## (score -36.93374 & scale 0.01706061).
## Hessian positive definite, eigenvalue range [6.704241e-07,39.64722].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                             k'      edf k-index p-value
## s(Broadleafforestin) 9.00e+00 4.12e+00    1.14    0.86
## s(Temperature)       9.00e+00 9.05e-05    0.87    0.11
## s(P.PET)             9.00e+00 2.74e+00    1.05    0.59
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Broadleafforestin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

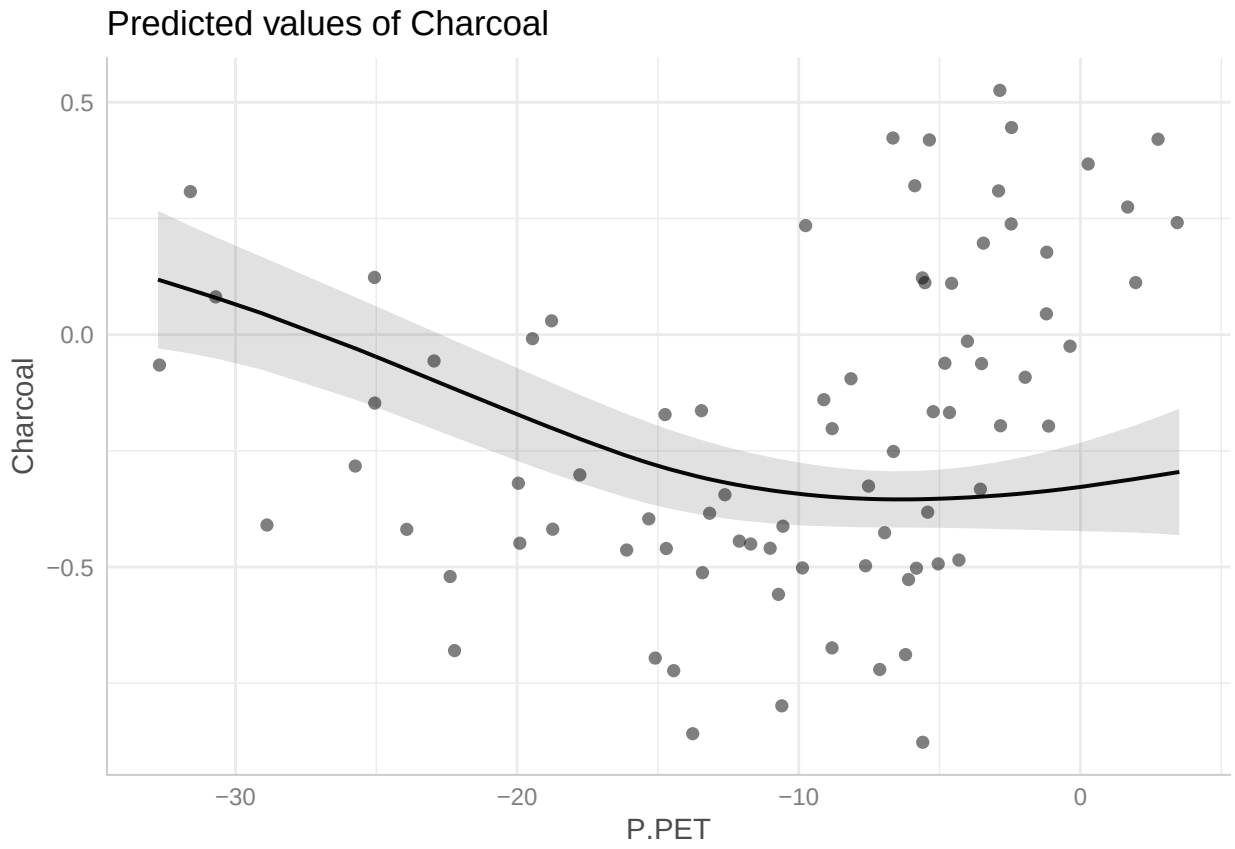
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.2104     0.0146  -14.41   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                            edf Ref.df      F  p-value
## s(Broadleafforestin) 4.123e+00      9 22.479  < 2e-16 ***
## s(Temperature)       9.049e-05      9  0.000    0.515
## s(P.PET)             2.740e+00      9  5.693 1.97e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.828   Deviance explained = 84.3%
## -REML = -36.934  Scale est. = 0.017061  n = 80
## [1] "Plotting predictions"
## $Broadleafforestin
```

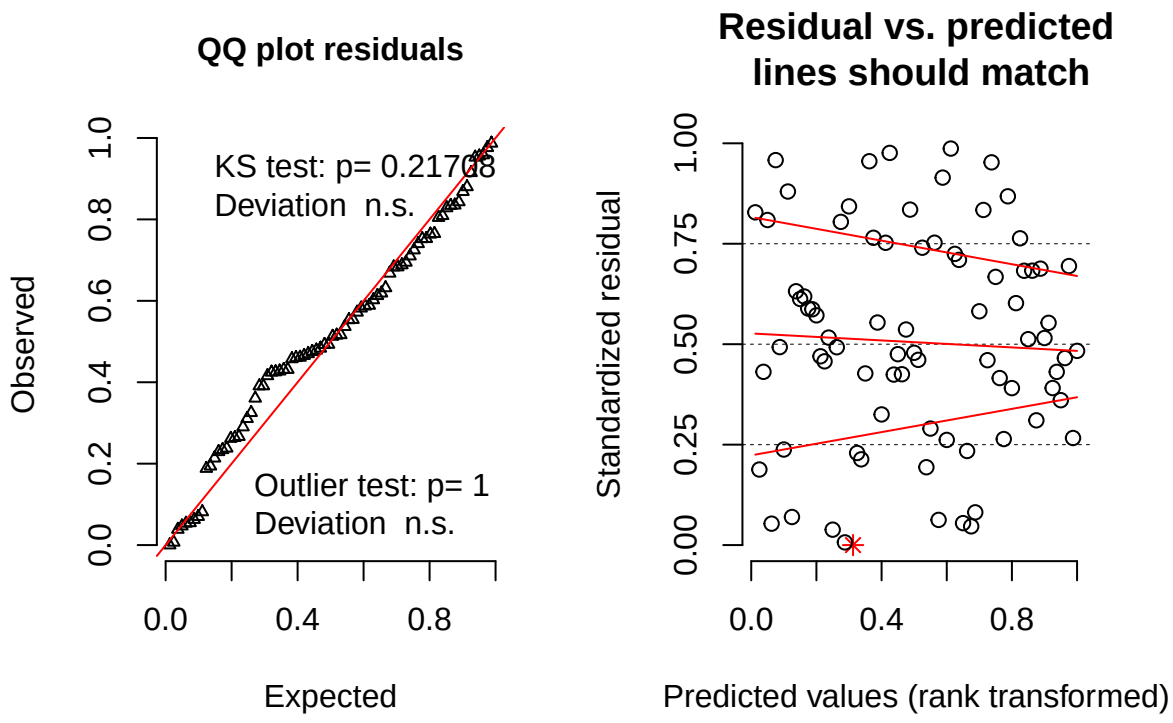



```
##
## $Temperature
```

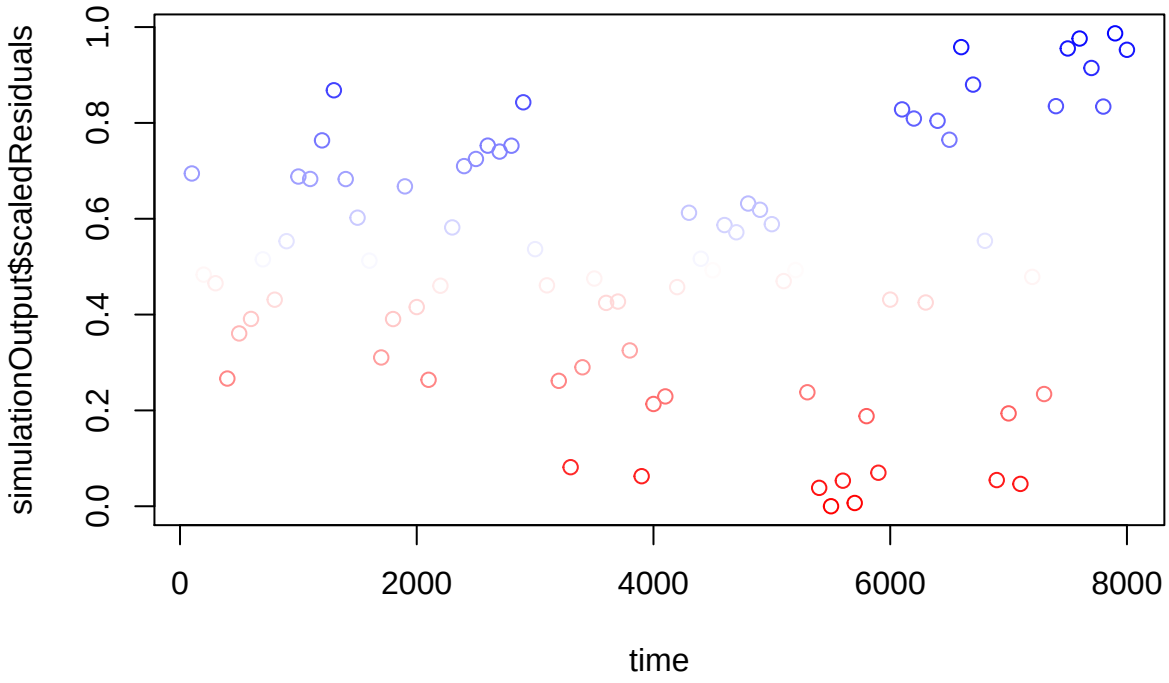

Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
0
1
Temperature

```
##
## $P.PET
```

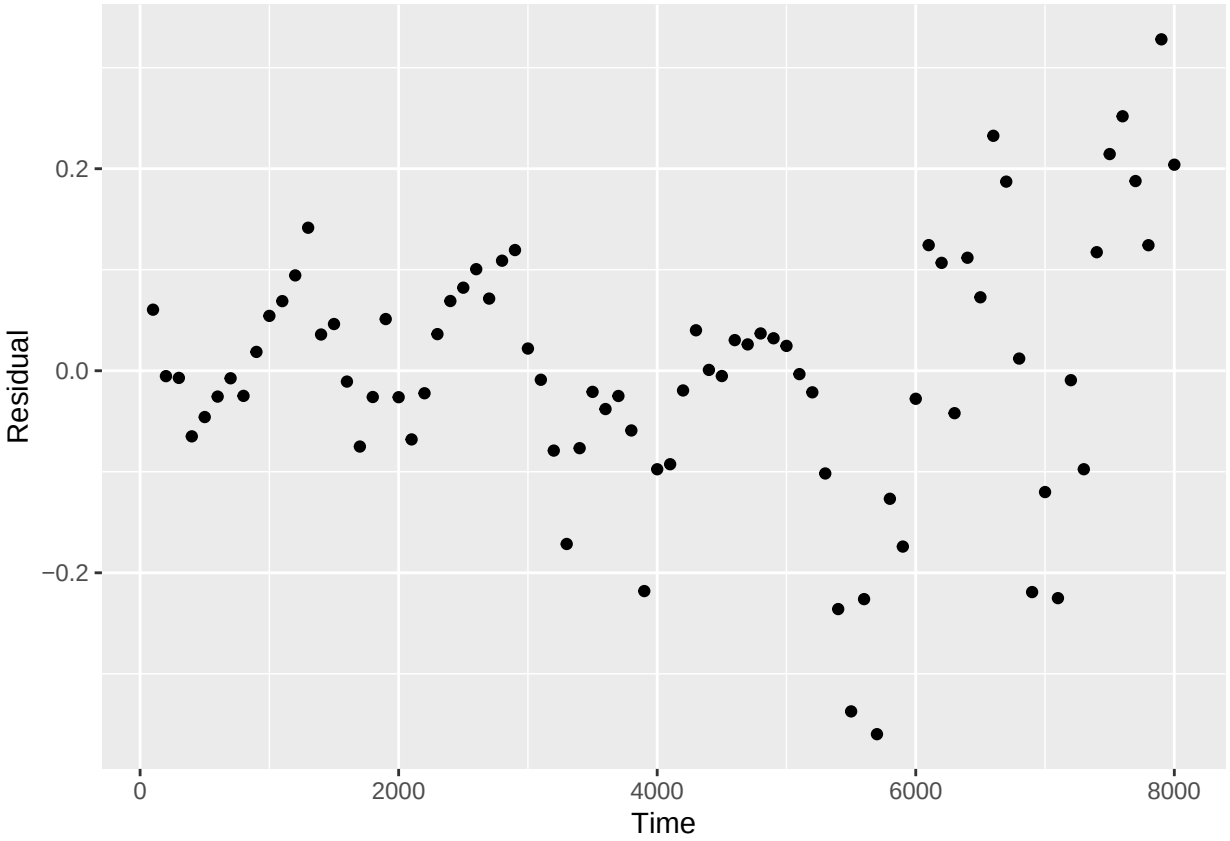

Predicted values of Charcoal
Charcoal
0.5
0.0
−0.5
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

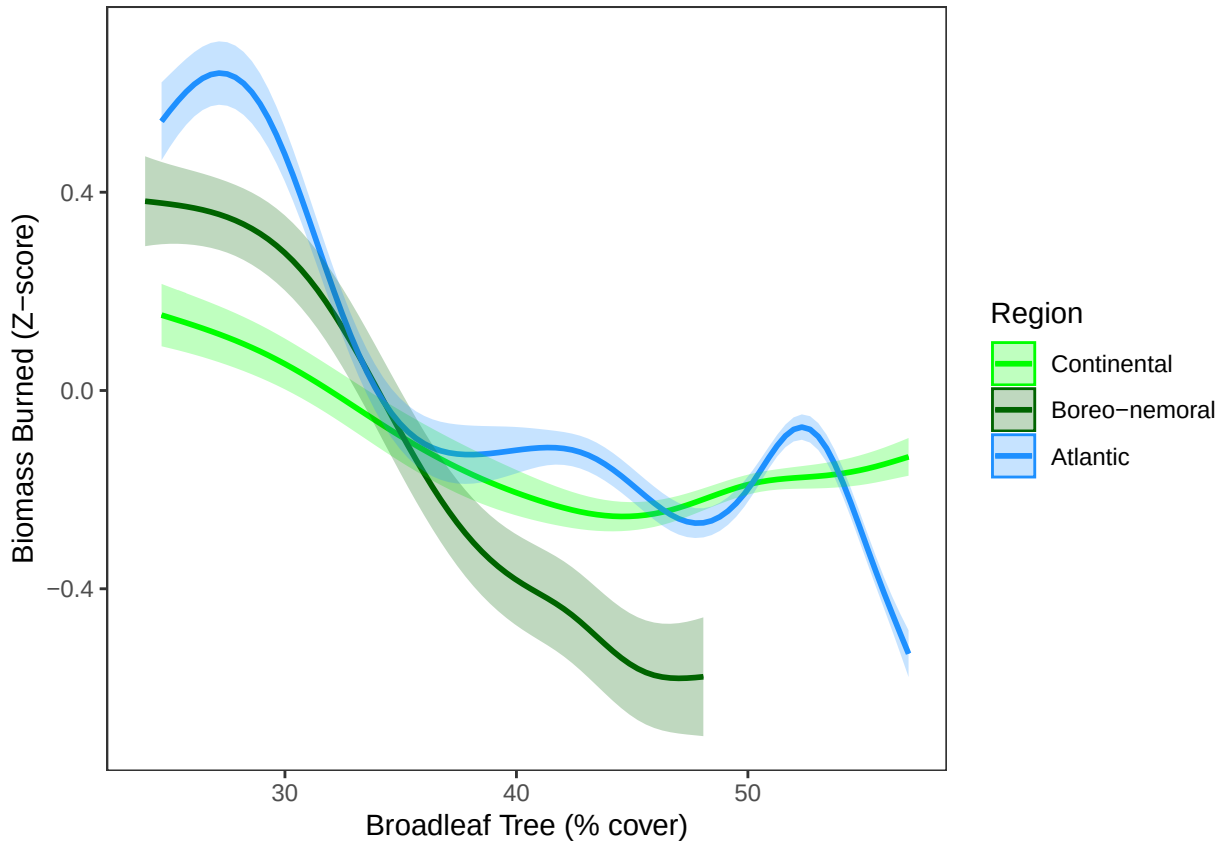



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.50639, p-value = 5.12e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

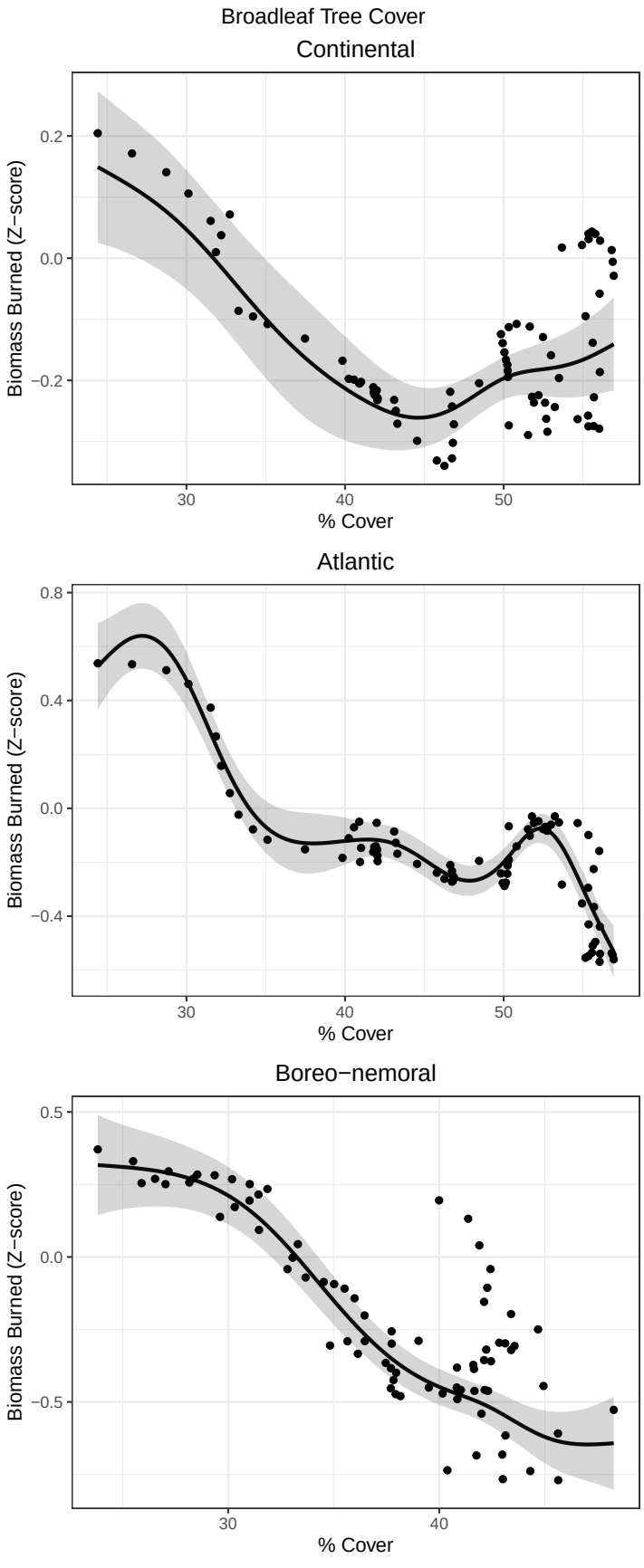


Broadleaf tree cover plot

Here we show the marginal response of biomass burned to broadleaf forest cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.


Biomass Burned (Z−score)
0.4
0.0
−0.4
30
40
50
Broadleaf Tree (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```

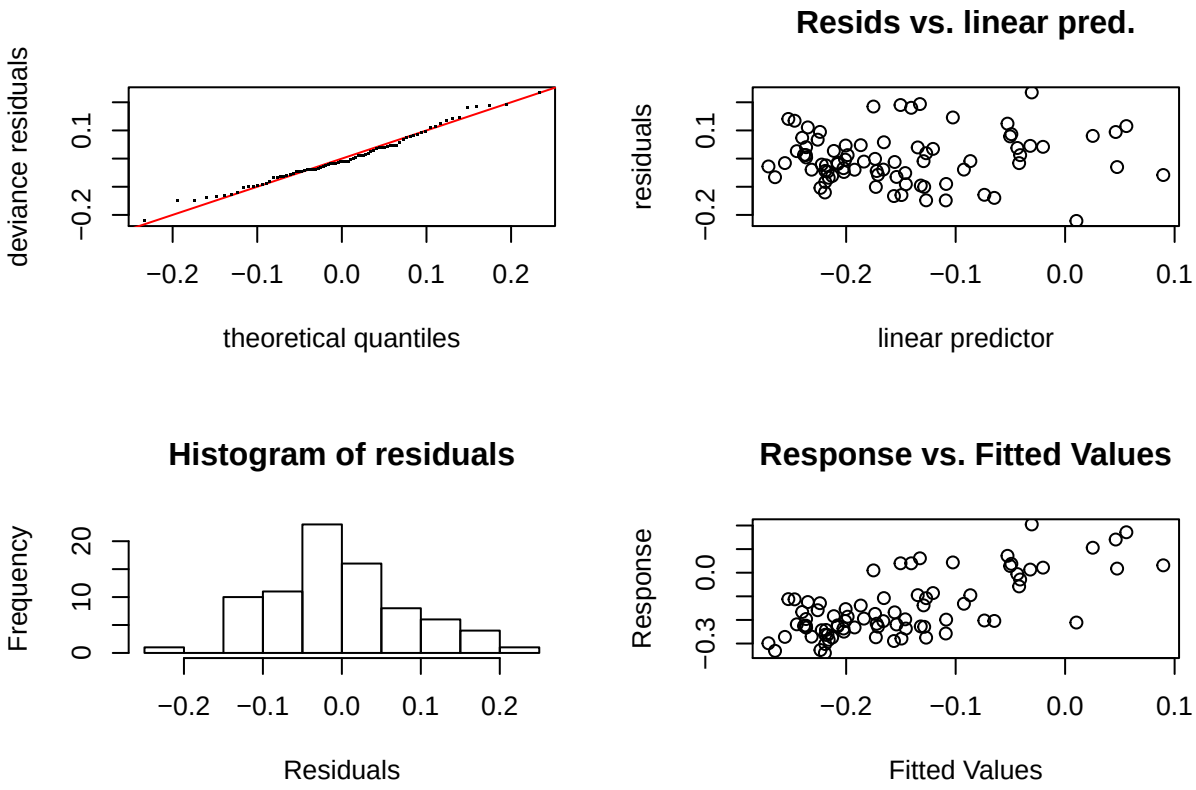

Broadleaf Tree Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
30
40
50
% Cover
Atlantic
Biomass Burned (Z−score)
0.8
0.4
0.0
−0.4
30
40
50
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.5
0.0
−0.5
30
40
% Cover

Needleleaf tree cover

Needleleaf tree cover, Continental ecoregion

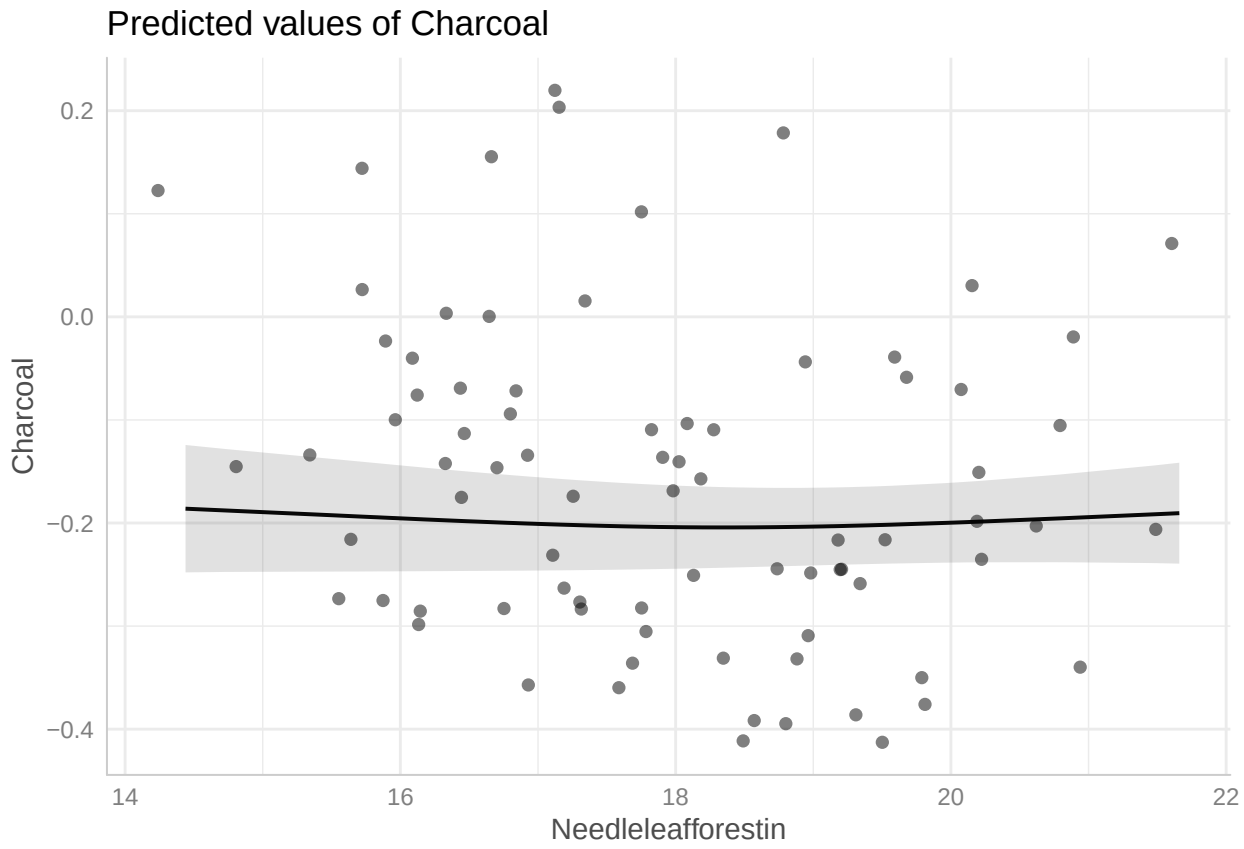
```
needle.continental <- charcoal.gam(Charcoal ~ s(Needleleafforestin) + s(Temperature)  + s(P.PET), data =
```

```
## [1] "Checking GAM"
```

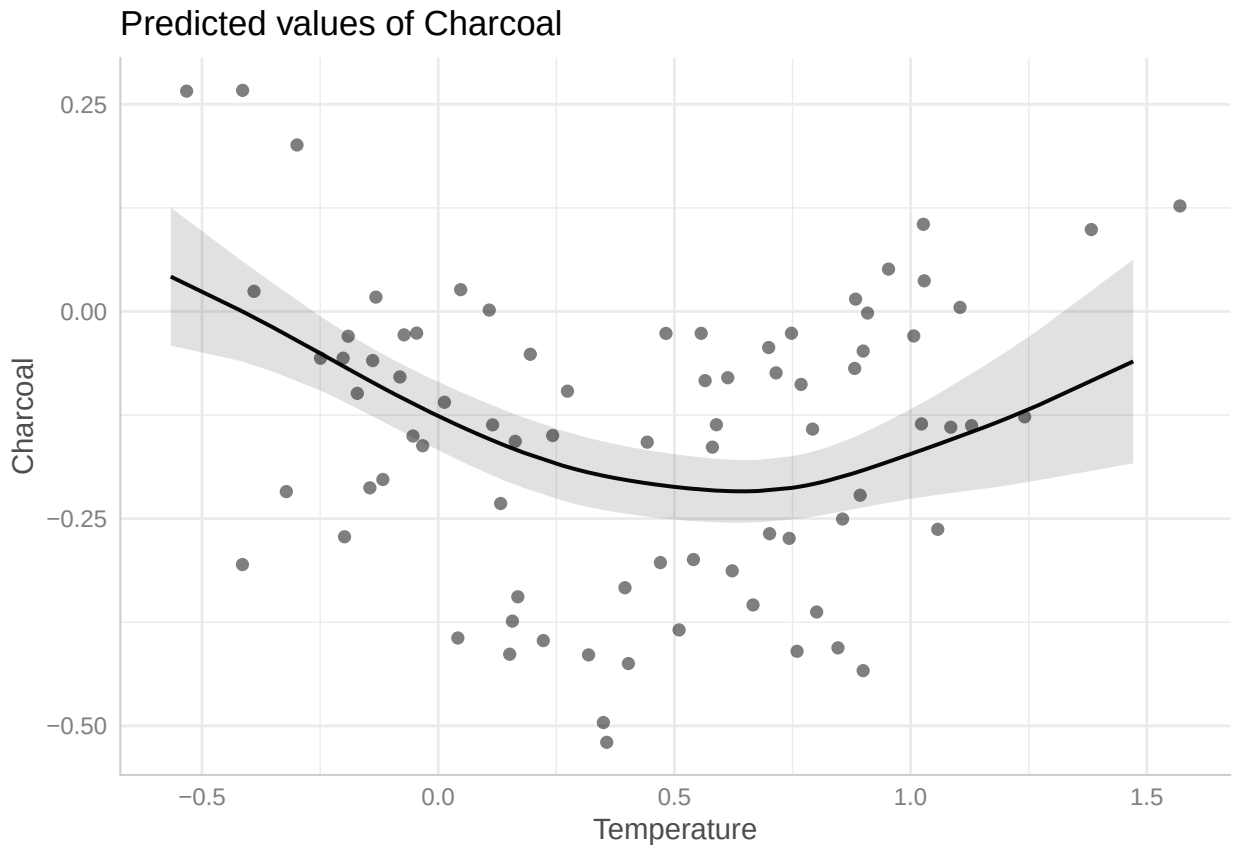



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-3.671855e-05,3.482512e-05]
## (score -67.52341 & scale 0.008724176).
## Hessian positive definite, eigenvalue range [5.017568e-07,39.55758].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                          k'   edf k-index p-value
## s(Needleleafforestin) 9.000 0.607    1.12    0.84
## s(Temperature)        9.000 2.767    0.99    0.43
## s(P.PET)              9.000 0.922    1.26    0.98
## $mfrow
```

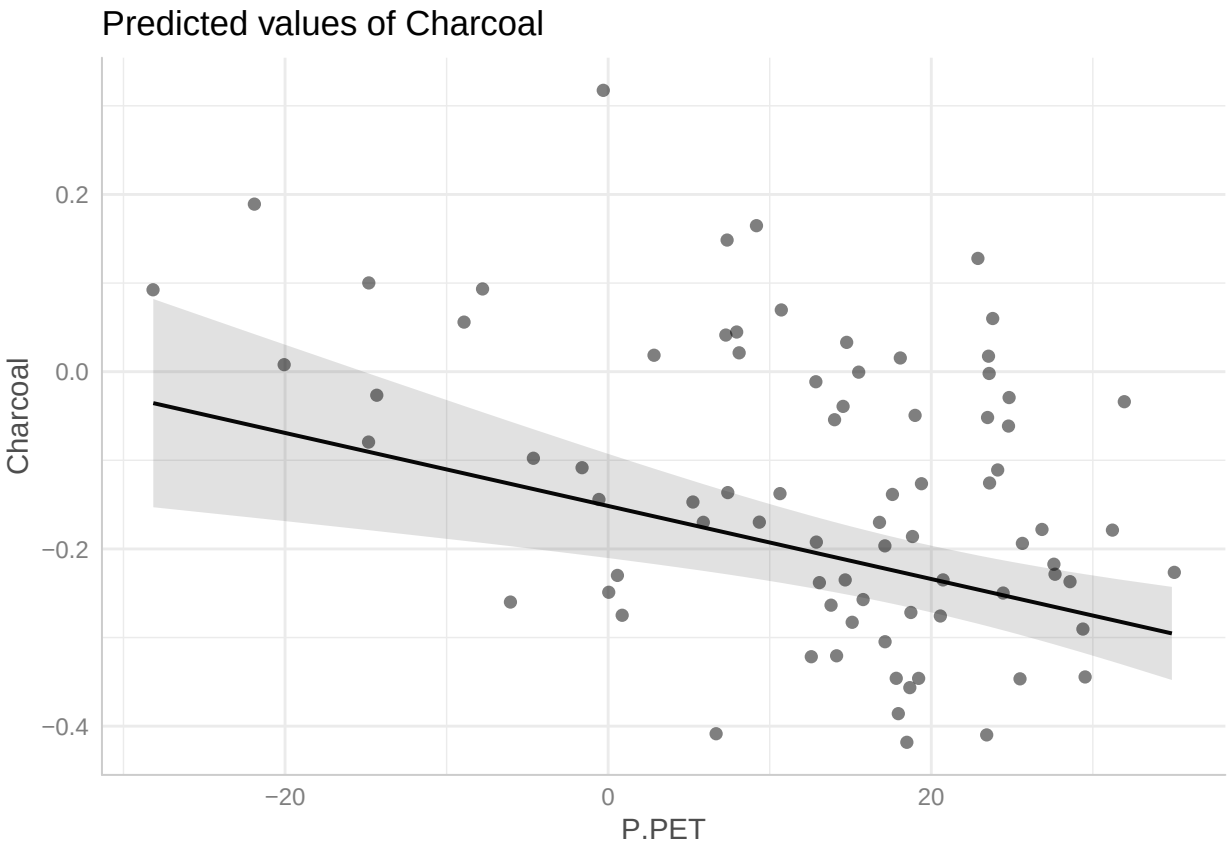
```
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Needleleafforestin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.14942    0.01044  -14.31   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                           edf Ref.df     F  p-value
## s(Needleleafforestin) 0.6073      9 0.082  0.26172
## s(Temperature)        2.7671      9 3.920 5.58e-08 ***
## s(P.PET)              0.9223      9 1.316  0.00038 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.472   Deviance explained = 50.1%
## -REML = -67.523  Scale est. = 0.0087242  n = 80
## [1] "Plotting predictions"
## $Needleleafforestin
```

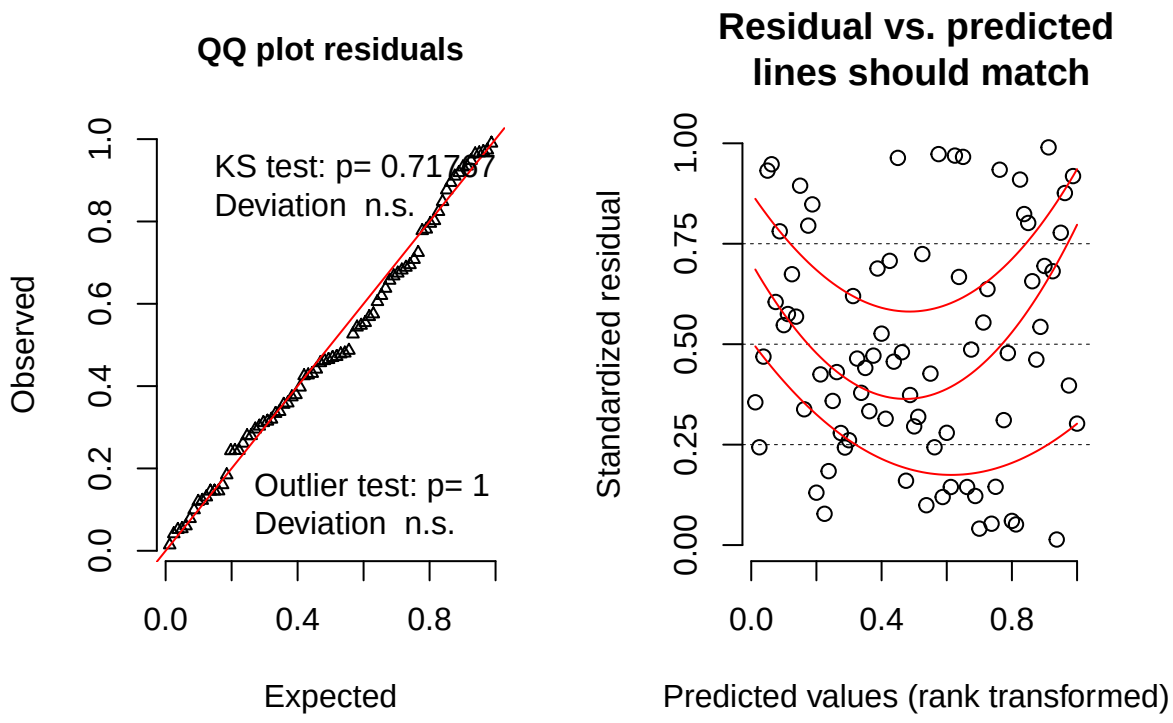



```
##
## $Temperature
```

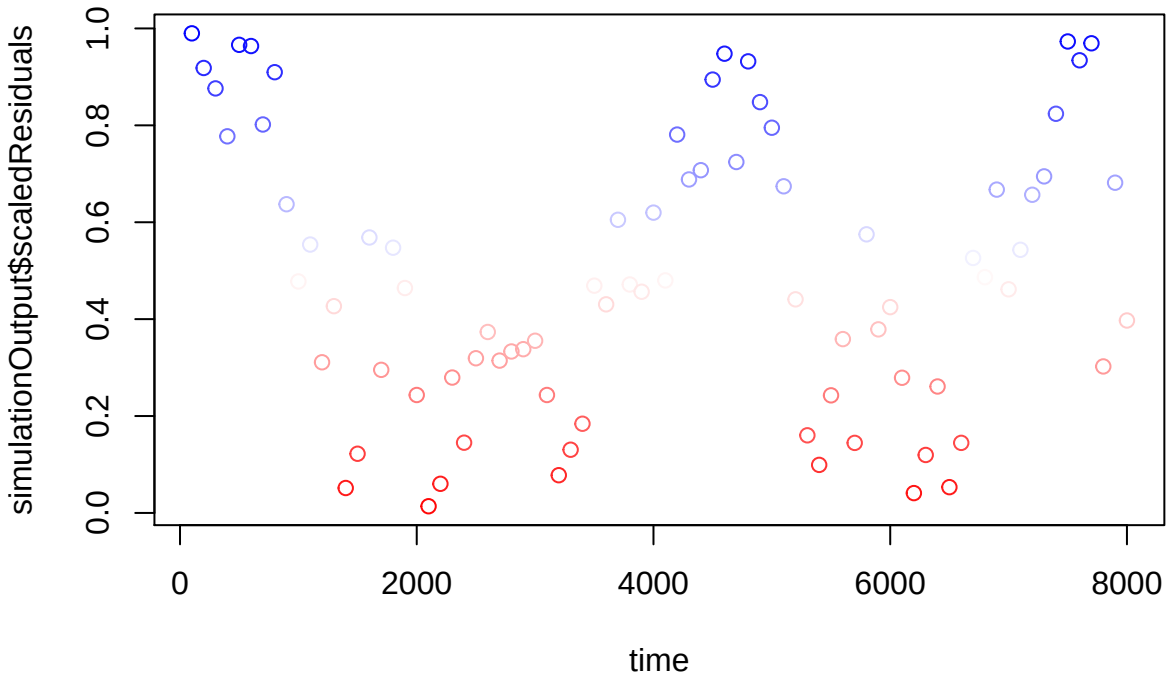

Predicted values of Charcoal
Charcoal
Temperature
0.25
0.00
−0.25
−0.50
−0.5
0.0
0.5
1.0
1.5

```
##
## $P.PET
```

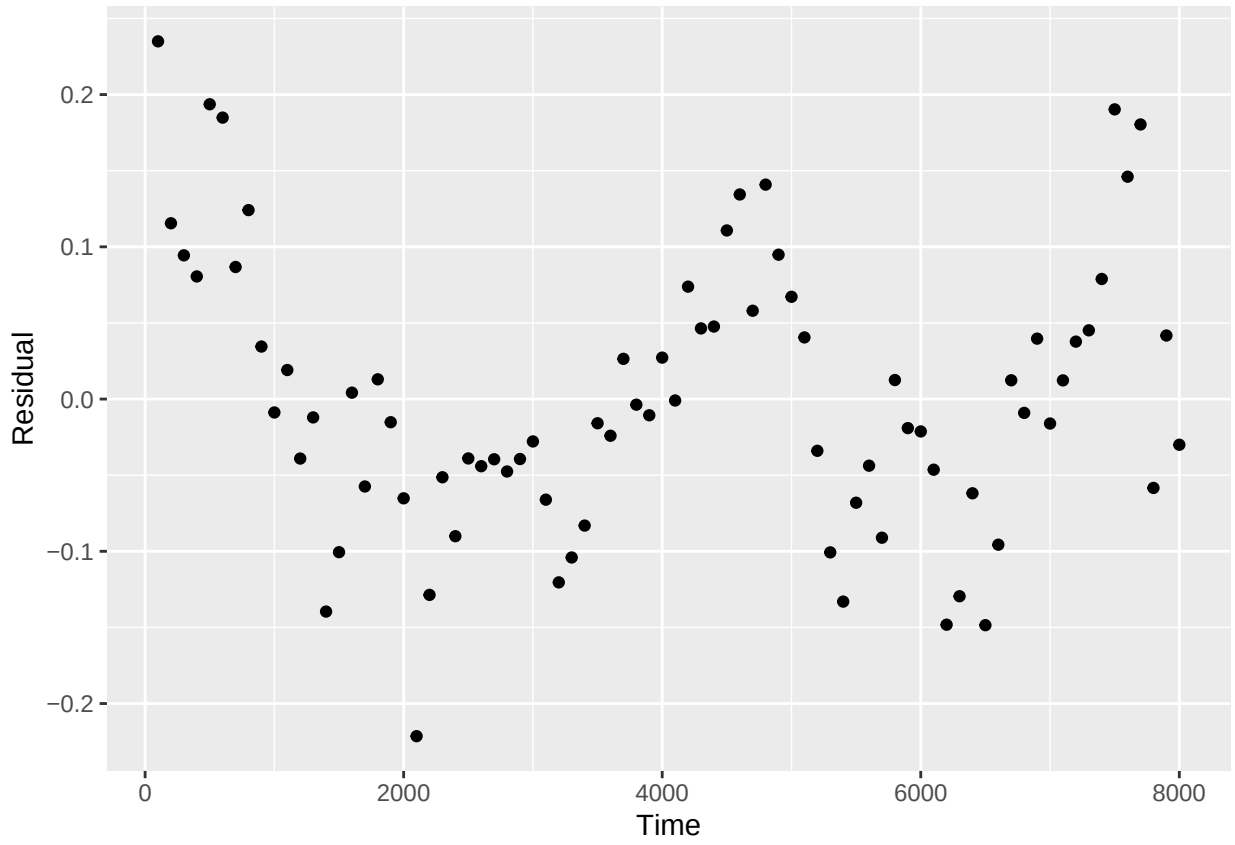

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



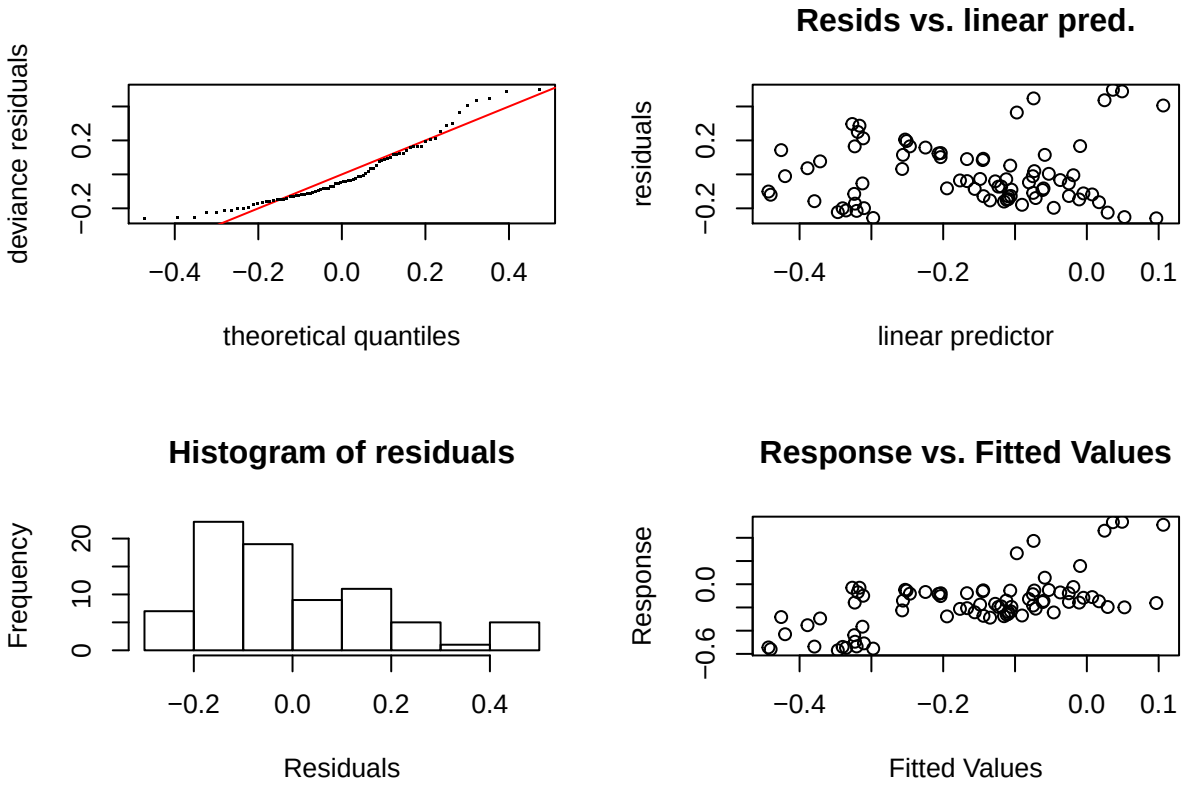

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.47336, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Needleleaf tree cover, Atlantic ecoregion

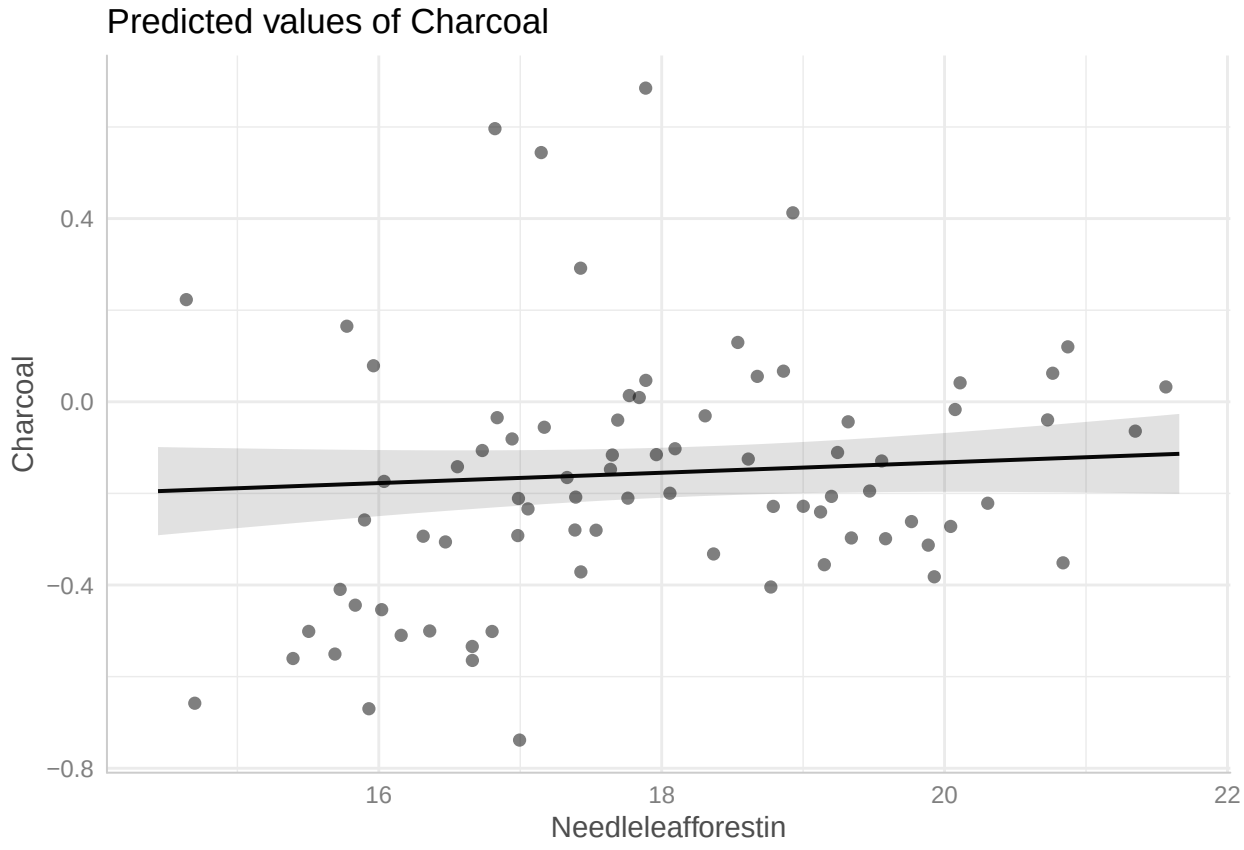
```
needle.atlantic <- charcoal.gam(Charcoal ~ s(Needleleafforestin) + s(Temperature)  + s(P.PET), data = A
```

```
## [1] "Checking GAM"
```

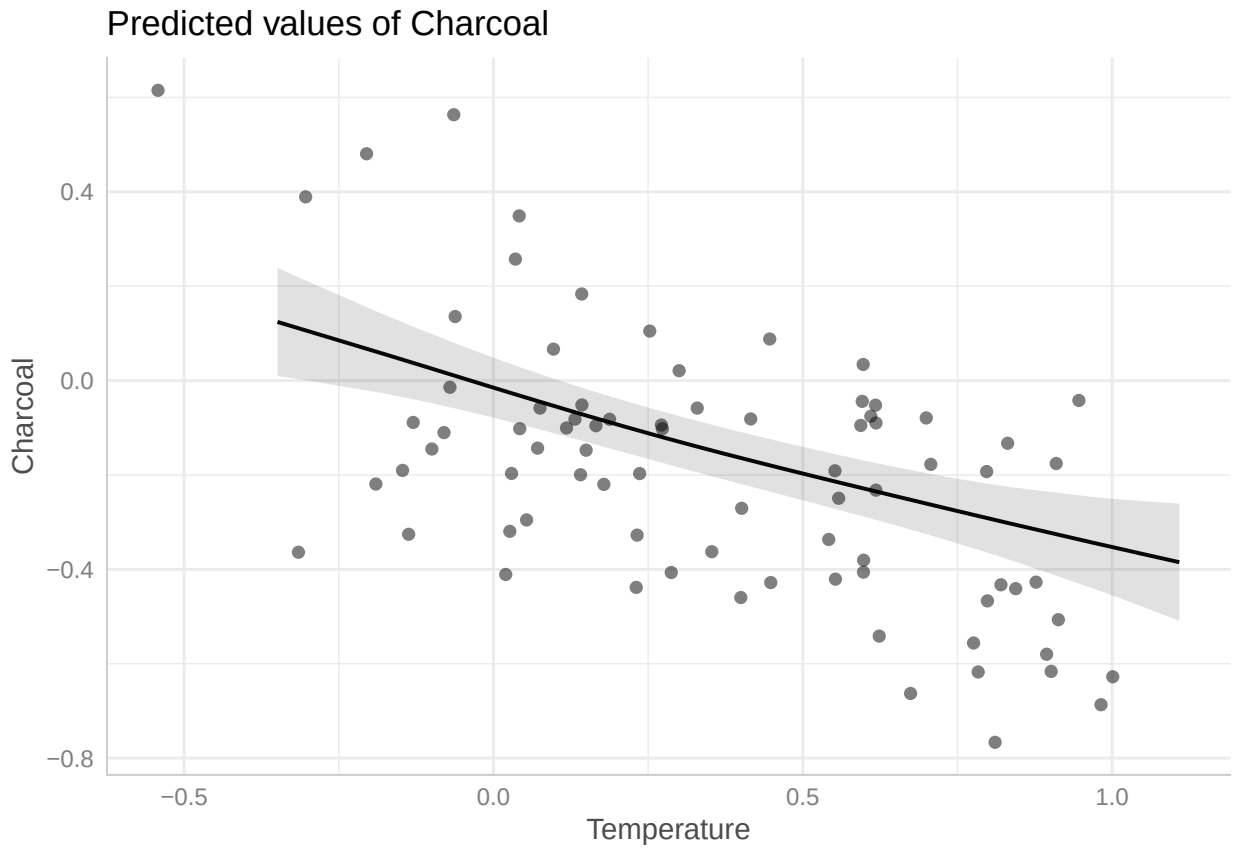



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 14 iterations.
## Gradient range [-5.809434e-06,4.591029e-06]
## (score -13.90265 & scale 0.03579219).
## Hessian positive definite, eigenvalue range [1.275032e-07,39.51623].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                          k'   edf k-index p-value
## s(Needleleafforestin) 9.000 0.539    0.86    0.10
## s(Temperature)        9.000 1.305    0.82    0.01 **
## s(P.PET)              9.000 1.122    0.94    0.23
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Needleleafforestin) + s(Temperature) + s(P.PET)
```

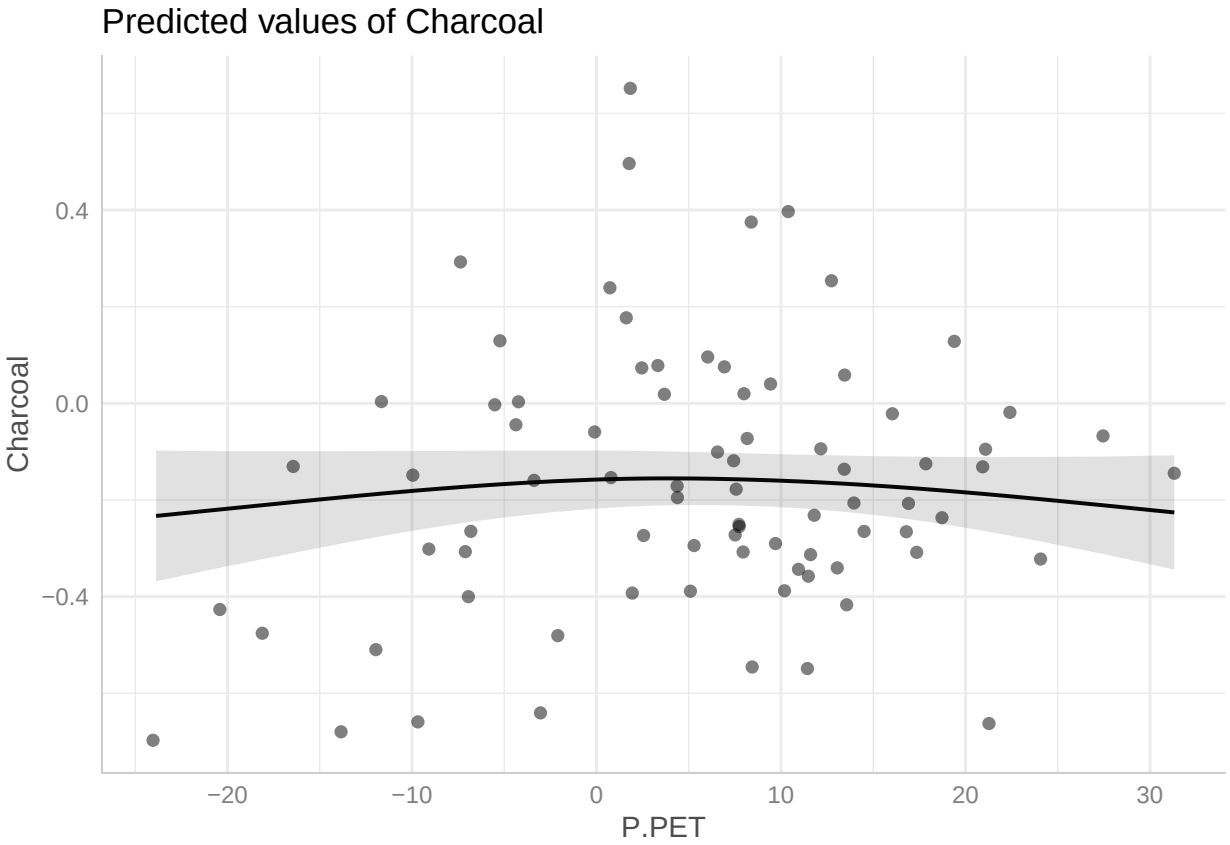
```
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.02115   -7.64 5.35e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                           edf Ref.df     F  p-value
## s(Needleleafforestin) 0.5387      9 0.130    0.126
## s(Temperature)        1.3051      9 3.911 2.15e-08 ***
## s(P.PET)              1.1223      9 0.191    0.199
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.367   Deviance explained = 39.1%
## -REML = -13.903  Scale est. = 0.035792  n = 80
## [1] "Plotting predictions"
## $Needleleafforestin
```

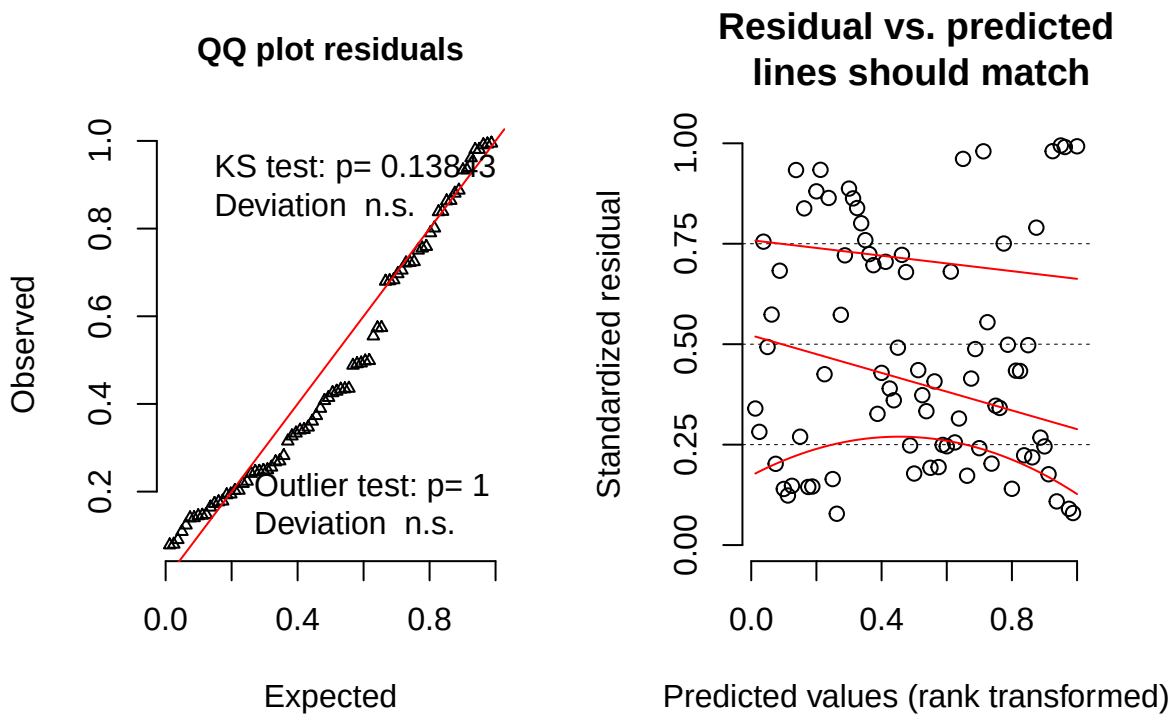



```
##
## $Temperature
```

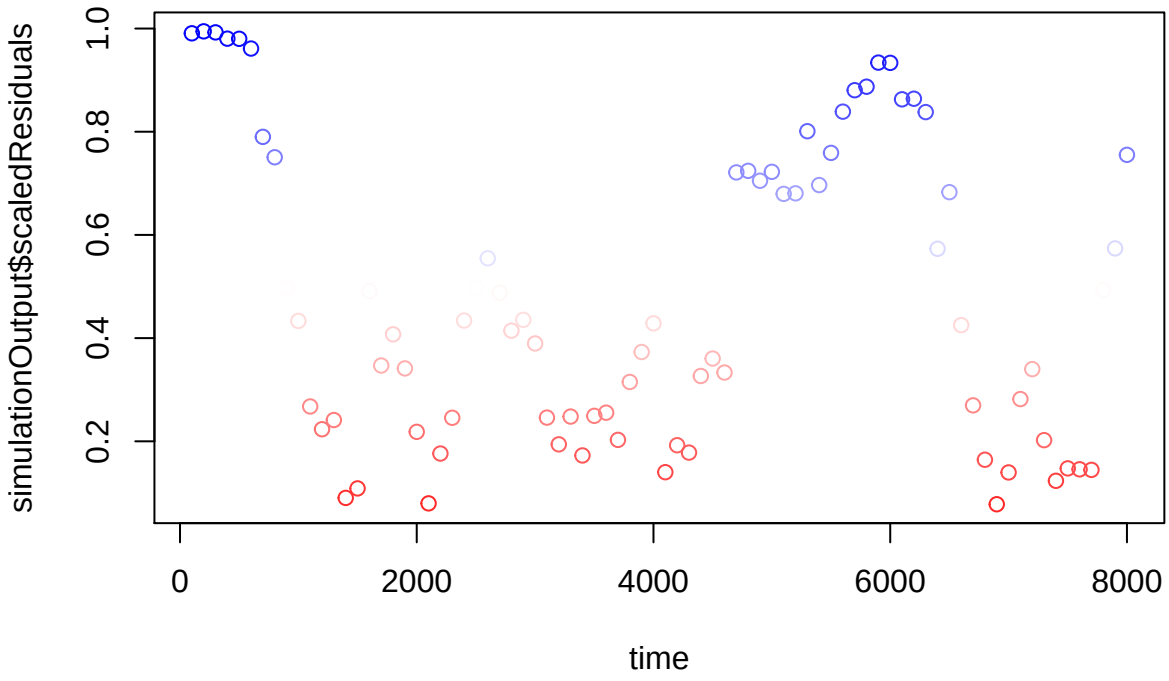

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.8
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

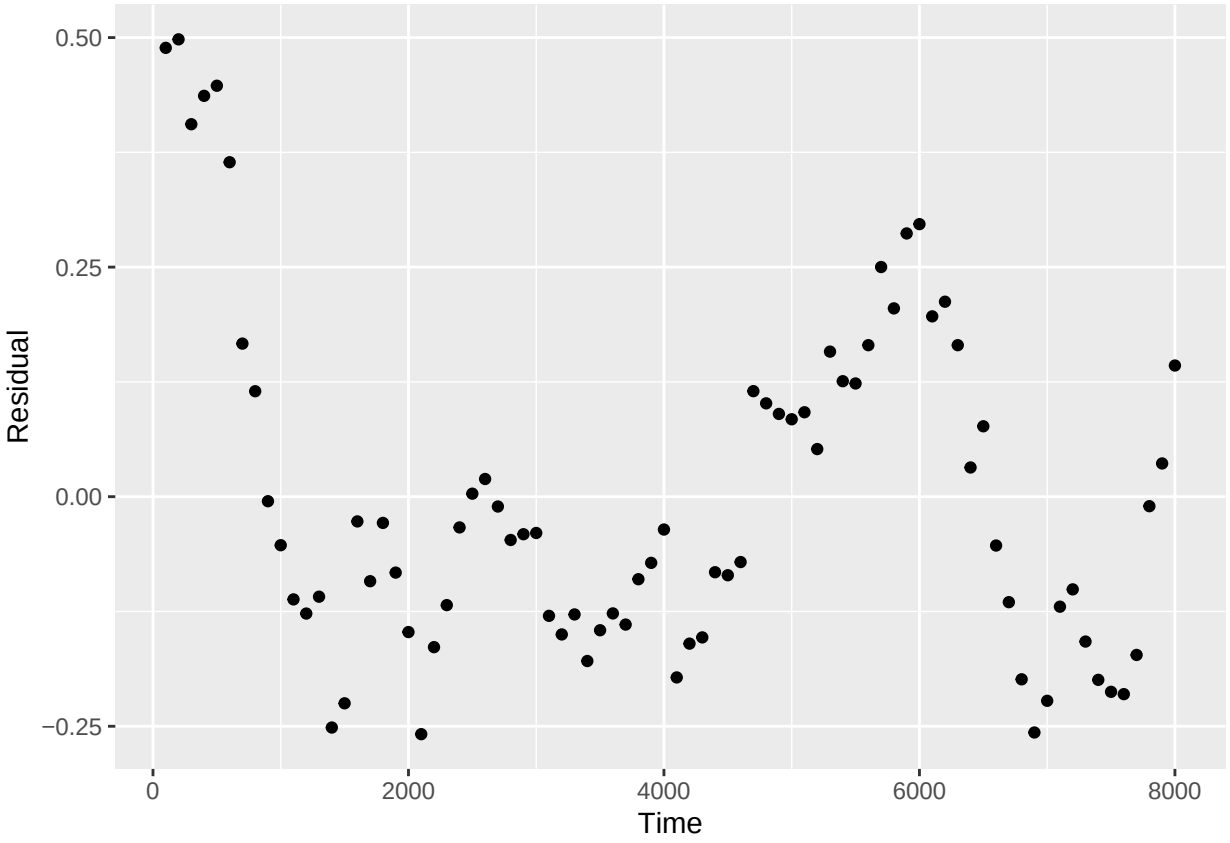

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



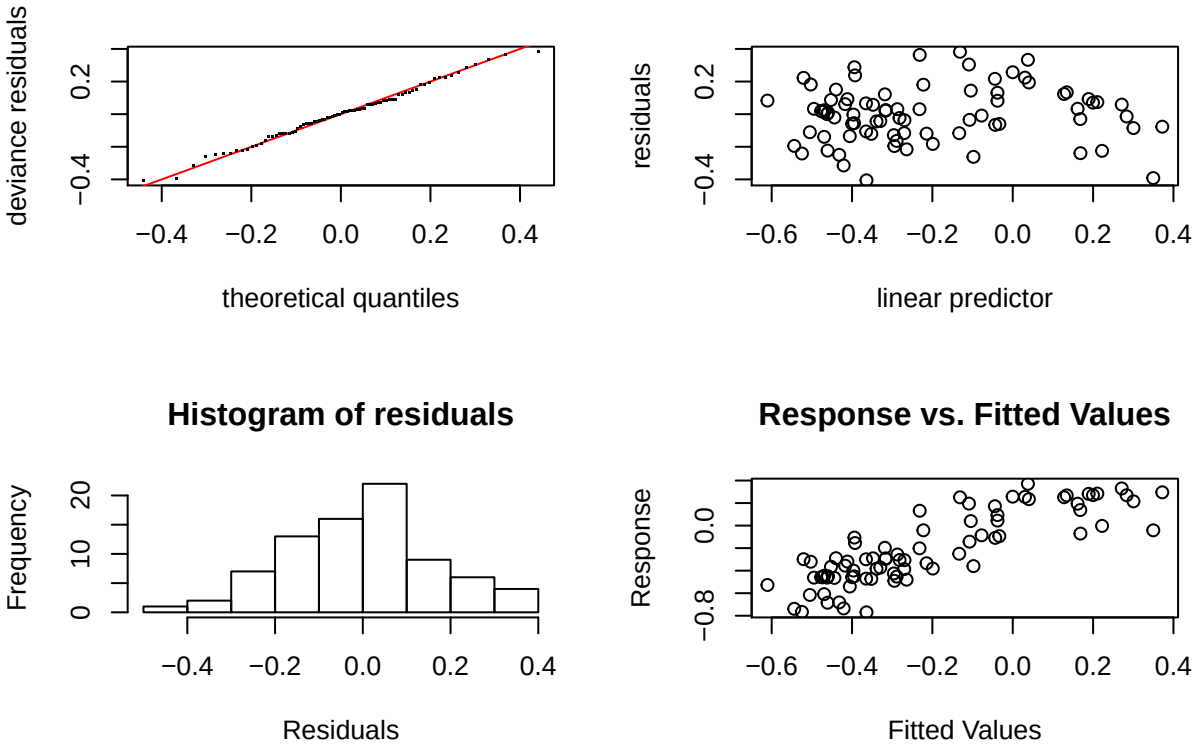

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.18747, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Needleleaf tree cover, Boreo-Nemoral ecoregion

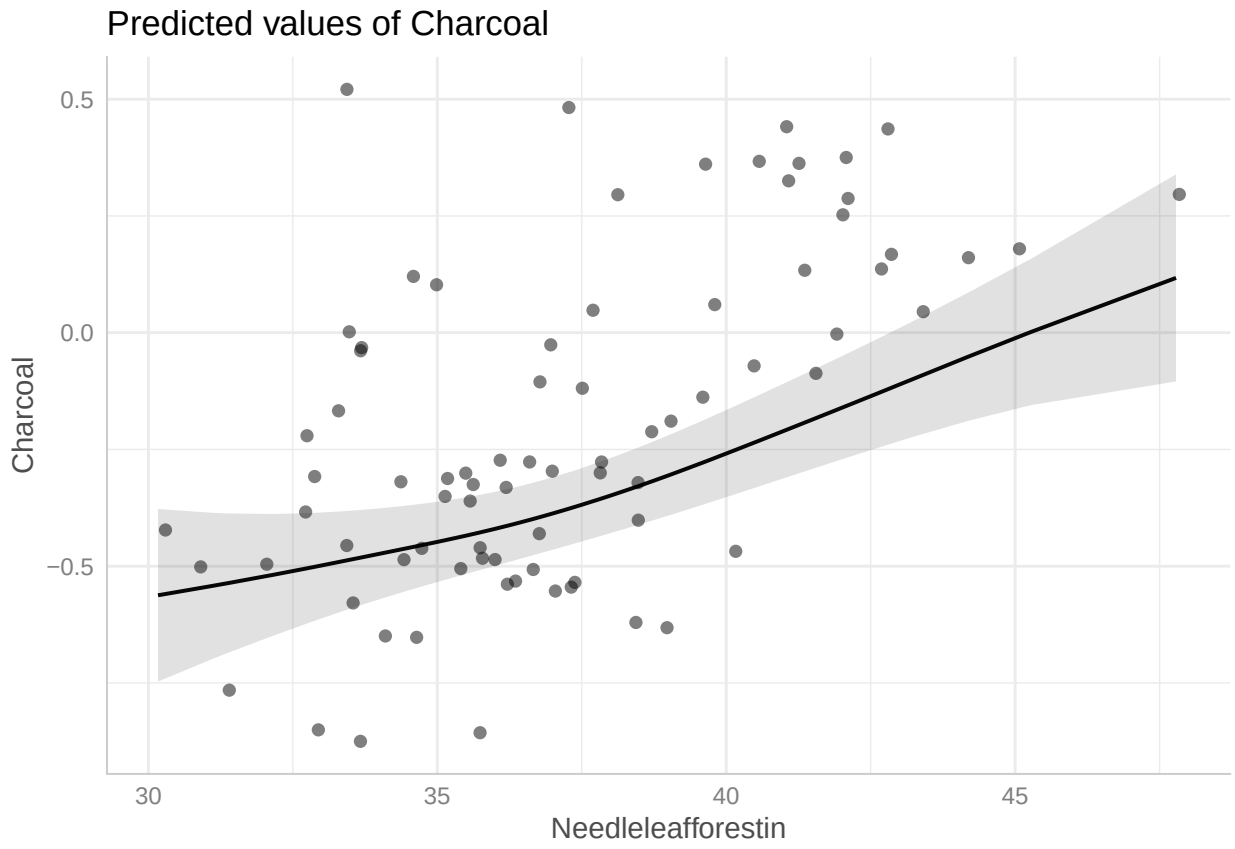
```
needle.boreonemoral <- charcoal.gam(Charcoal ~ s(Needleleafforestin) + s(Temperature)  + s(P.PET), data
```

```
## [1] "Checking GAM"
```

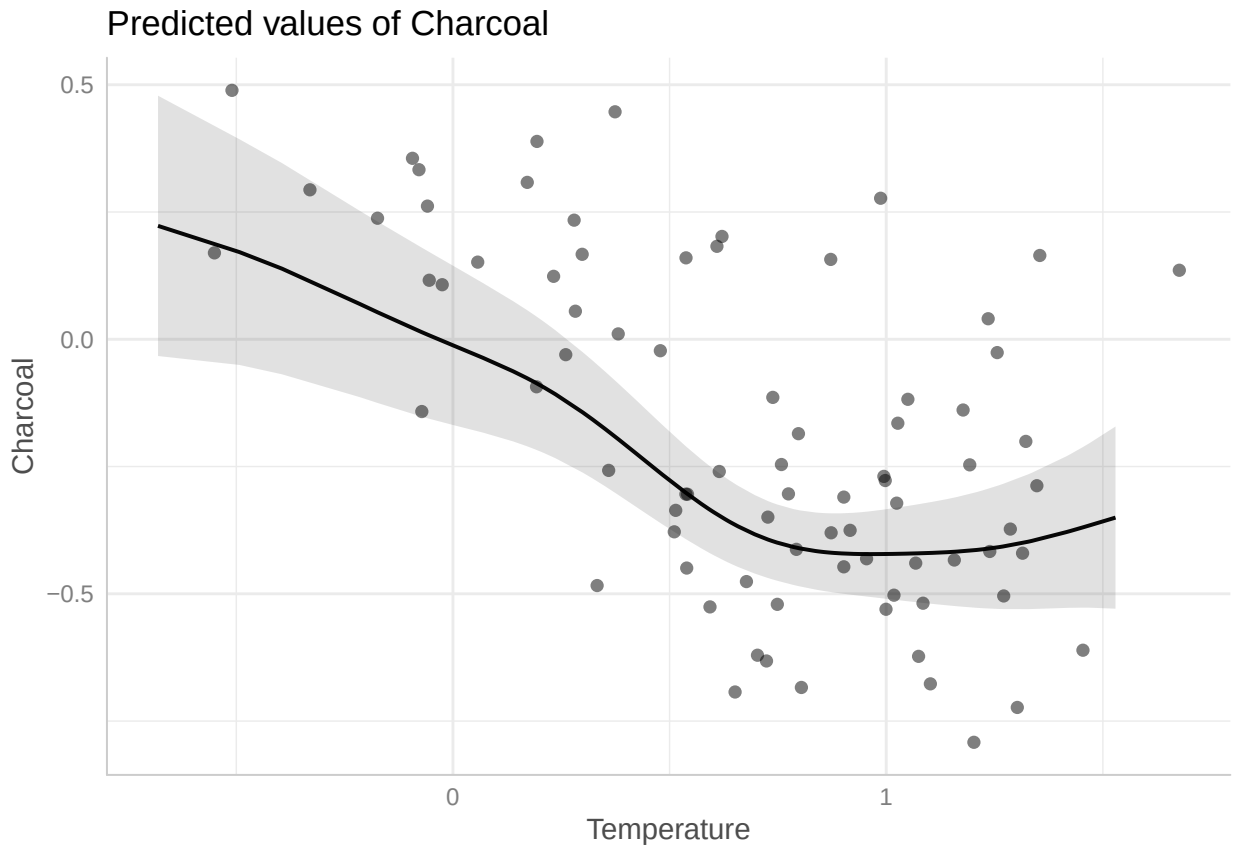



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-4.91621e-06,4.841804e-06]
## (score -13.52827 & scale 0.03114691).
## Hessian positive definite, eigenvalue range [4.916201e-06,39.60288].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                          k'  edf k-index p-value
## s(Needleleafforestin) 9.00 1.85    0.99    0.40
## s(Temperature)        9.00 3.22    0.92    0.23
## s(P.PET)              9.00 2.26    0.99    0.43
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Needleleafforestin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

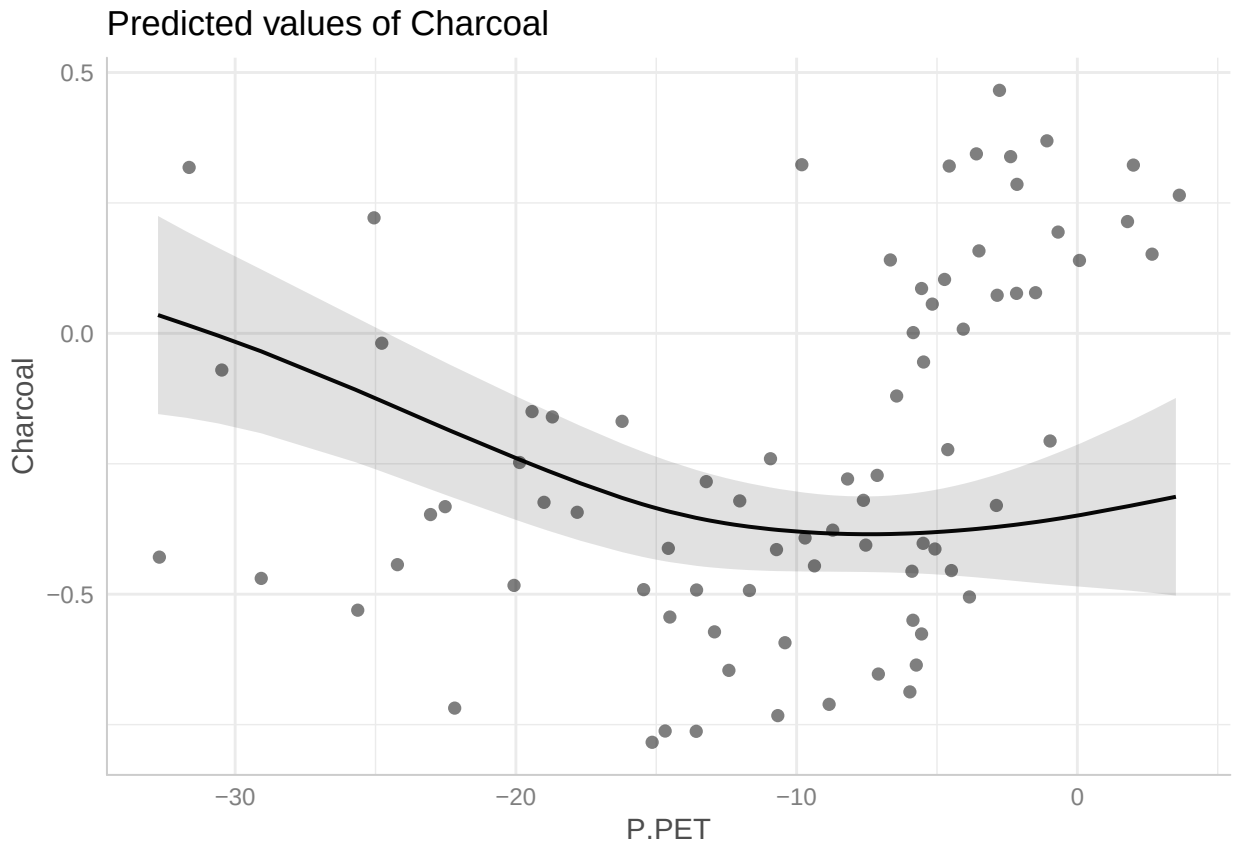
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.01973  -10.66   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                          edf Ref.df     F  p-value
## s(Needleleafforestin) 1.849      9 3.114 5.79e-07 ***
## s(Temperature)        3.218      9 3.761 1.73e-07 ***
## s(P.PET)              2.261      9 2.384 1.94e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.686   Deviance explained = 71.5%
## -REML = -13.528  Scale est. = 0.031147  n = 80
## [1] "Plotting predictions"
## $Needleleafforestin
```

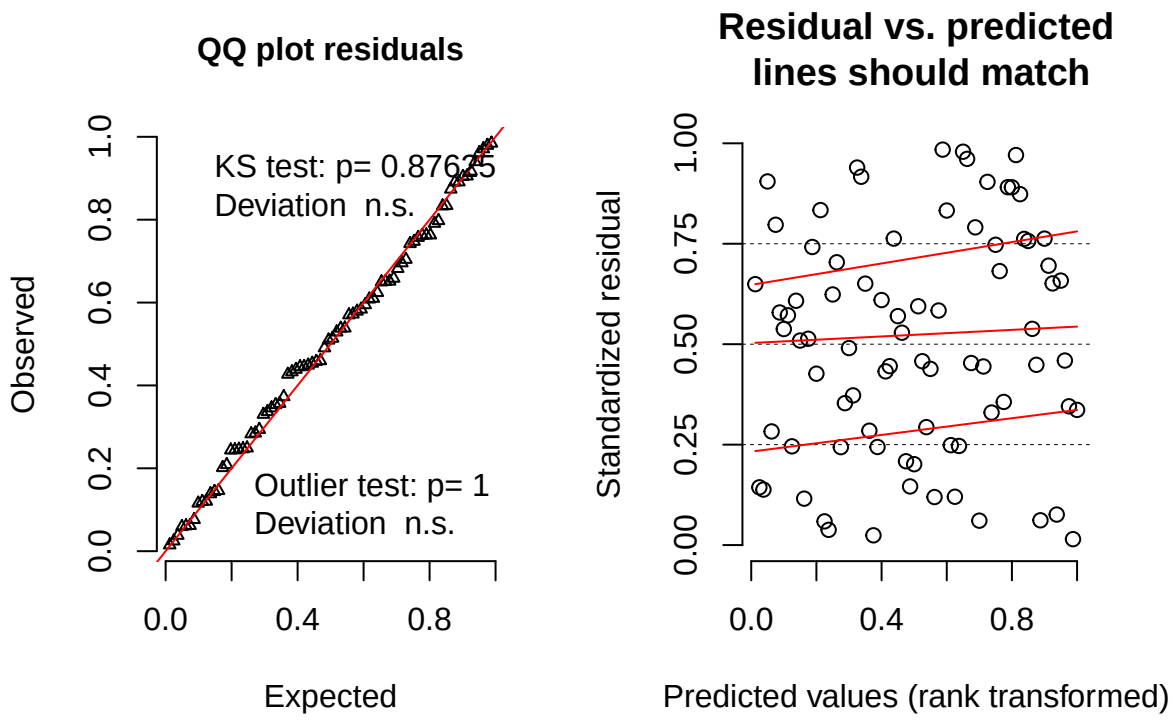



```
##
## $Temperature
```

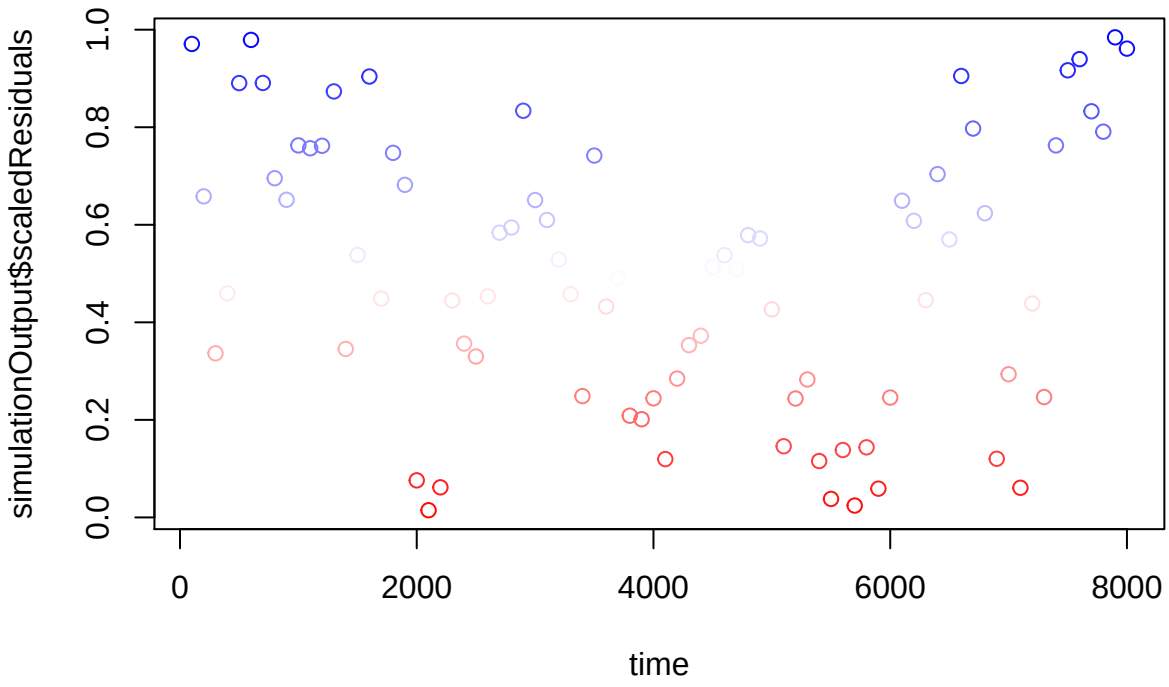

Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
0
1
Temperature

```
##
## $P.PET
```

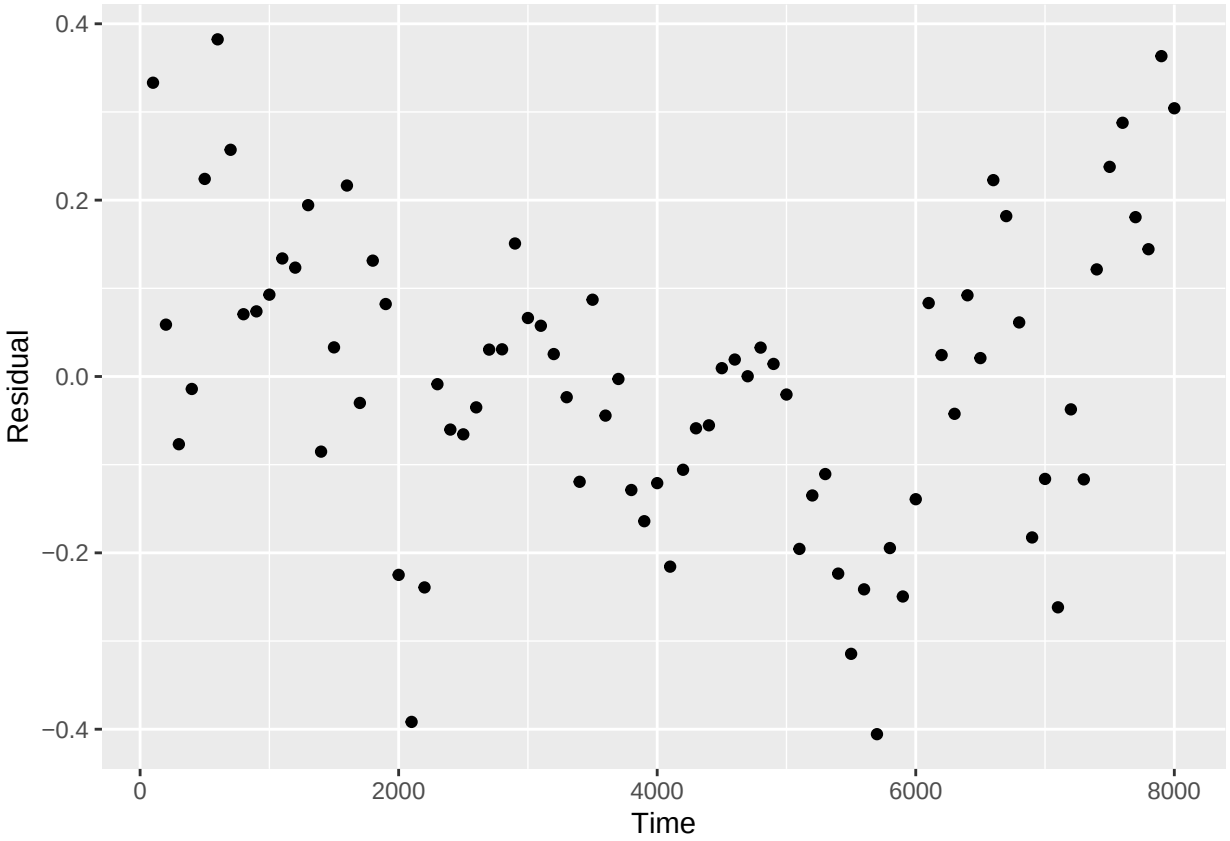

Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

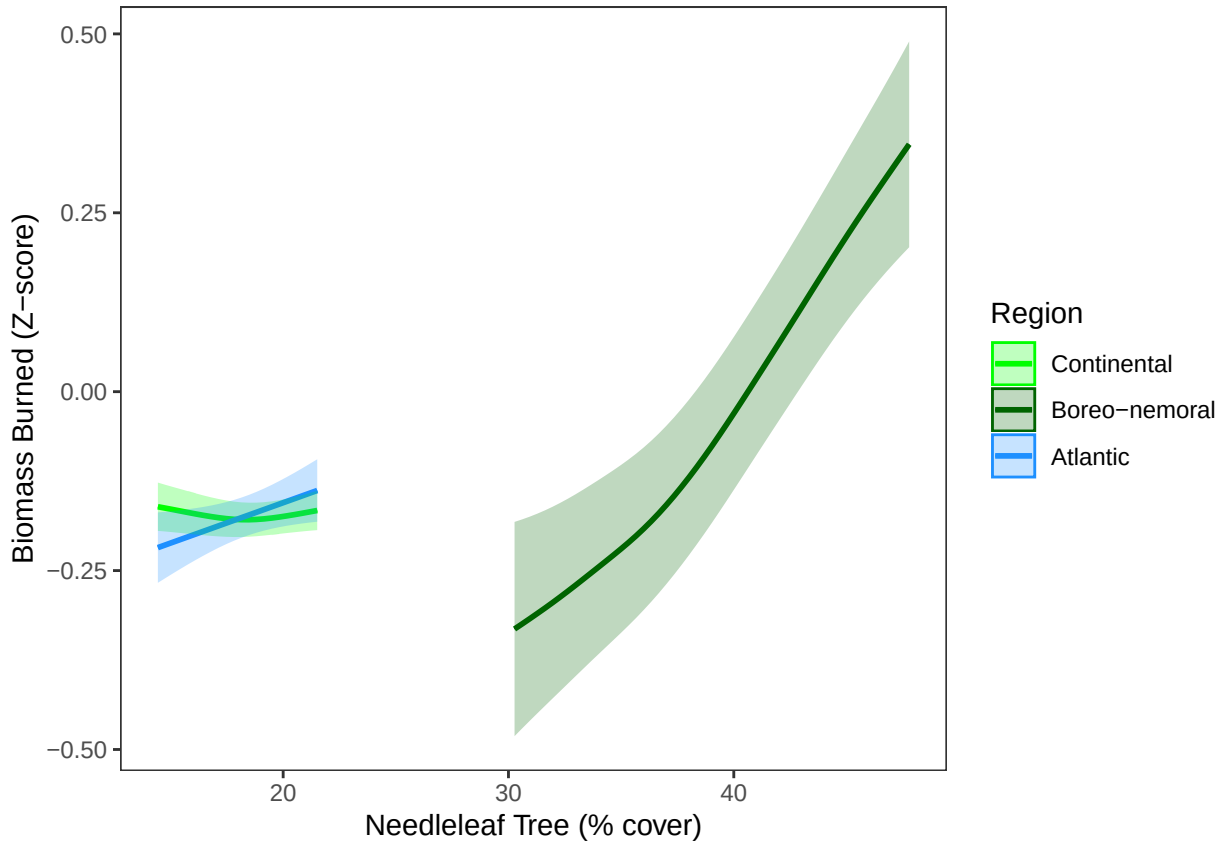



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.64176, p-value = 1.675e-12
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

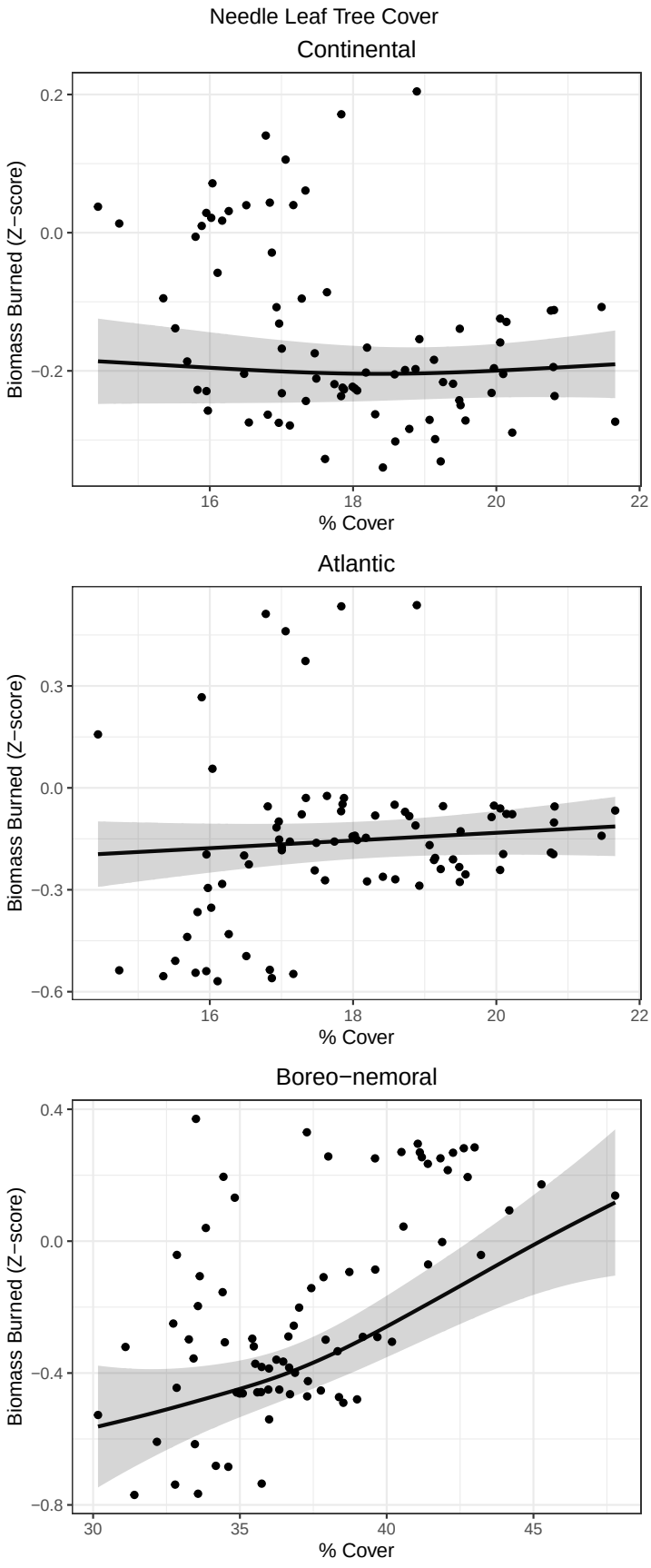


Needleleaf tree cover plot

Here we show the marginal response of biomass burned to needleleaf forest cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.


0.50
0.25
0.00
−0.25
−0.50
Biomass Burned (Z−score)
20
30
40
Needleleaf Tree (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```

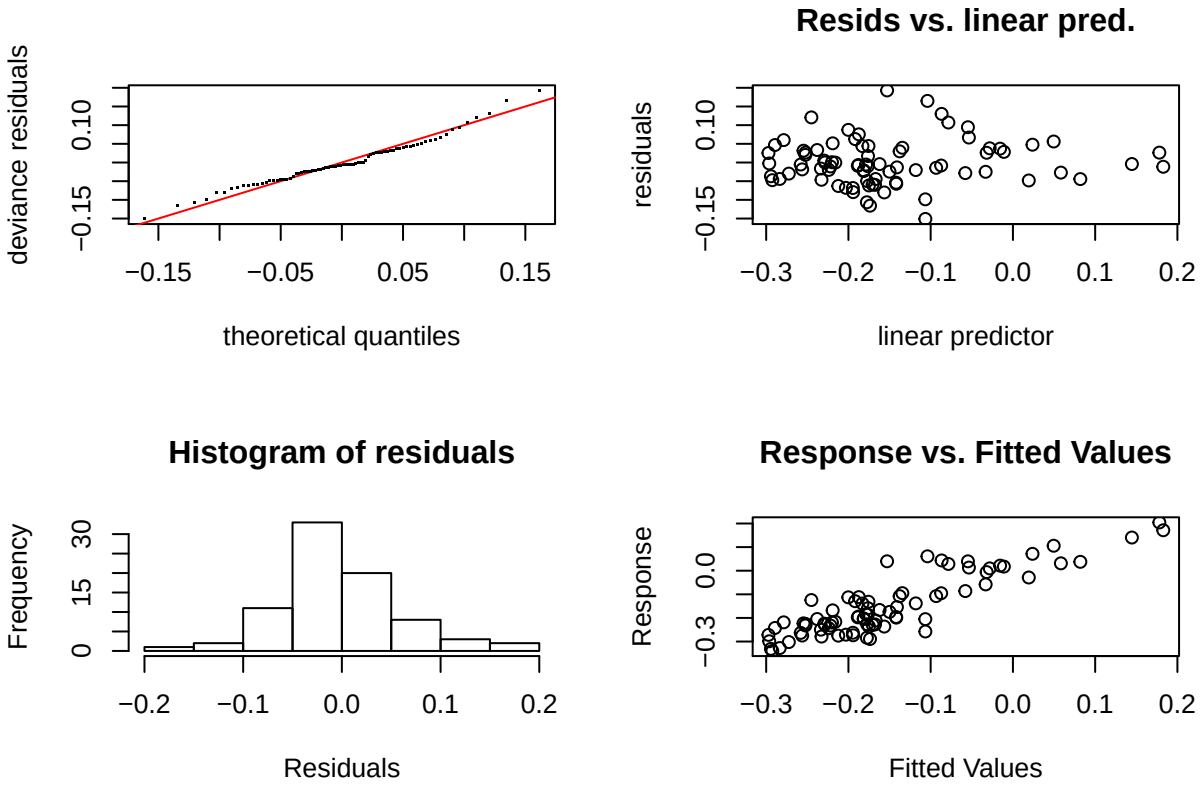

Needle Leaf Tree Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
16
18
20
22
% Cover
Atlantic
Biomass Burned (Z−score)
0.3
0.0
−0.3
−0.6
16
18
20
22
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.4
0.0
−0.4
−0.8
30
35
40
45
% Cover

Heath/Scrubland

Heath/Scrubland, Continental ecoregion

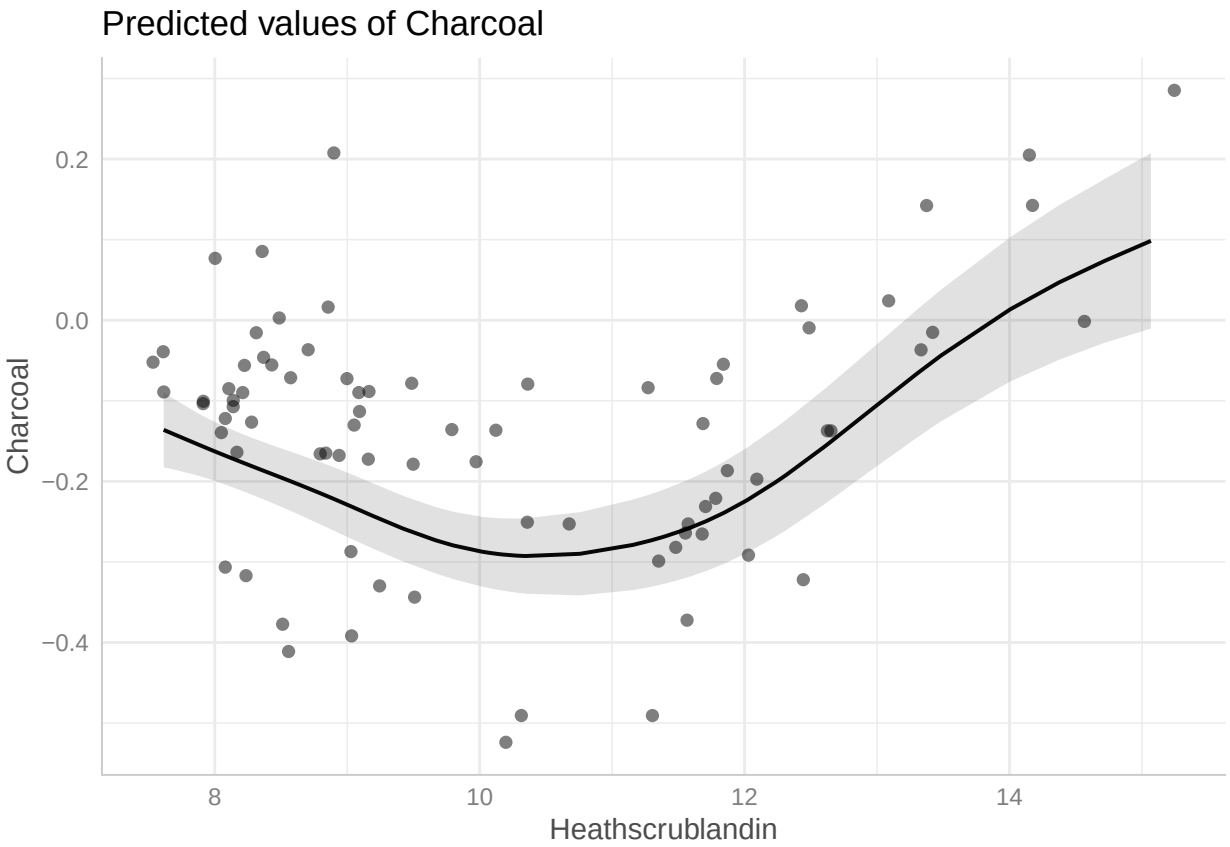
```
scrub.continental <- charcoal.gam(Charcoal ~ s(Heathscrublandin) + s(Temperature)  + s(P.PET), data = A
```

```
## [1] "Checking GAM"
```

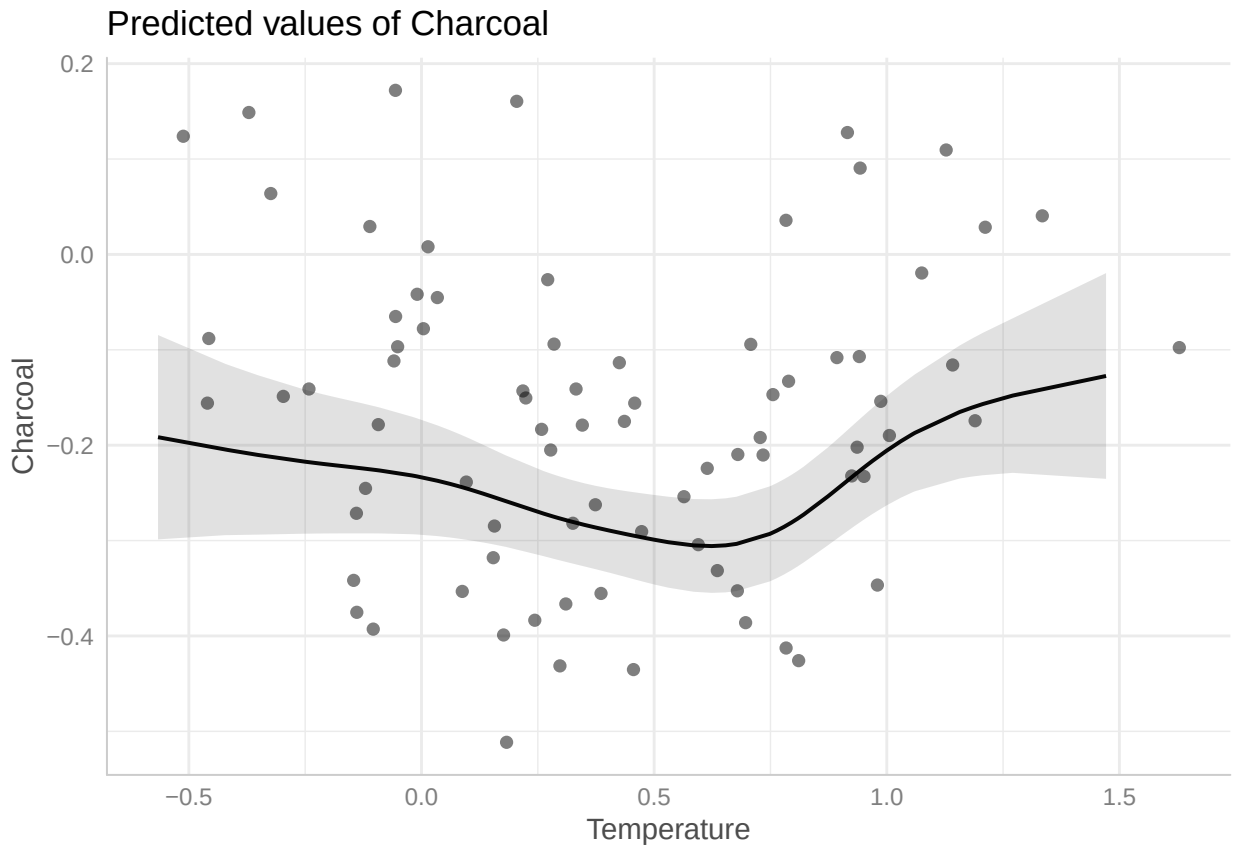



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 9 iterations.
## Gradient range [-1.181102e-05,6.144709e-06]
## (score -89.14724 & scale 0.0041755).
## Hessian positive definite, eigenvalue range [2.749896e-06,39.70913].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                       k'  edf k-index p-value
## s(Heathscrublandin) 9.00 3.80    0.99    0.45
## s(Temperature)      9.00 4.11    1.08    0.70
## s(P.PET)            9.00 1.39    1.07    0.67
## $mfrow
```

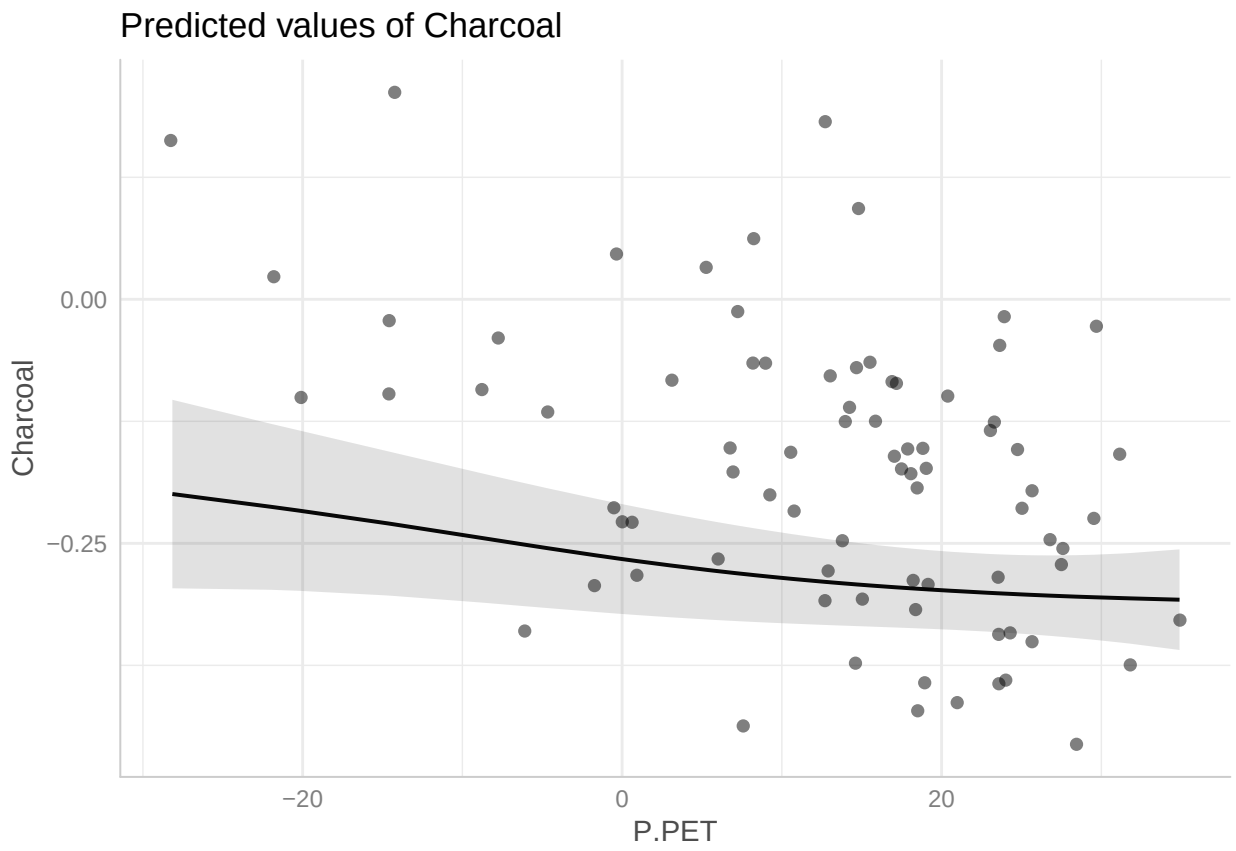
```
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Heathscrublandin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.007225  -20.68   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                        edf Ref.df     F  p-value
## s(Heathscrublandin) 3.798      9 9.096  4.4e-15 ***
## s(Temperature)      4.115      9 2.478 0.000104 ***
## s(P.PET)            1.395      9 0.580 0.022575 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.747   Deviance explained = 77.7%
## -REML = -89.147  Scale est. = 0.0041755  n = 80
## [1] "Plotting predictions"
## $Heathscrublandin
```

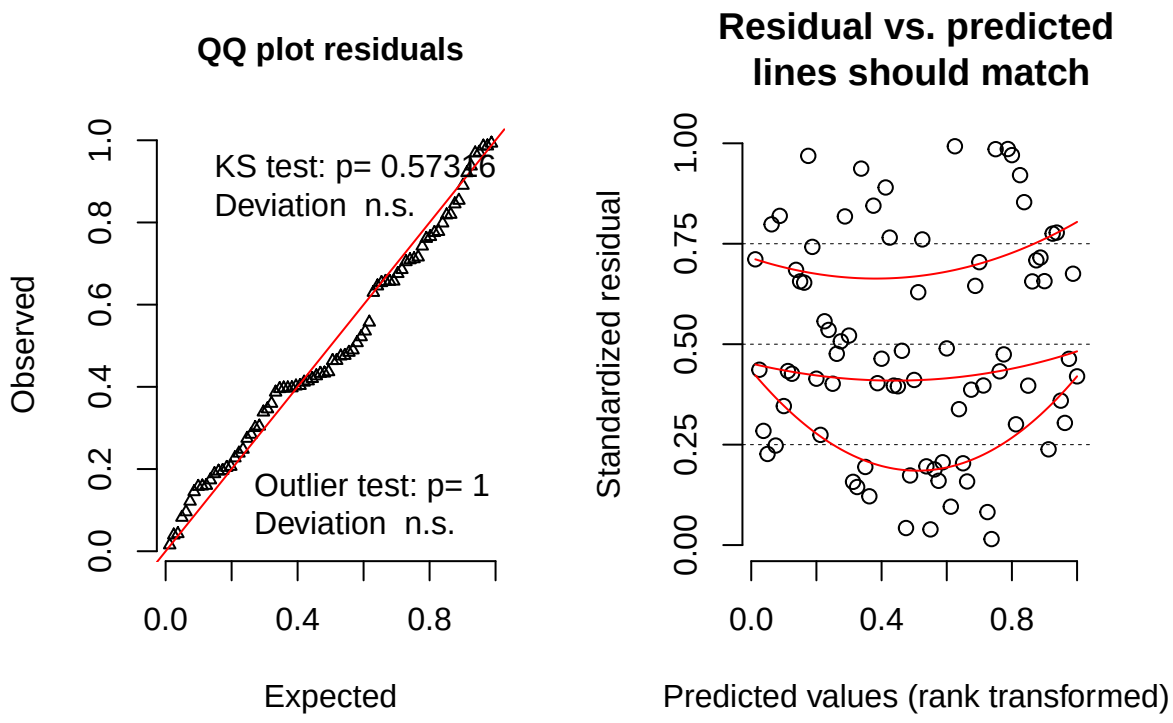



```
##
## $Temperature
```

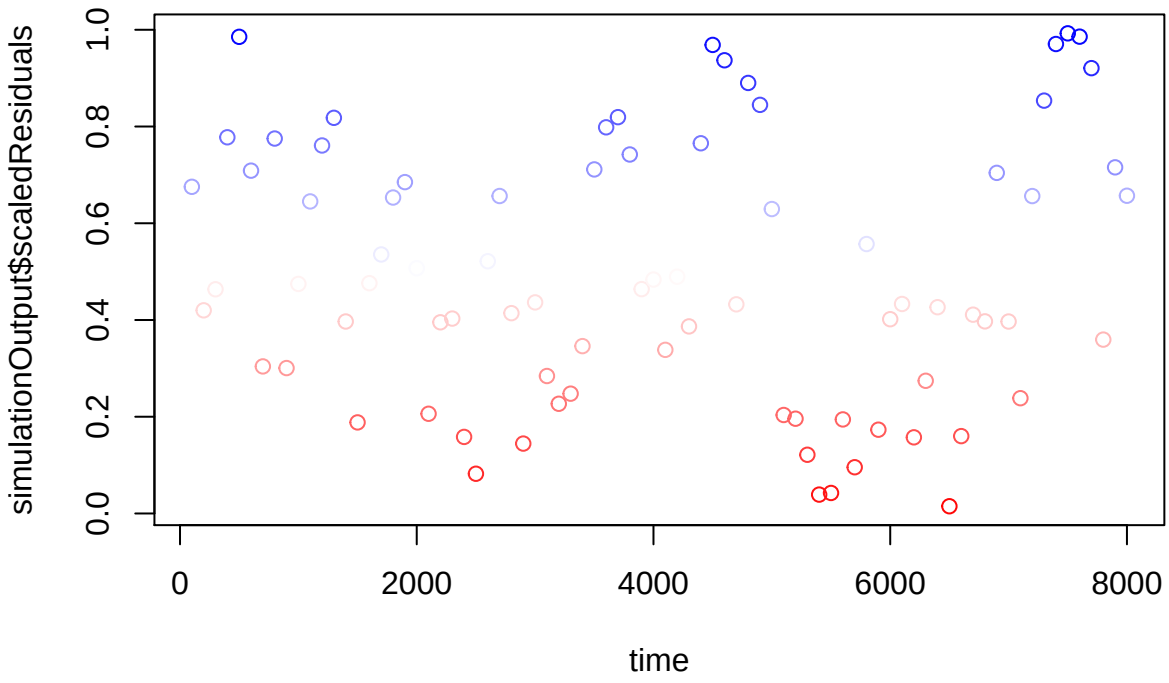

Predicted values of Charcoal
0.2
0.0
−0.2
−0.4
Charcoal
−0.5
0.0
0.5
1.0
1.5
Temperature

```
##
## $P.PET
```

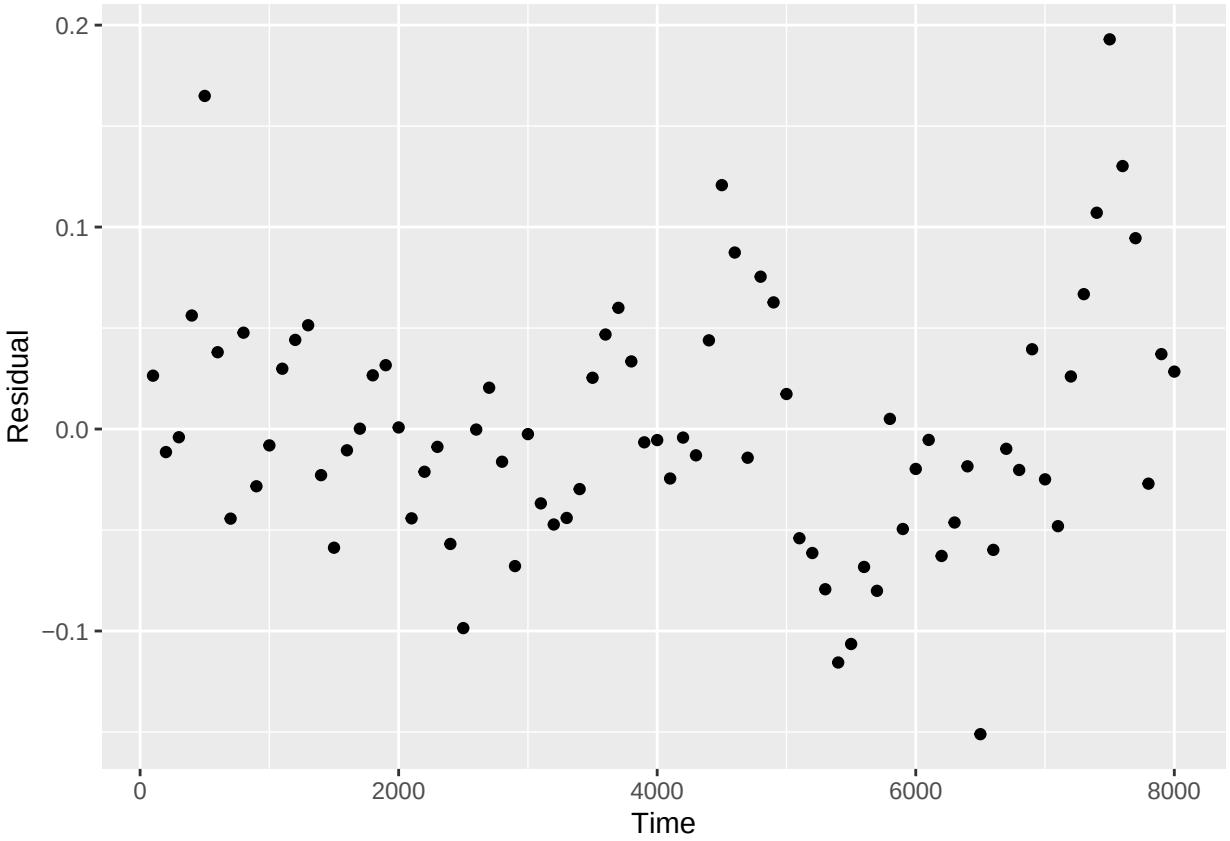

Predicted values of Charcoal
Charcoal
0.00
−0.25
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



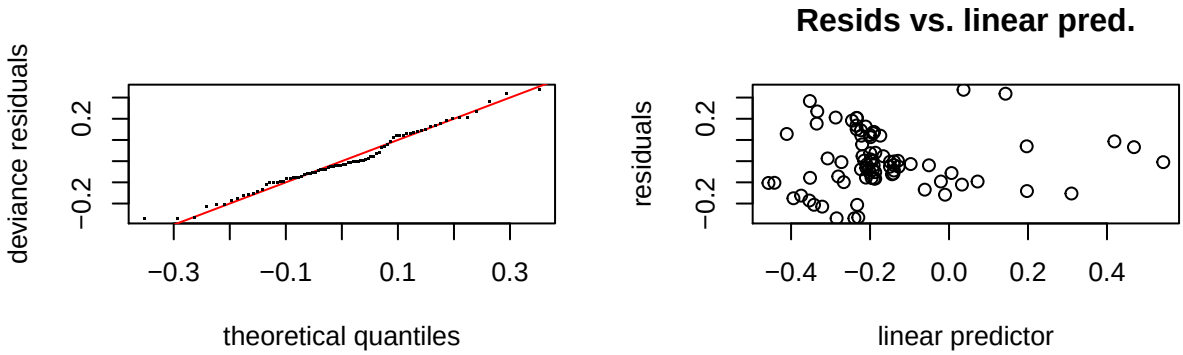

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.85385, p-value = 1.484e-08
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

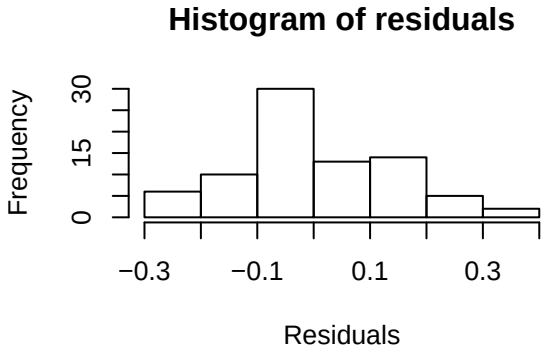


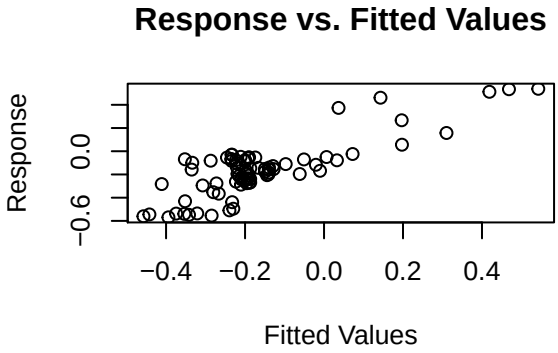
Heath/Scrubland, Atlantic ecoregion

```
scrub.atlantic <- charcoal.gam(Charcoal ~ s(Heathscrublandin) + s(Temperature)  + s(P.PET), data = AllE
```

```
## [1] "Checking GAM"
```

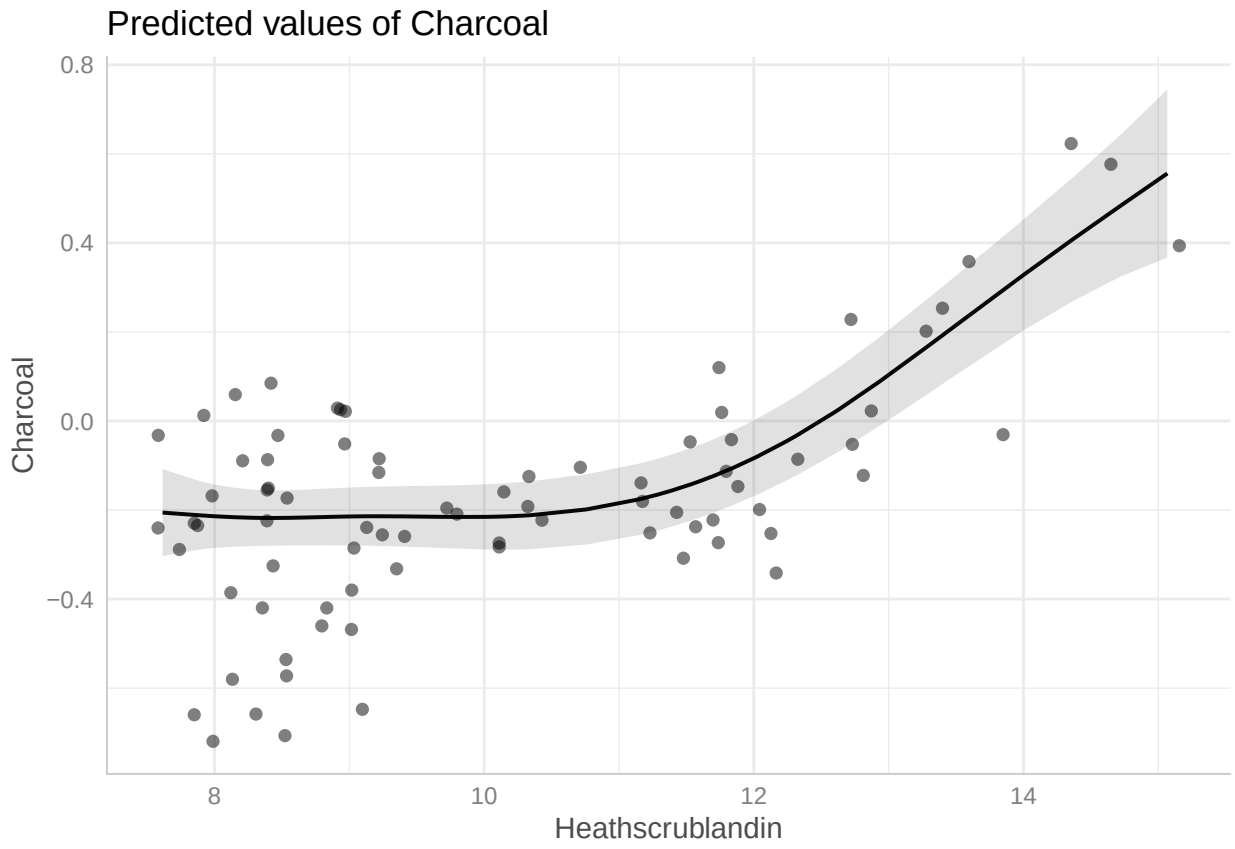




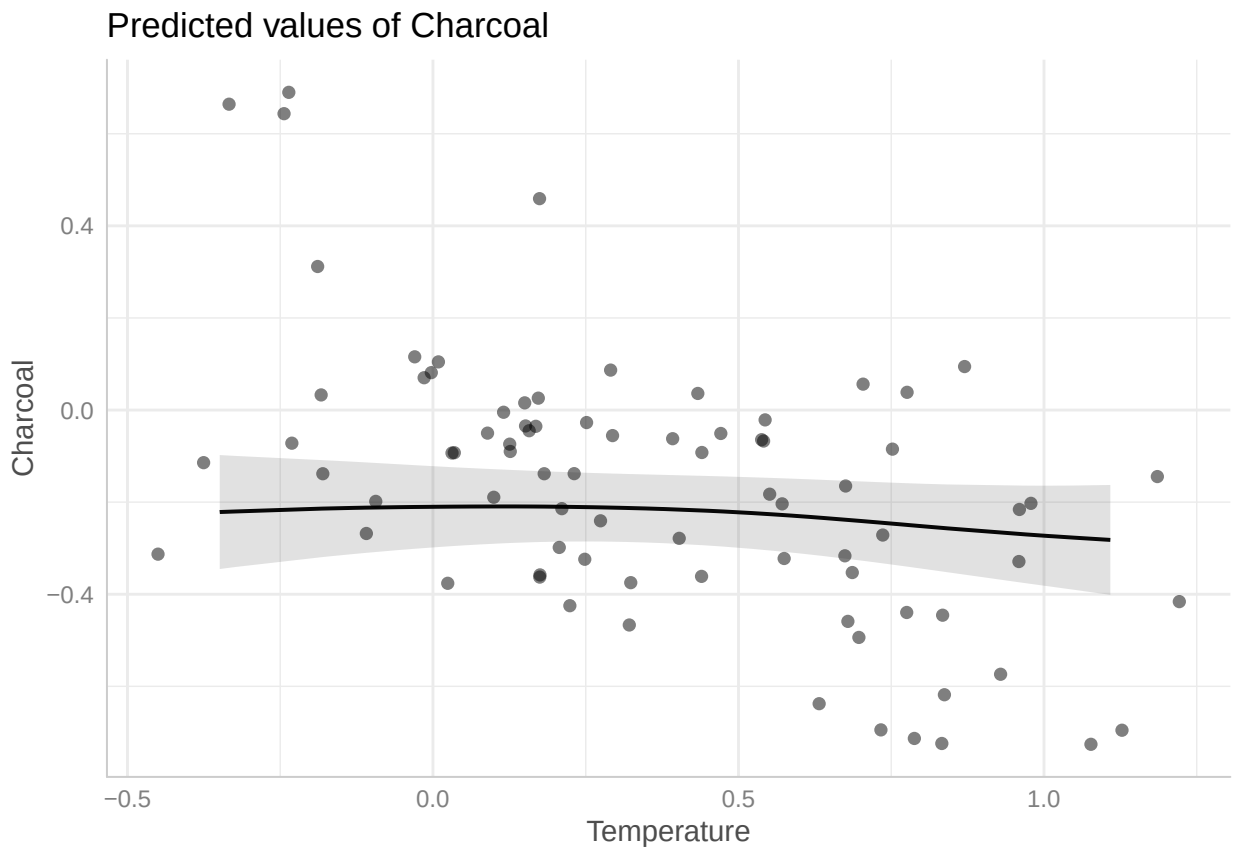



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-1.27329e-05,3.21502e-05]
## (score -32.60928 & scale 0.01988639).
## Hessian positive definite, eigenvalue range [0.001578365,39.57095].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                         k'   edf k-index p-value
## s(Heathscrublandin) 9.000 3.333    1.23    0.98
## s(Temperature)      9.000 0.972    1.26    0.98
## s(P.PET)            9.000 1.850    1.02    0.52
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Heathscrublandin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

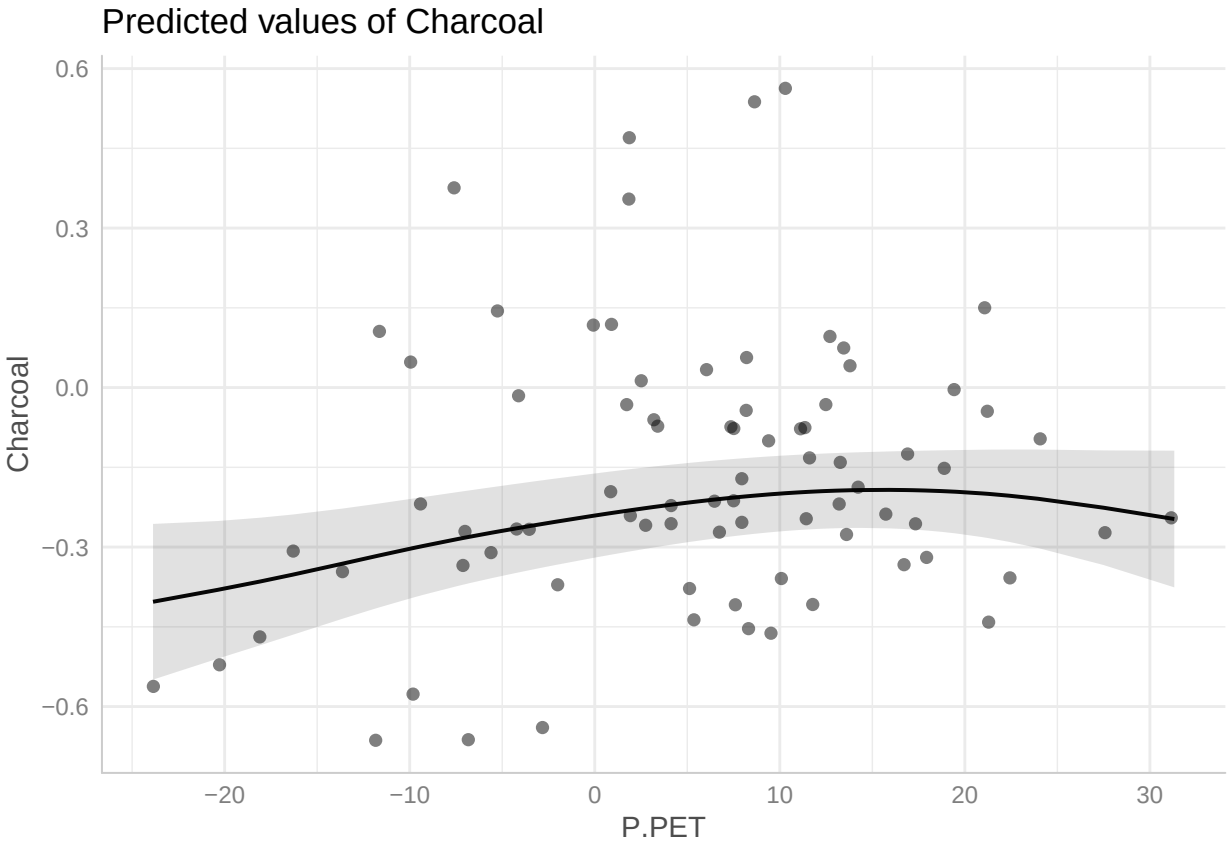
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.01577  -10.25 9.03e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                         edf Ref.df     F  p-value
## s(Heathscrublandin) 3.3330      9 8.158 7.97e-15 ***
## s(Temperature)      0.9719      9 0.191  0.13929
## s(P.PET)            1.8497      9 1.009  0.00417 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.648   Deviance explained = 67.6%
## -REML = -32.609  Scale est. = 0.019886  n = 80
## [1] "Plotting predictions"
## $Heathscrublandin
```

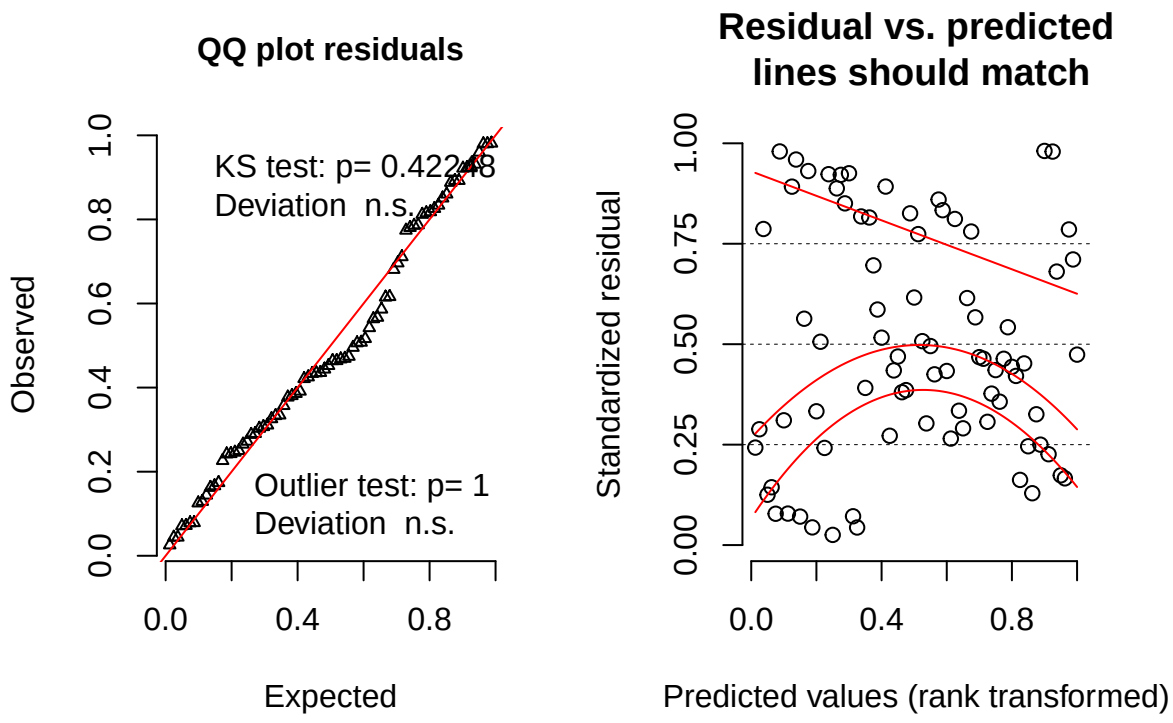



```
##
## $Temperature
```

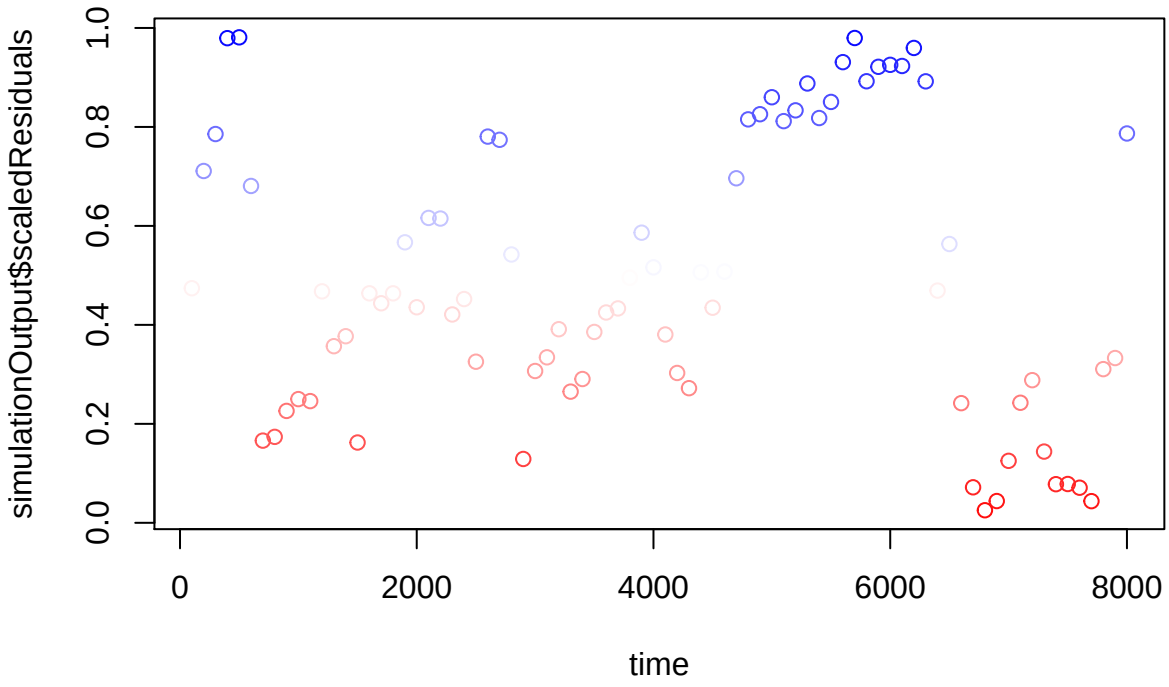

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

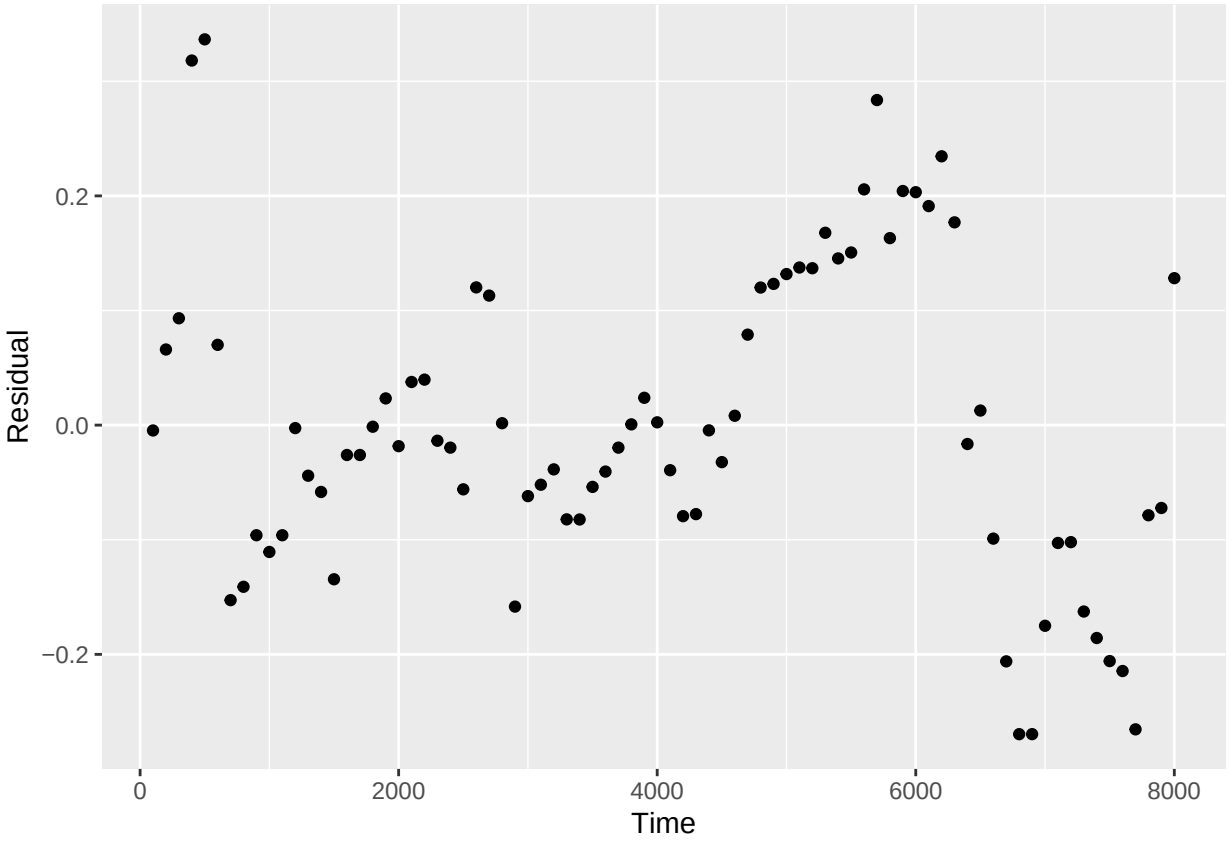

Predicted values of Charcoal
Charcoal
0.6
0.3
0.0
−0.3
−0.6
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



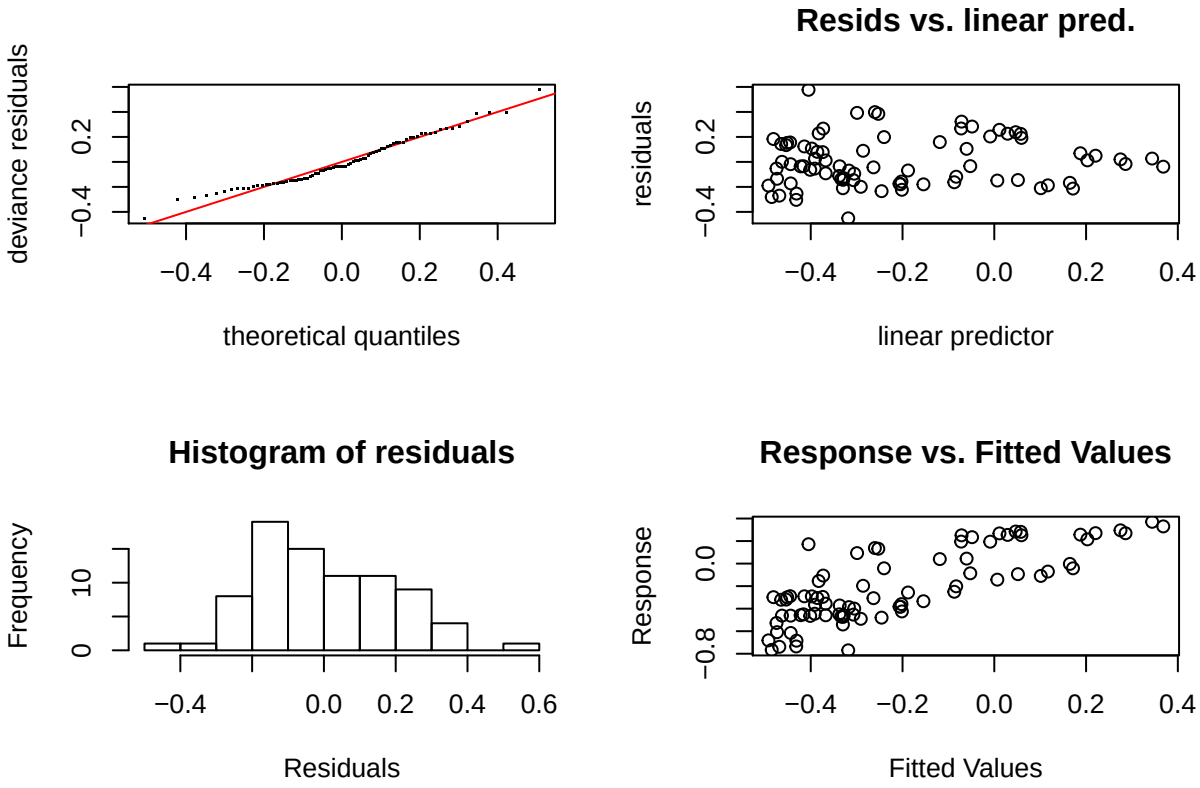

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.33642, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Heath/Scrubland, Boreo-Nemoral ecoregion

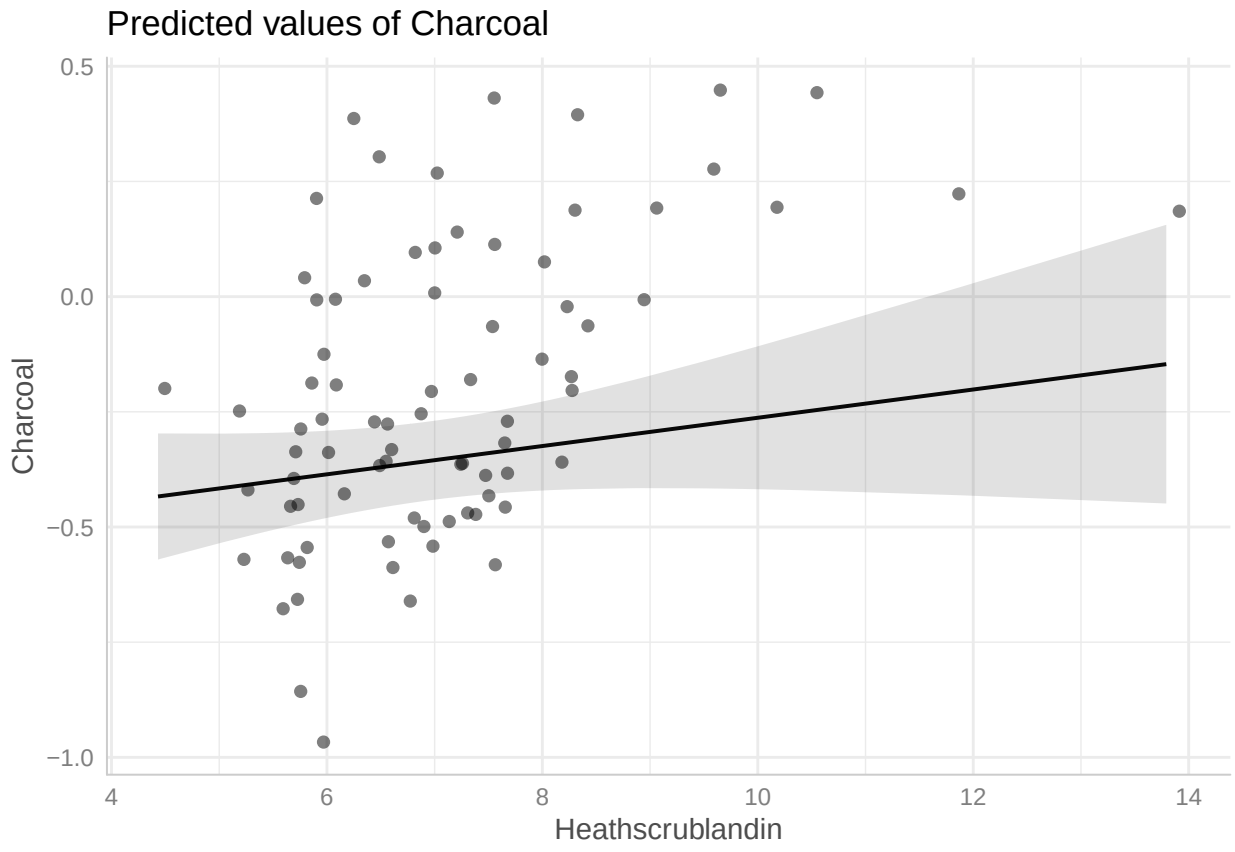
```
scrub.boreonemoral <- charcoal.gam(Charcoal ~ s(Heathscrublandin) + s(Temperature)  + s(P.PET), data = A
```

```
## [1] "Checking GAM"
```

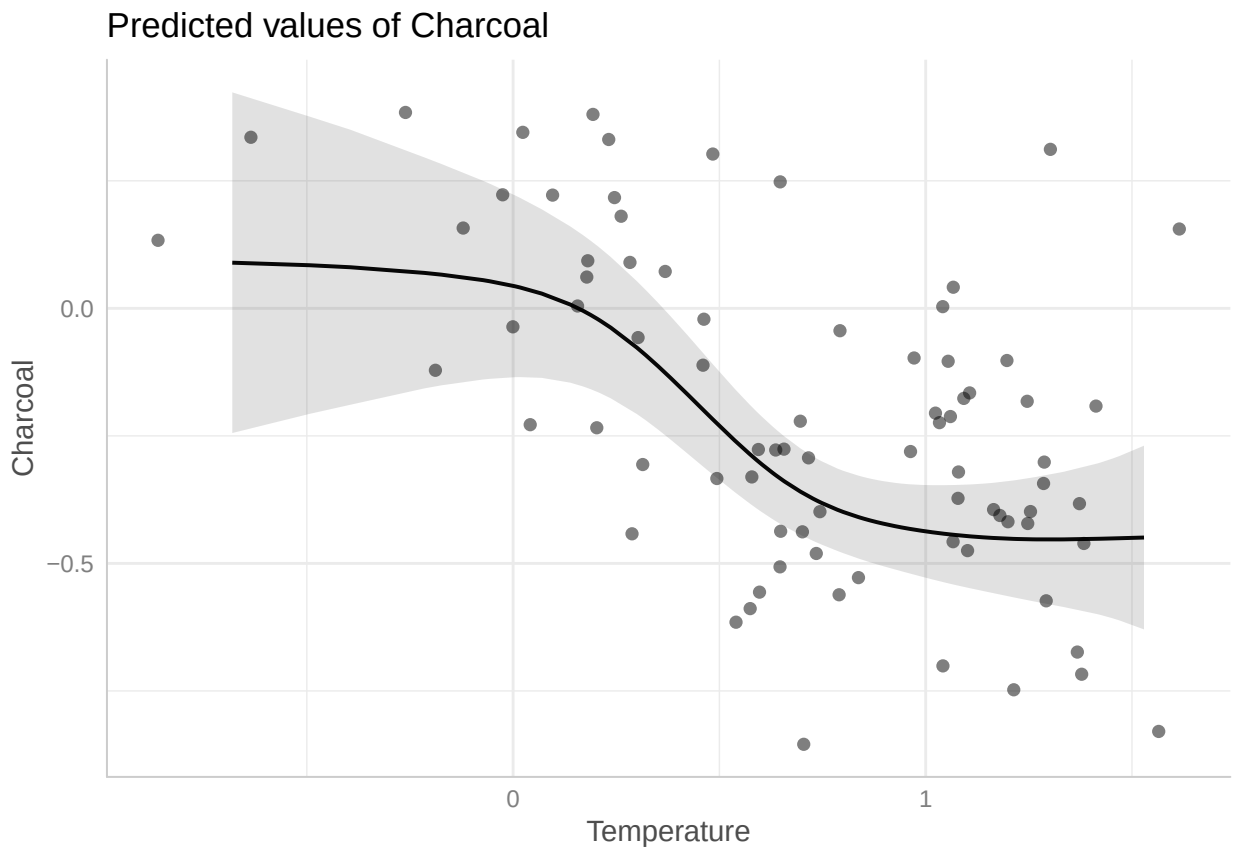



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 15 iterations.
## Gradient range [-1.919209e-06,1.541329e-06]
## (score -4.275707 & scale 0.04116738).
## Hessian positive definite, eigenvalue range [5.868978e-08,39.60019].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                        k'   edf k-index p-value
## s(Heathscrublandin) 9.000 0.668    0.85    0.09 .
## s(Temperature)      9.000 3.190    0.91    0.18
## s(P.PET)            9.000 2.216    1.16    0.89
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Heathscrublandin) + s(Temperature) + s(P.PET)
```

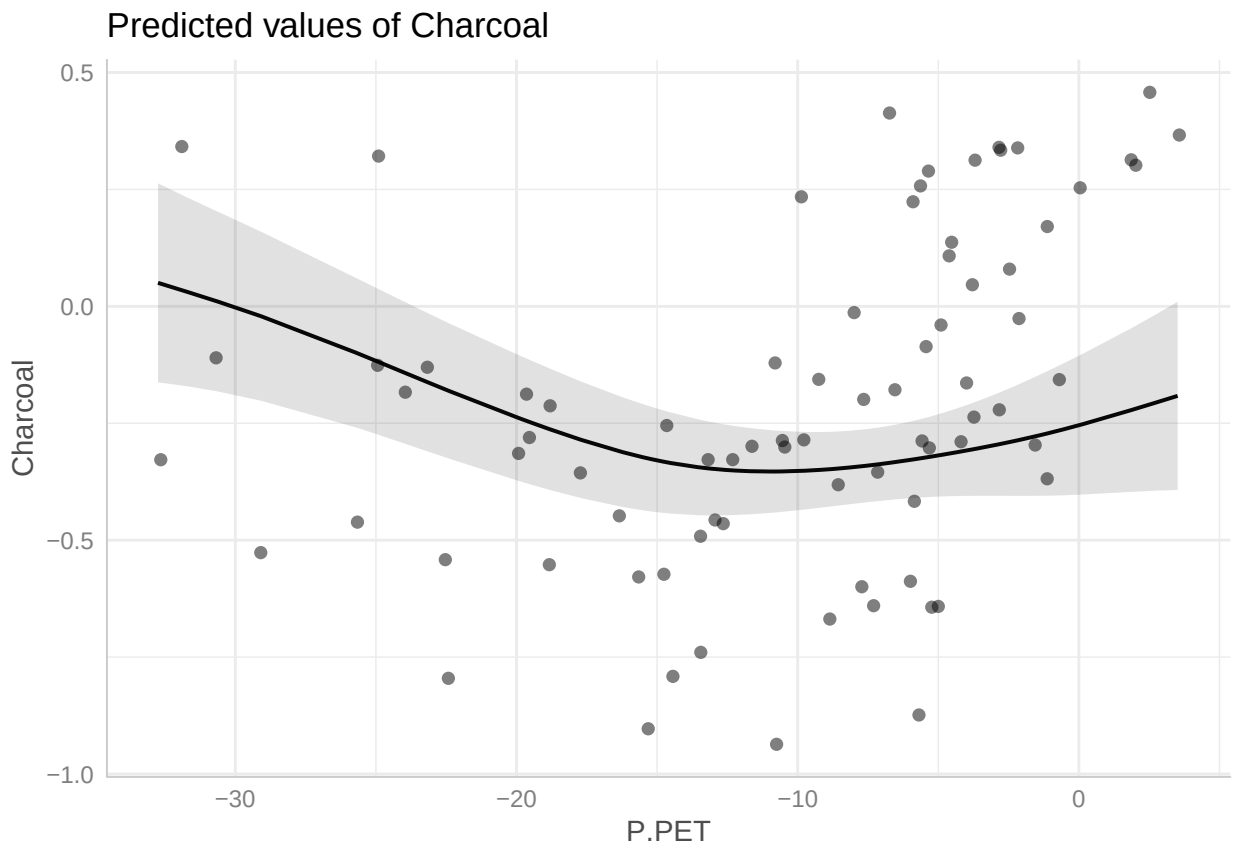
```
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.02268  -9.274 5.77e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                        edf Ref.df     F  p-value
## s(Heathscrublandin) 0.668      9 0.224 0.072065 .
## s(Temperature)      3.190      9 2.865 4.89e-06 ***
## s(P.PET)            2.216      9 1.728 0.000305 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.585   Deviance explained = 61.7%
## -REML = -4.2757  Scale est. = 0.041167  n = 80
## [1] "Plotting predictions"
## $Heathscrublandin
```

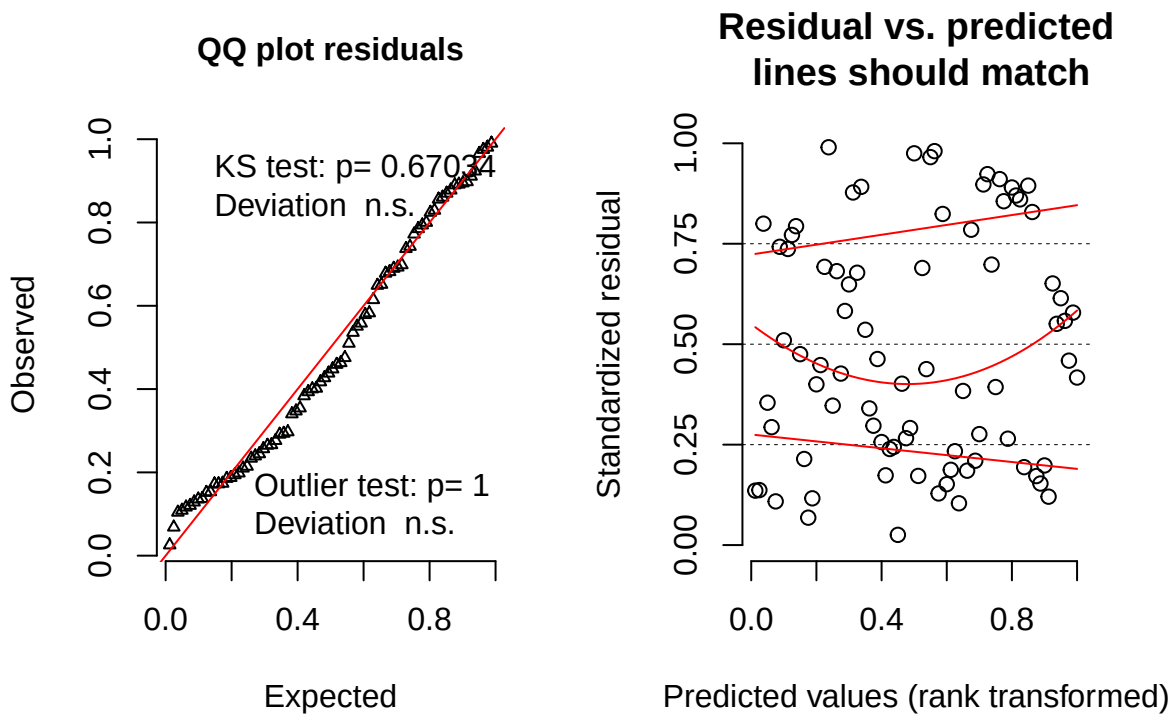



```
##
## $Temperature
```

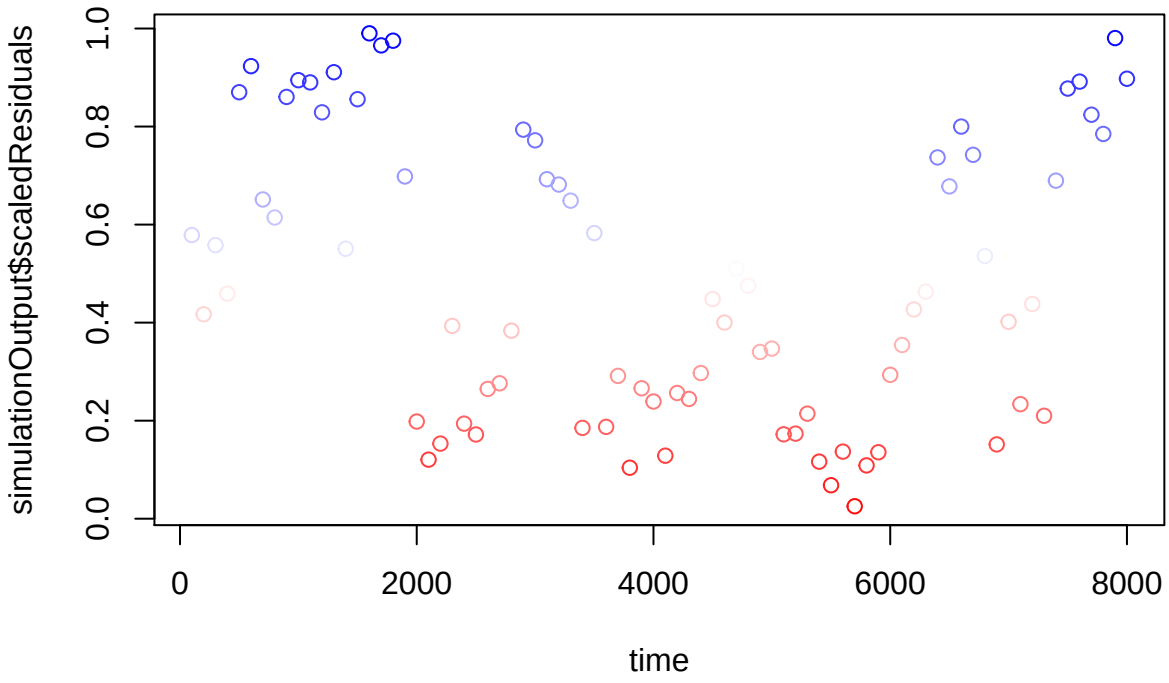

Predicted values of Charcoal
Charcoal
0.0
−0.5
0
1
Temperature

```
##
## $P.PET
```

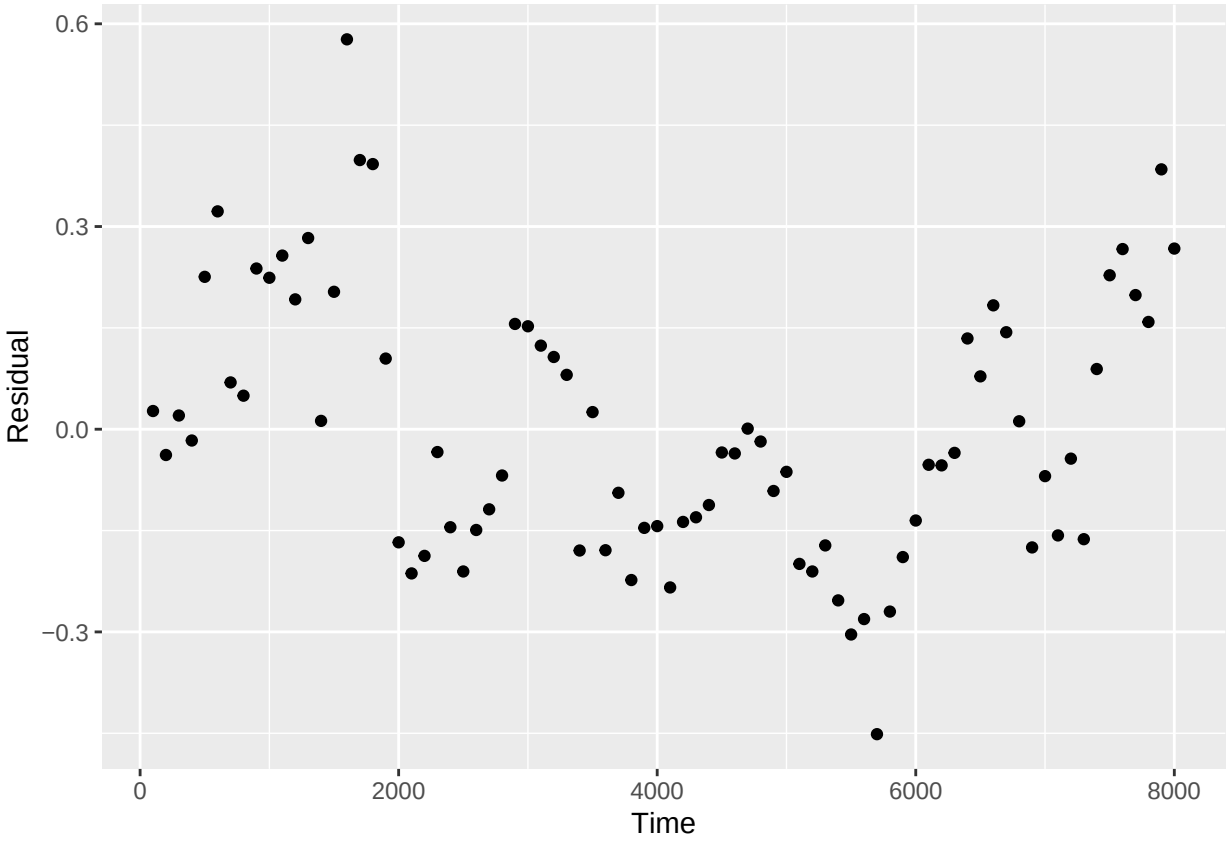

Predicted values of Charcoal
0.5
0.0
−0.5
−1.0
Charcoal
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

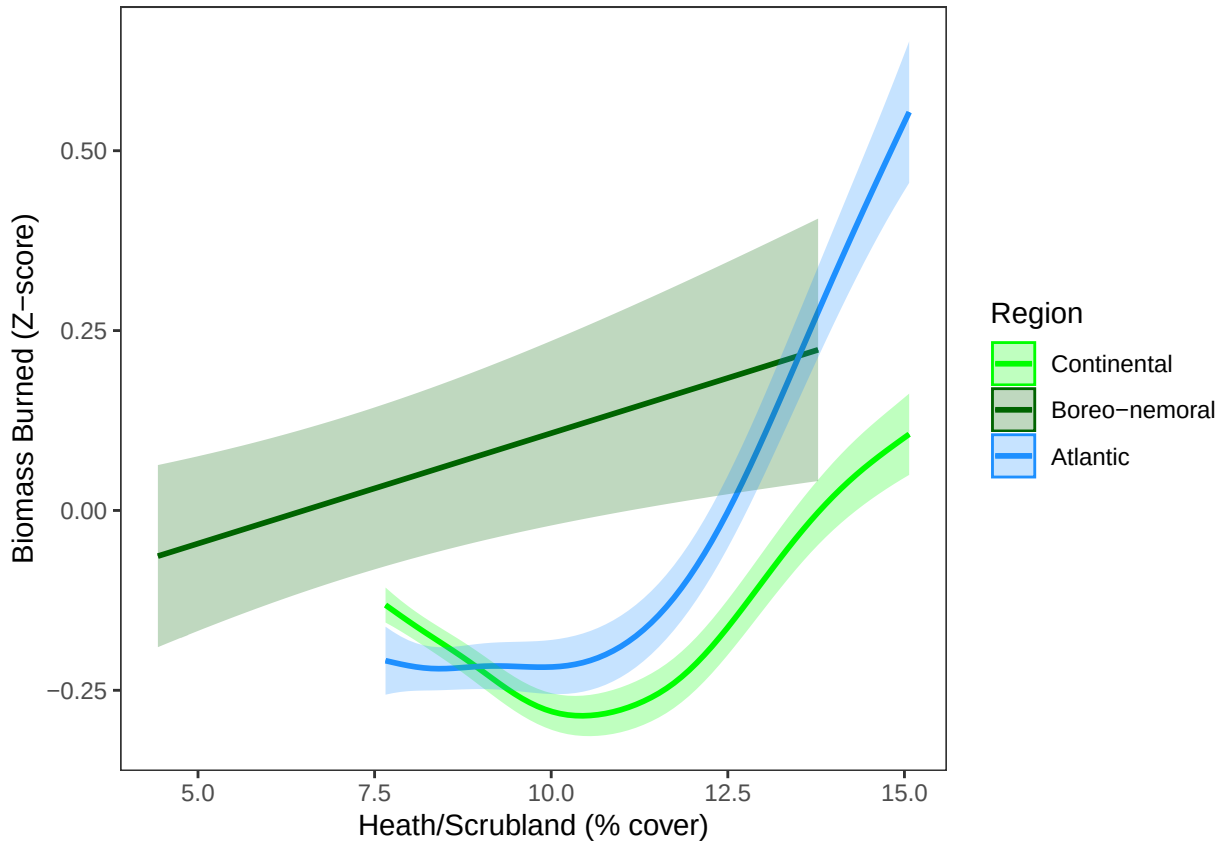



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.4326, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

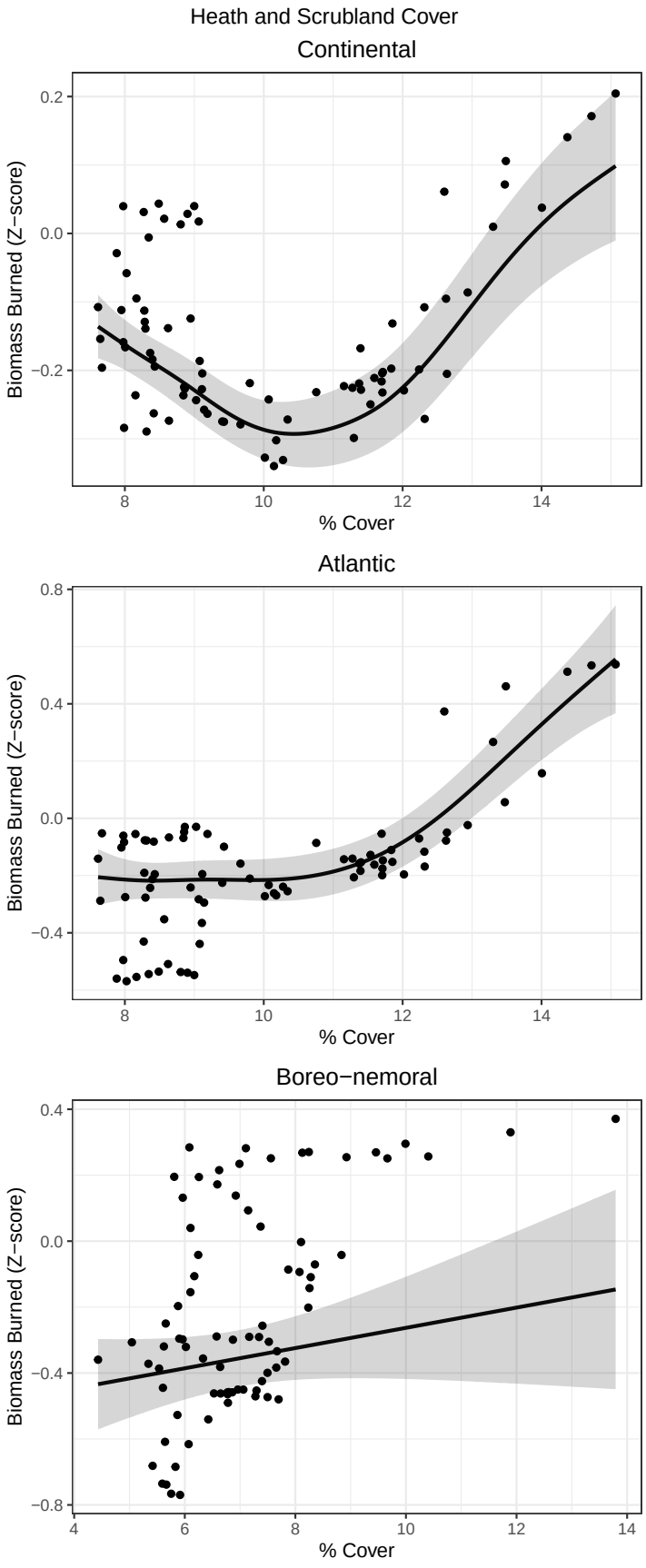


Heath/Scrubland cover plot

Here we show the marginal response of biomass burned to Heath/Scrubland cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.


Biomass Burned (Z−score)
0.50
0.25
0.00
−0.25
5.0
7.5
10.0
12.5
15.0
Heath/Scrubland (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```

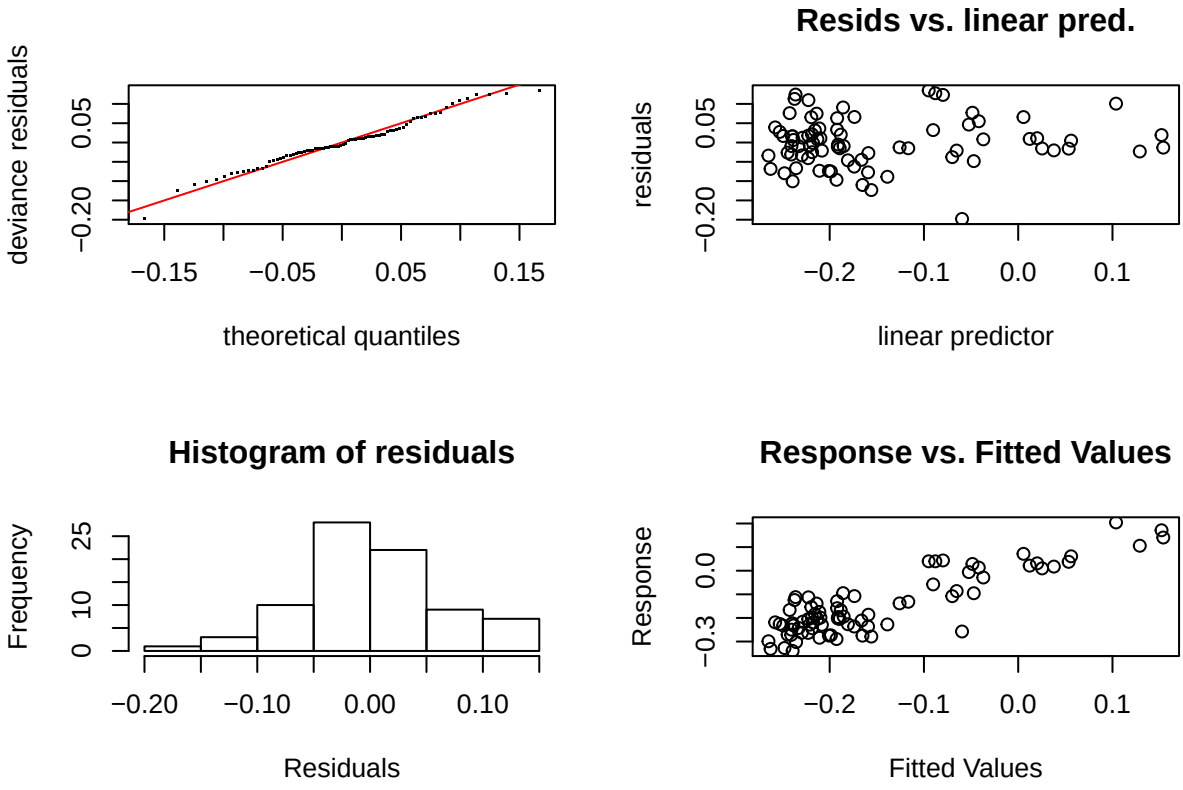

Heath and Scrubland Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
8
10
12
14
% Cover
Atlantic
Biomass Burned (Z−score)
0.8
0.4
0.0
−0.4
8
10
12
14
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.4
0.0
−0.4
−0.8
4
6
8
10
12
14
% Cover

Arable/disturbed land

Arable/disturbed land, Continental ecoregion

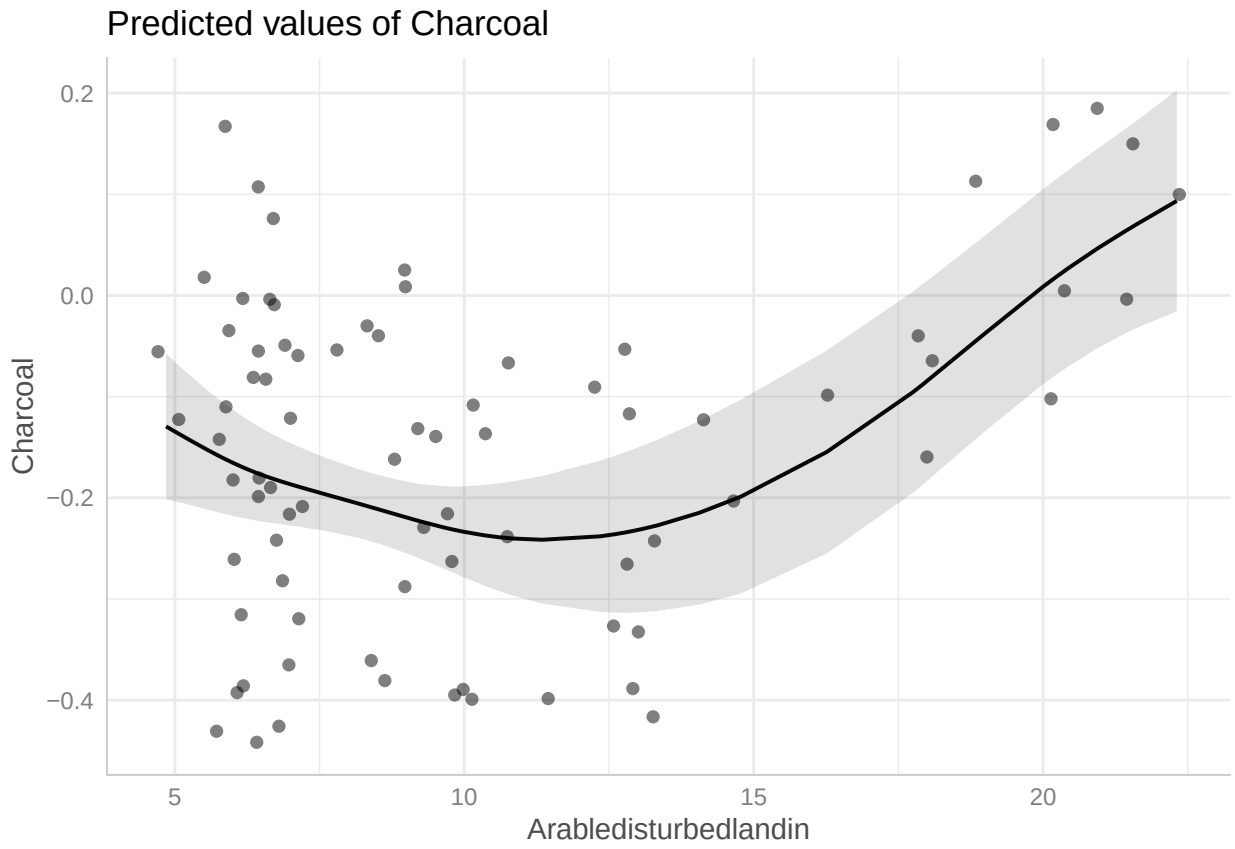
```
arable.continental <- charcoal.gam(Charcoal ~ s(Arabledisturbedlandin) + s(Temperature)  + s(P.PET), da
```

```
## [1] "Checking GAM"
```

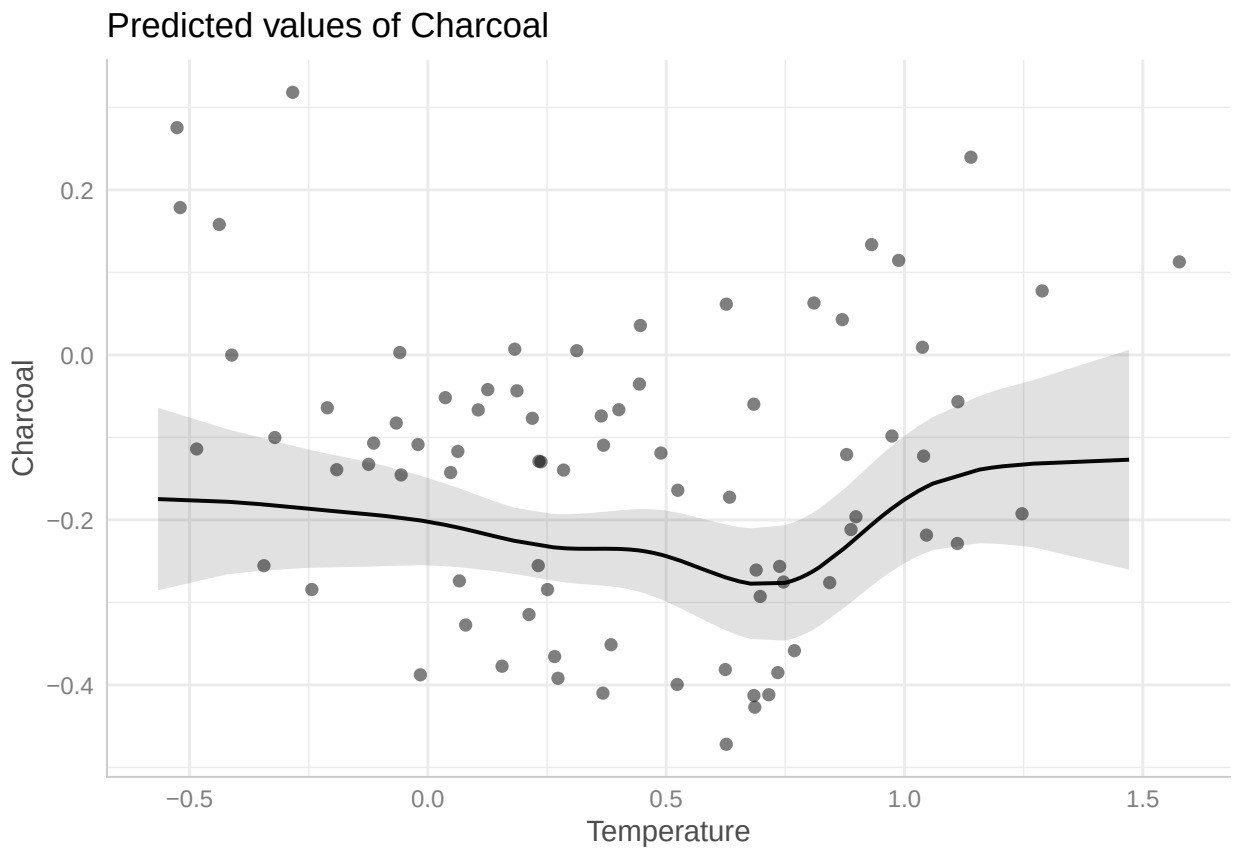



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 15 iterations.
## Gradient range [-4.11805e-05,0.0002885247]
## (score -86.15972 & scale 0.004454921).
## Hessian positive definite, eigenvalue range [1.627516e-06,39.73204].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                             k'   edf k-index p-value
## s(Arabledisturbedlandin) 9.000 3.115    0.73   0.015 *
## s(Temperature)           9.000 5.106    1.05   0.640
## s(P.PET)                 9.000 0.821    1.01   0.395
## ---
```

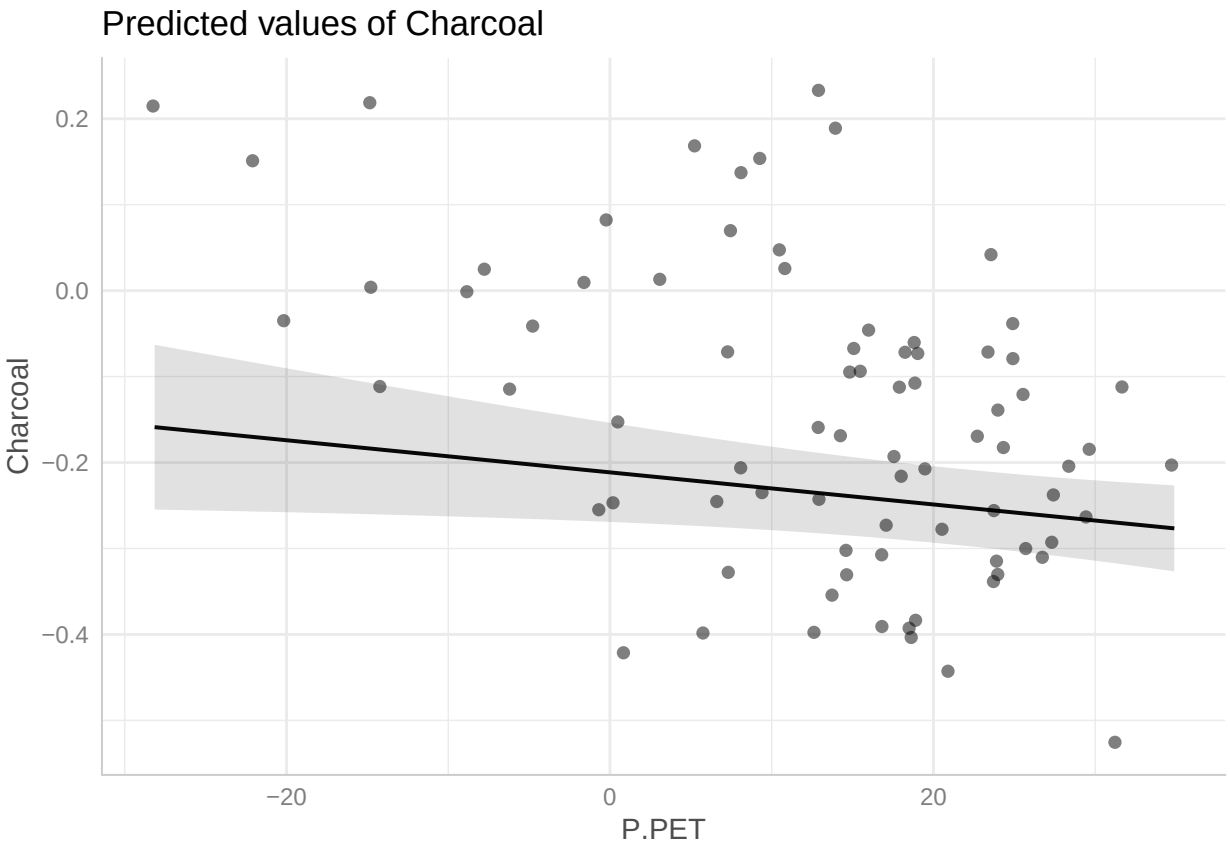
```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Arabledisturbedlandin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.007462  -20.02   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                              edf Ref.df     F  p-value
## s(Arabledisturbedlandin) 3.1148      9 7.578 3.23e-13 ***
## s(Temperature)           5.1063      9 2.177 0.000973 ***
## s(P.PET)                 0.8213      9 0.509 0.019546 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =   0.73   Deviance explained = 76.1%
## -REML = -86.16  Scale est. = 0.0044549  n = 80
## [1] "Plotting predictions"
## $Arabledisturbedlandin
```

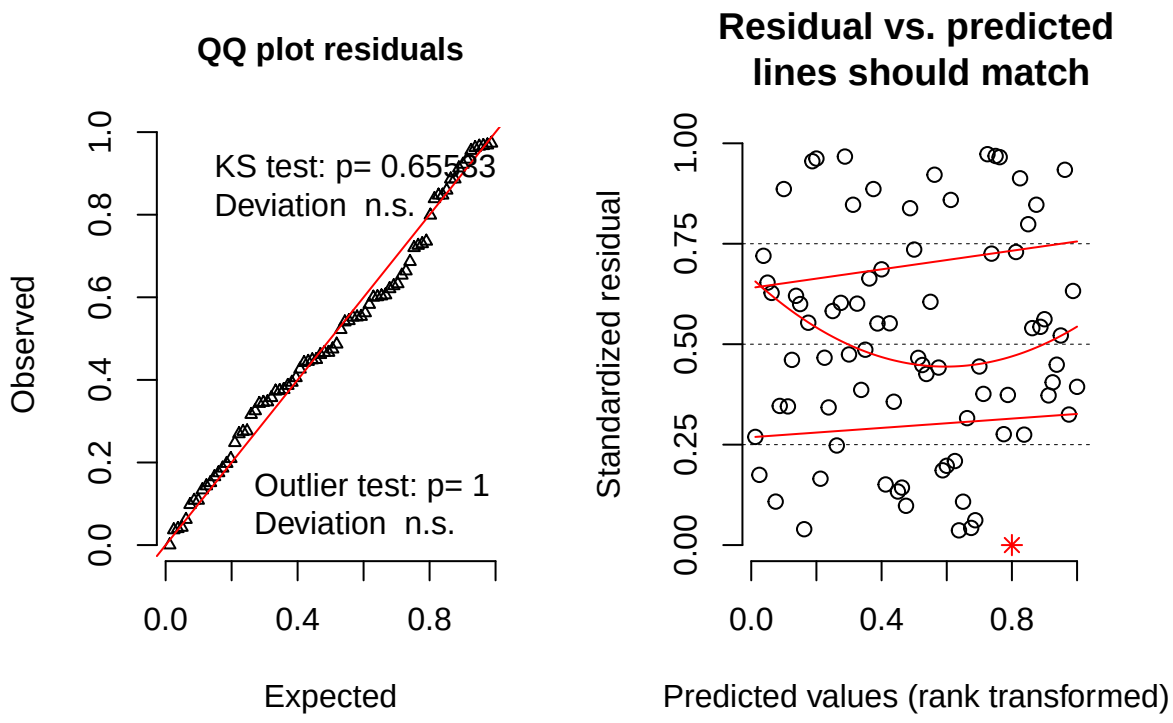



```
##
## $Temperature
```

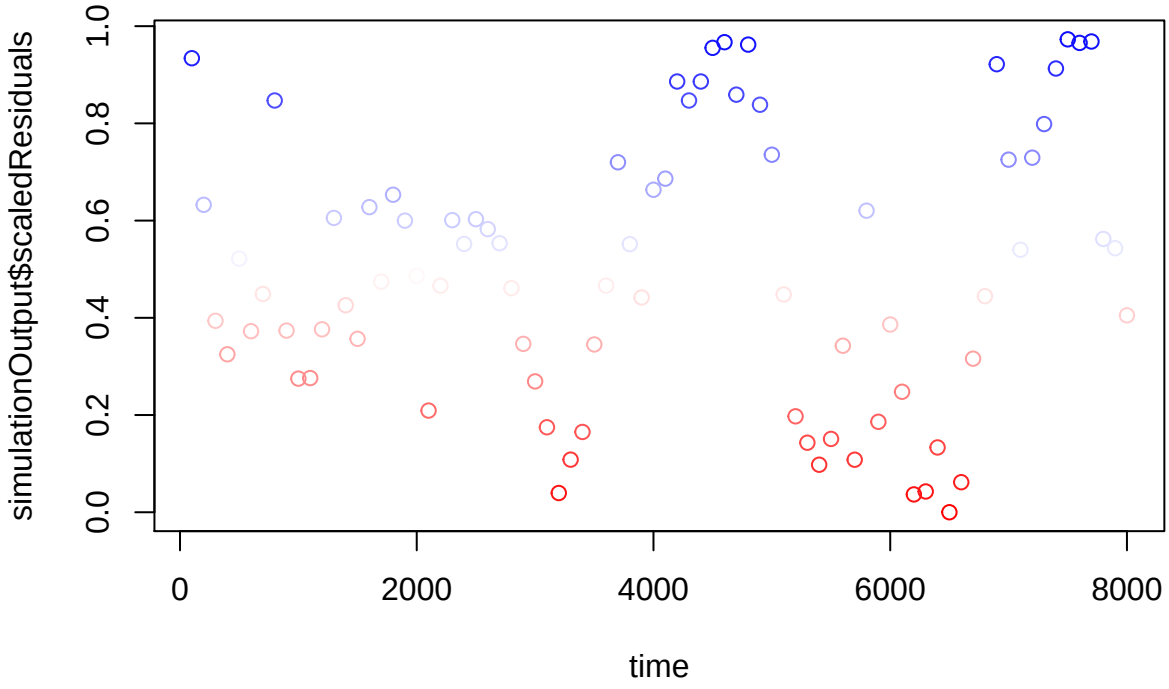

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−0.5
0.0
0.5
1.0
1.5
Temperature

```
##
## $P.PET
```

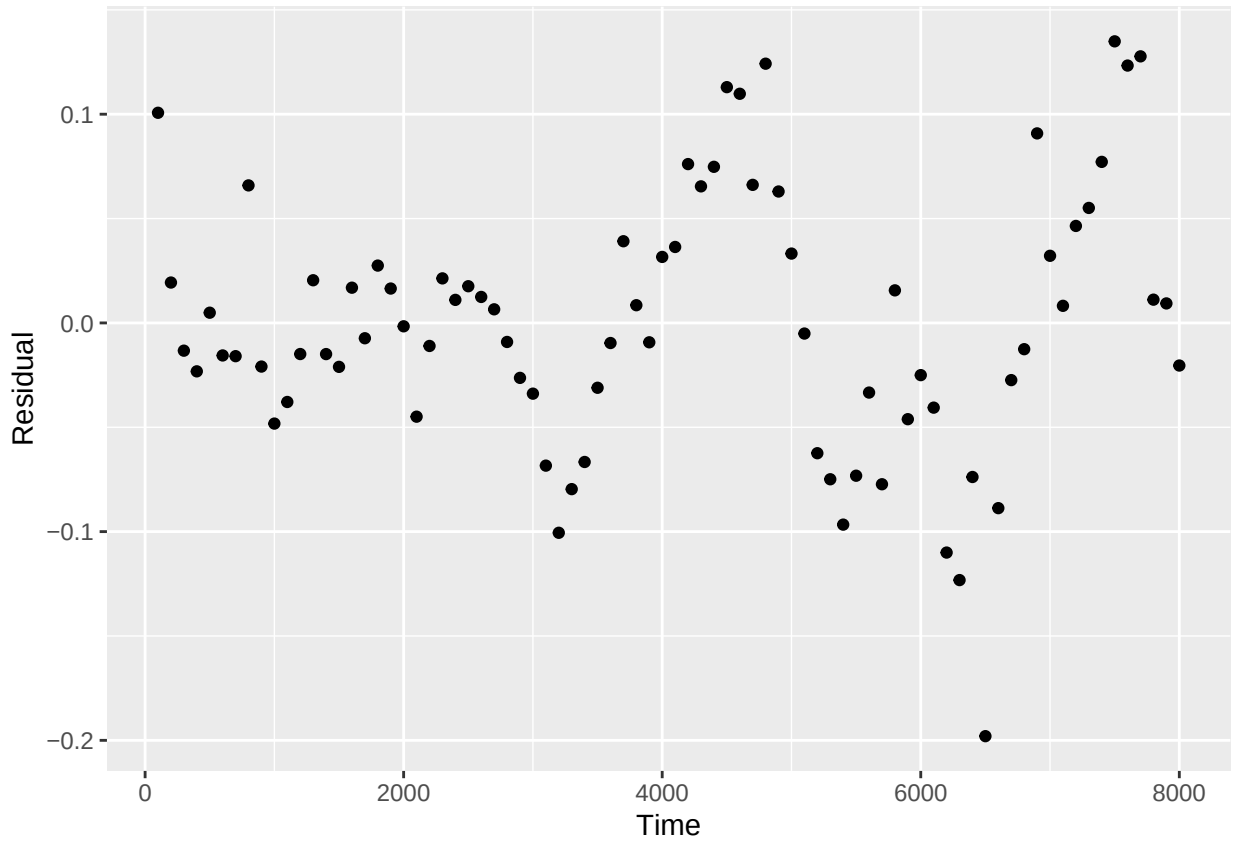

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



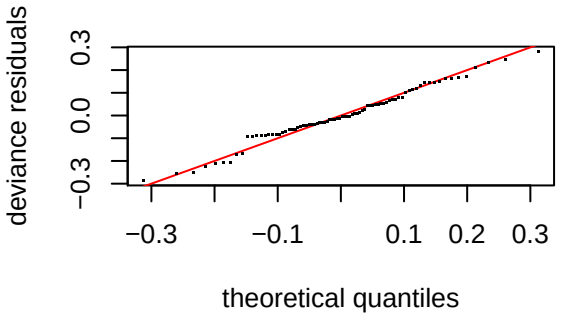

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.47182, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

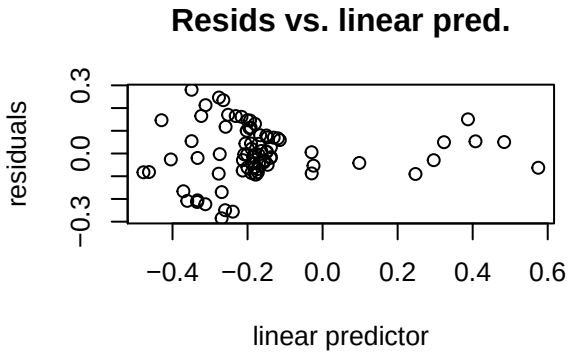


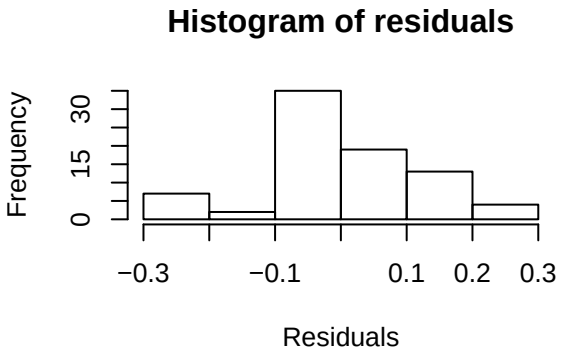
Arable/disturbed land, Atlantic ecoregion

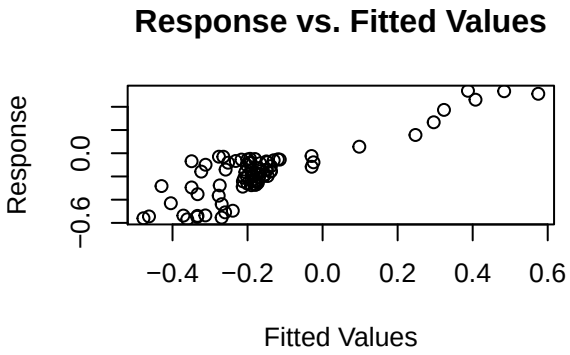
```
arable.atlantic <- charcoal.gam(Charcoal ~ s(Arabledisturbedlandin) + s(Temperature)  + s(P.PET), data =
```

```
## [1] "Checking GAM"
```



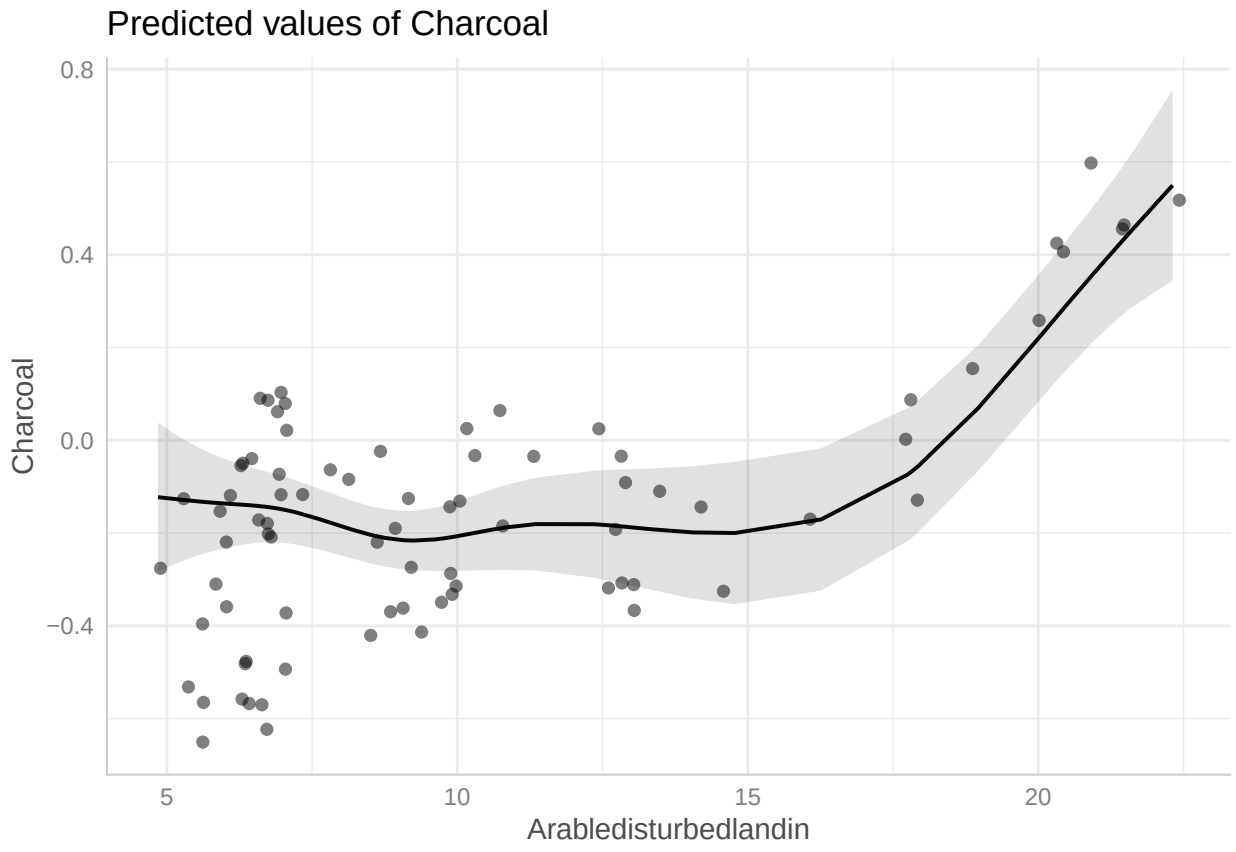




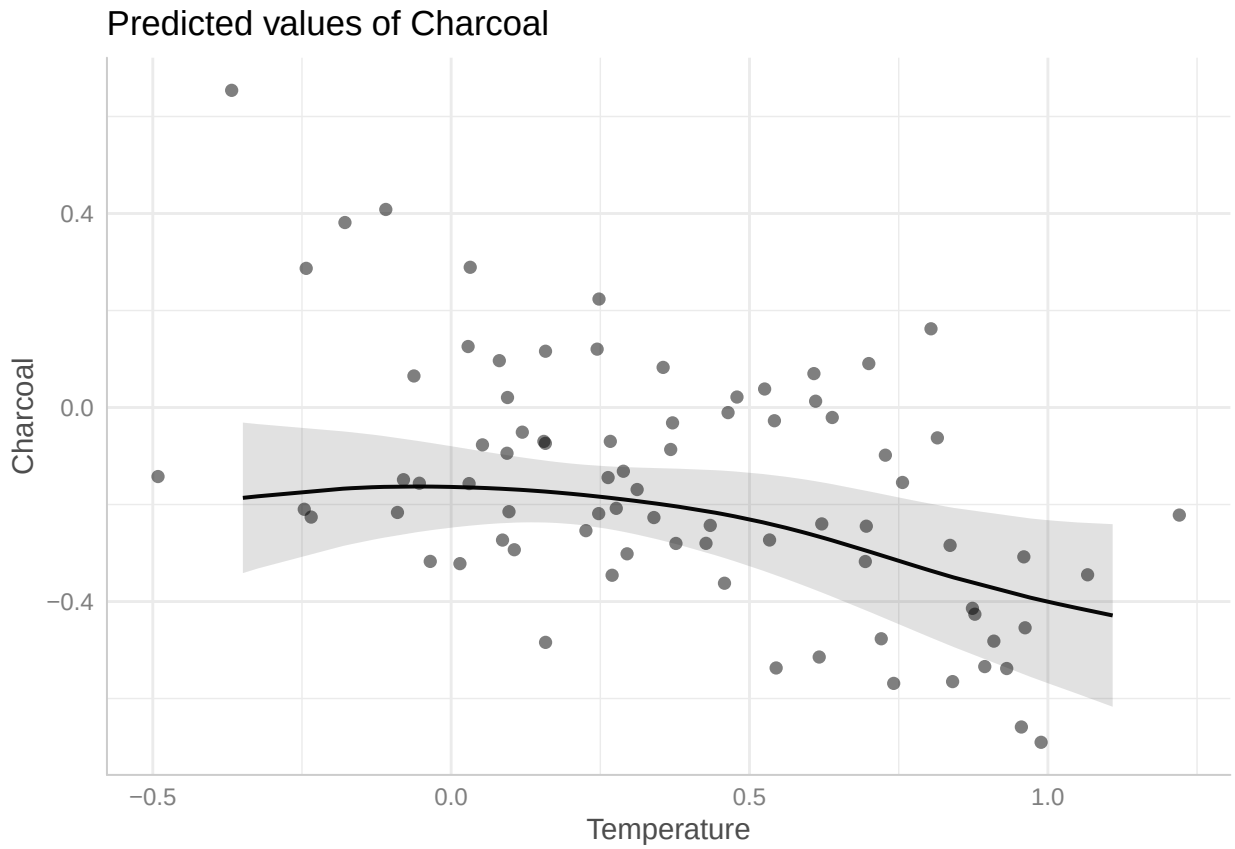



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 14 iterations.
## Gradient range [-8.165404e-06,1.135047e-05]
## (score -38.26363 & scale 0.01565882).
## Hessian positive definite, eigenvalue range [0.0254846,39.6302].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                            k'  edf k-index p-value
## s(Arabledisturbedlandin) 9.00 4.64    0.68  <2e-16 ***
## s(Temperature)           9.00 1.99    1.31    0.99
## s(P.PET)                 9.00 1.65    1.05    0.61
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Arabledisturbedlandin) + s(Temperature) + s(P.PET)
```

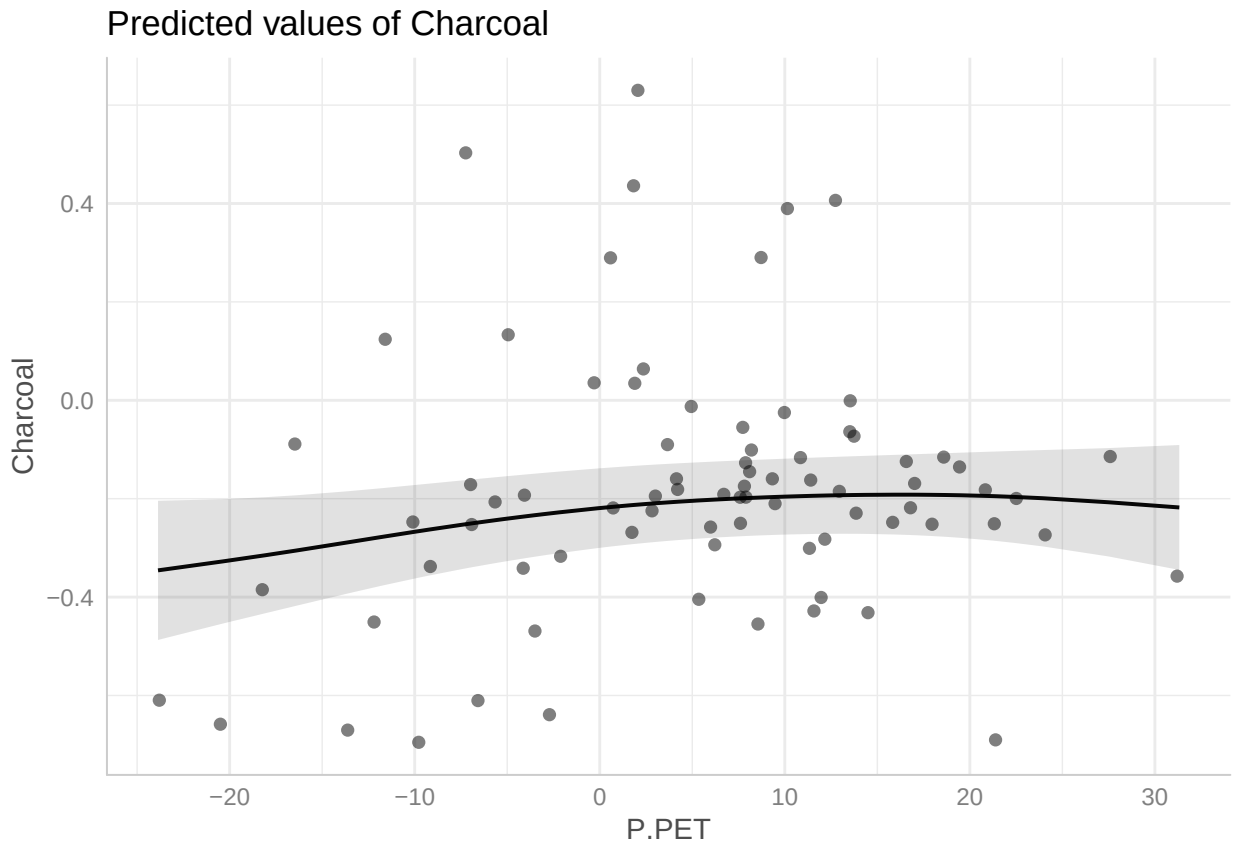
```
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.01399  -11.55   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                              edf Ref.df      F p-value
## s(Arabledisturbedlandin) 4.641      9 11.208 < 2e-16 ***
## s(Temperature)           1.992      9  0.938 0.00519 **
## s(P.PET)                 1.647      9  0.618 0.02552 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.723   Deviance explained = 75.2%
## -REML = -38.264  Scale est. = 0.015659  n = 80
## [1] "Plotting predictions"
## $Arabledisturbedlandin
```

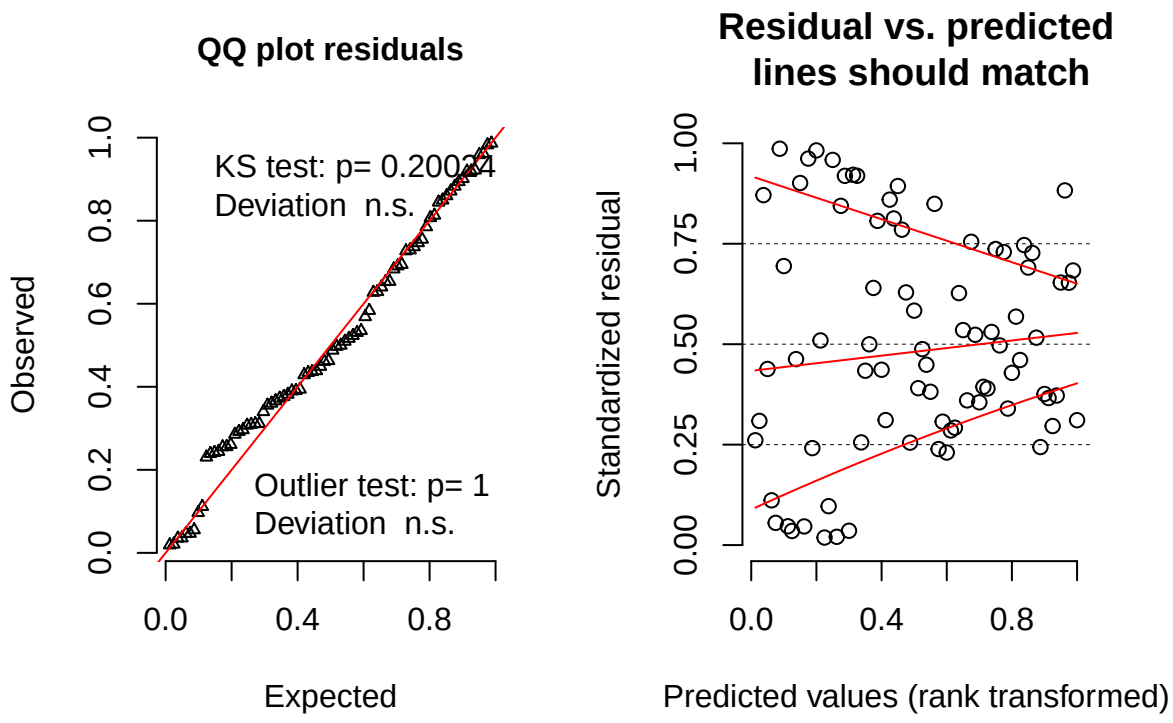



```
##
## $Temperature
```

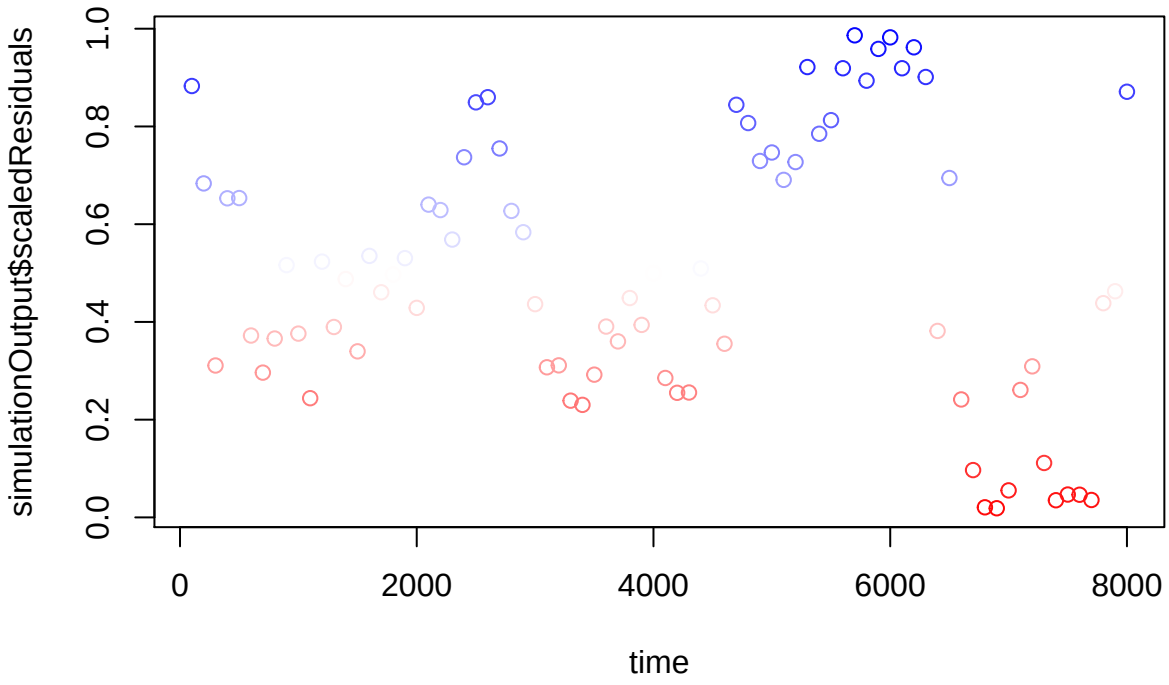

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

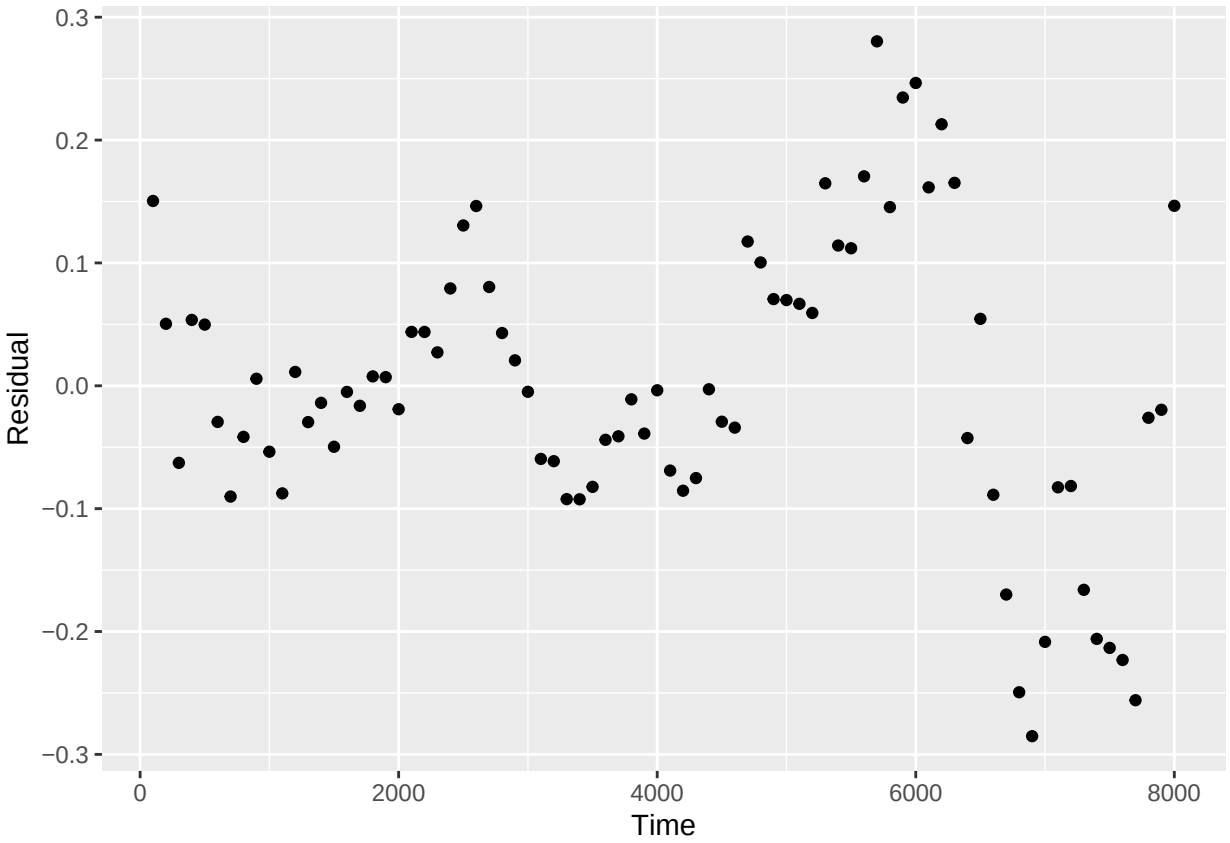

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



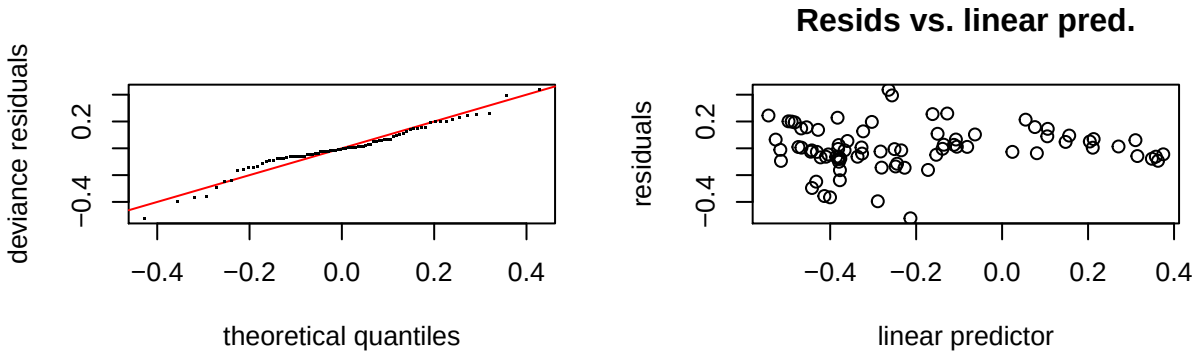

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.39298, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

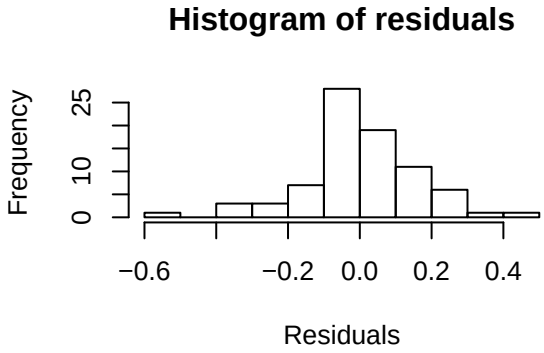


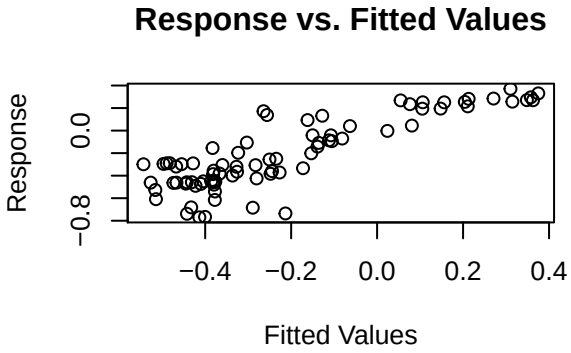
Arable/disturbed land, Boreo-Nemoral ecoregion

```
arable.boreonemoral <- charcoal.gam(Charcoal ~ s(Arabledisturbedlandin) + s(Temperature)  + s(P.PET), da
```

```
## [1] "Checking GAM"
```

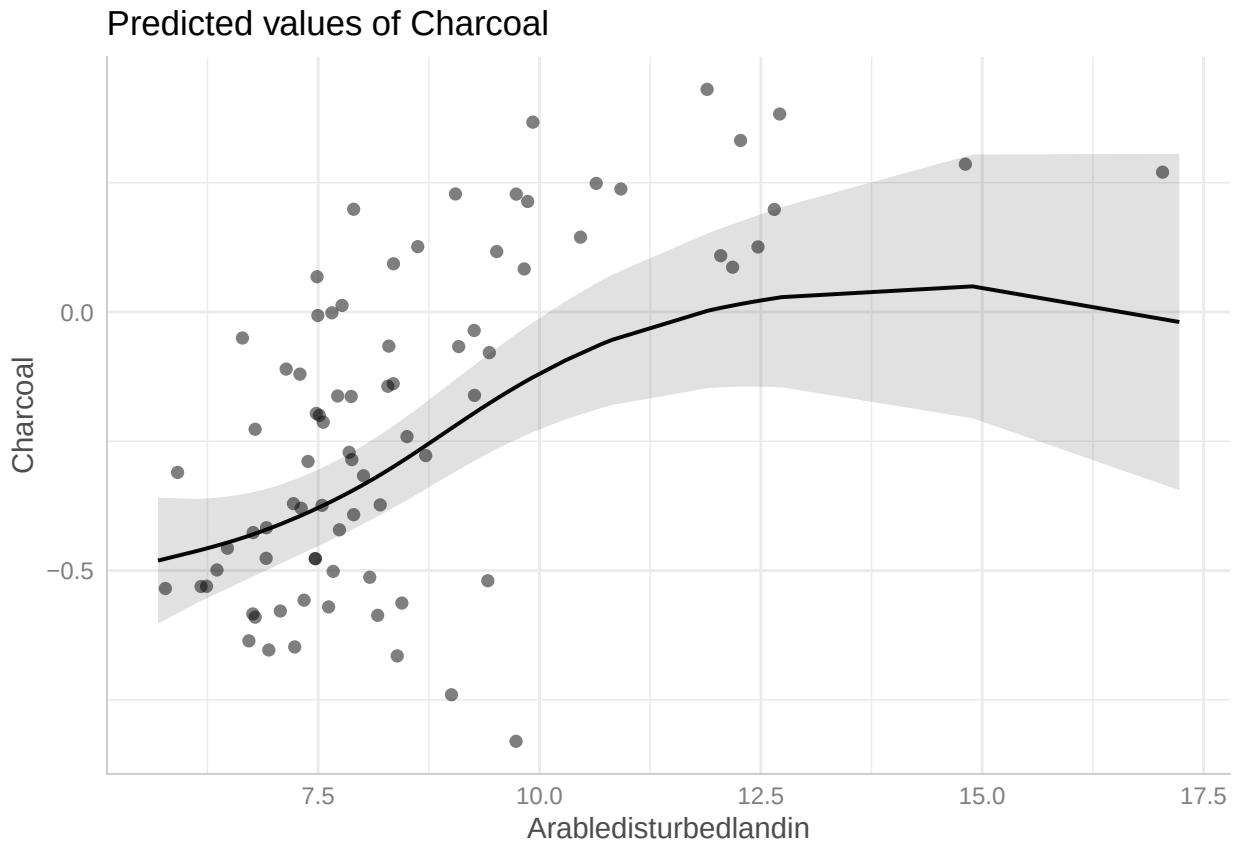




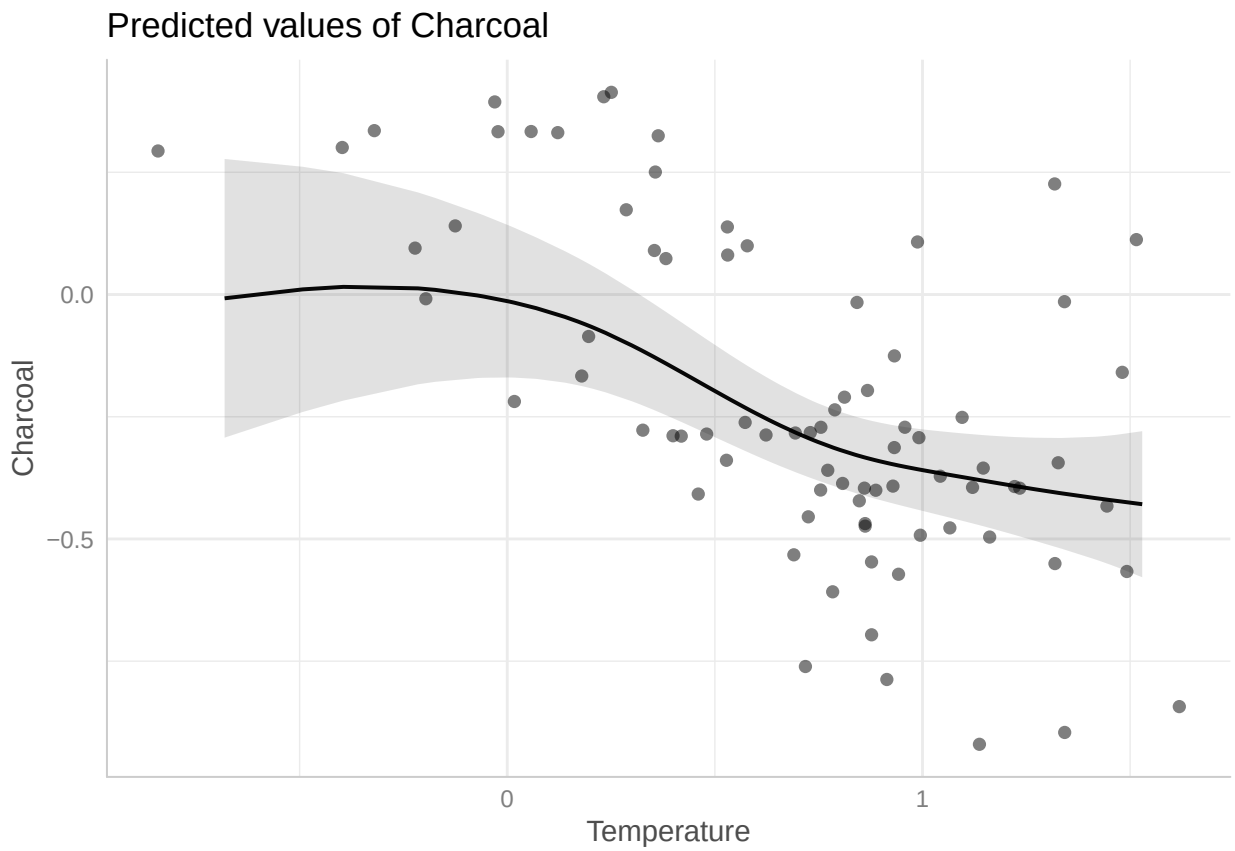



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-1.065331e-05,2.773487e-05]
## (score -15.94575 & scale 0.02931754).
## Hessian positive definite, eigenvalue range [5.096656e-07,39.62093].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                             k'  edf k-index p-value
## s(Arabledisturbedlandin) 9.00 2.53    1.06    0.66
## s(Temperature)           9.00 2.55    0.97    0.34
## s(P.PET)                 9.00 2.47    1.11    0.79
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Arabledisturbedlandin) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

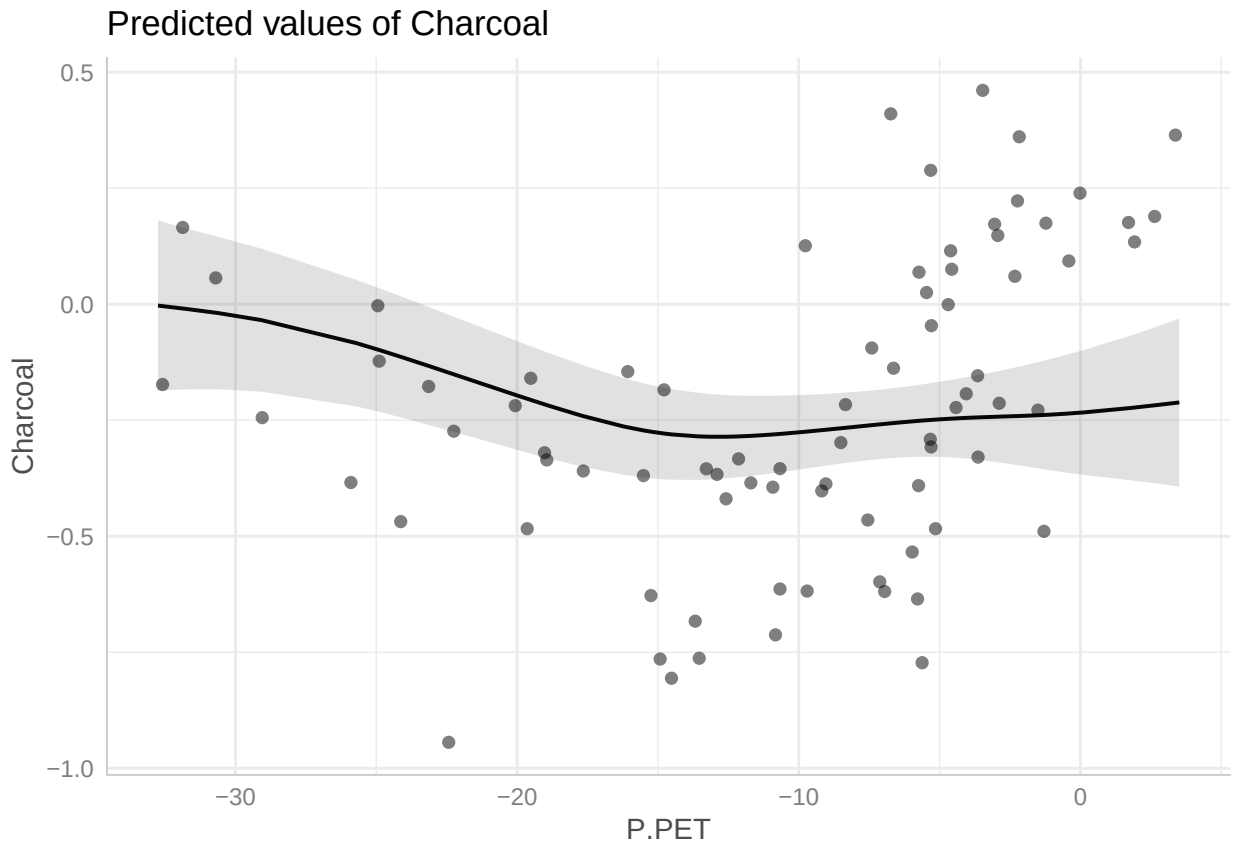
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.01914  -10.99   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                             edf Ref.df     F  p-value
## s(Arabledisturbedlandin) 2.527      9 4.116 2.15e-08 ***
## s(Temperature)           2.545      9 2.087 6.59e-05 ***
## s(P.PET)                 2.469      9 1.382  0.00201 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.704   Deviance explained = 73.2%
## -REML = -15.946  Scale est. = 0.029318  n = 80
## [1] "Plotting predictions"
## $Arabledisturbedlandin
```

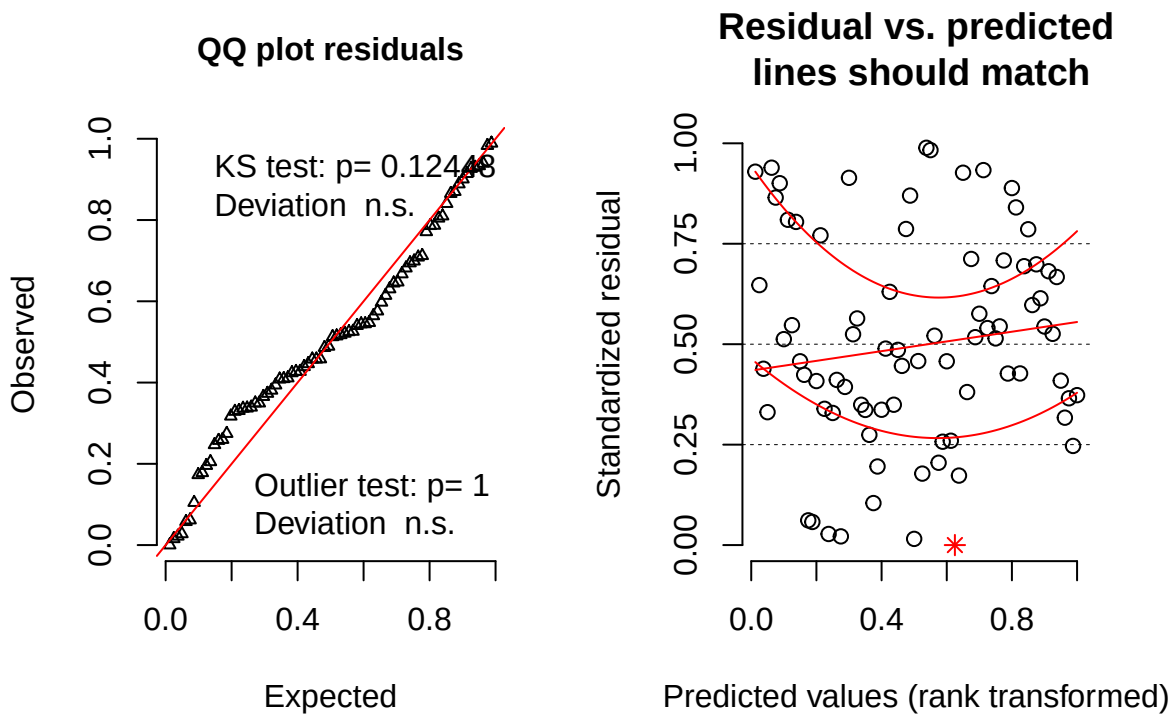



```
##
## $Temperature
```

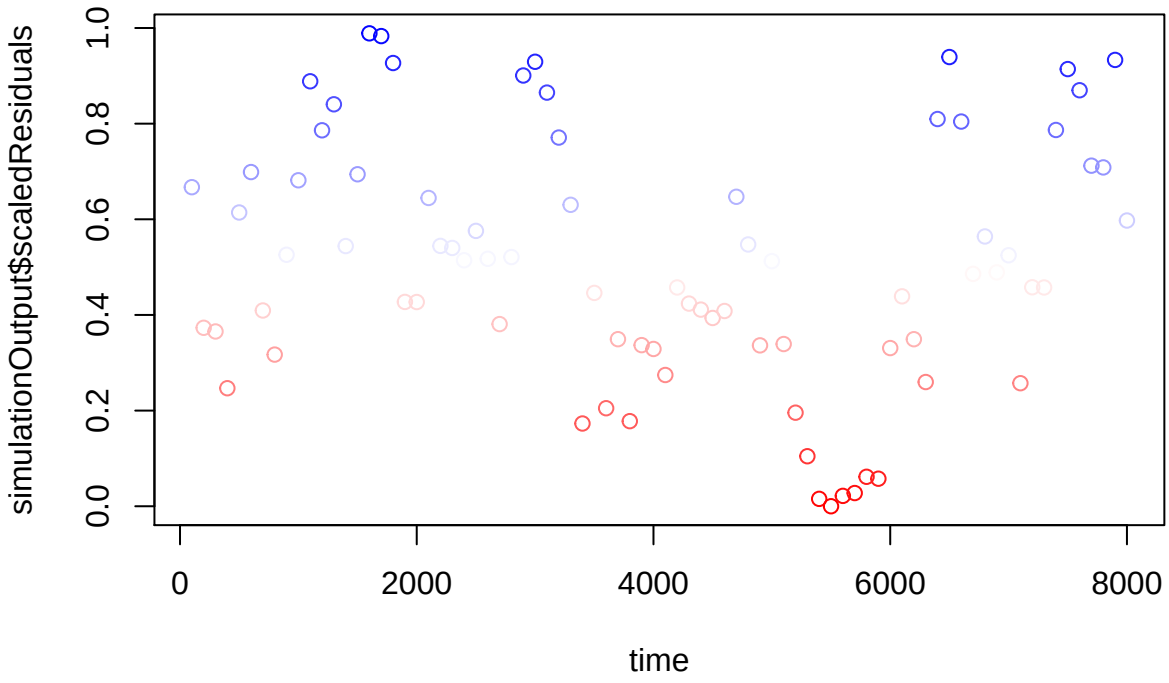

Predicted values of Charcoal
Charcoal
0.0
−0.5
0
1
Temperature

```
##
## $P.PET
```

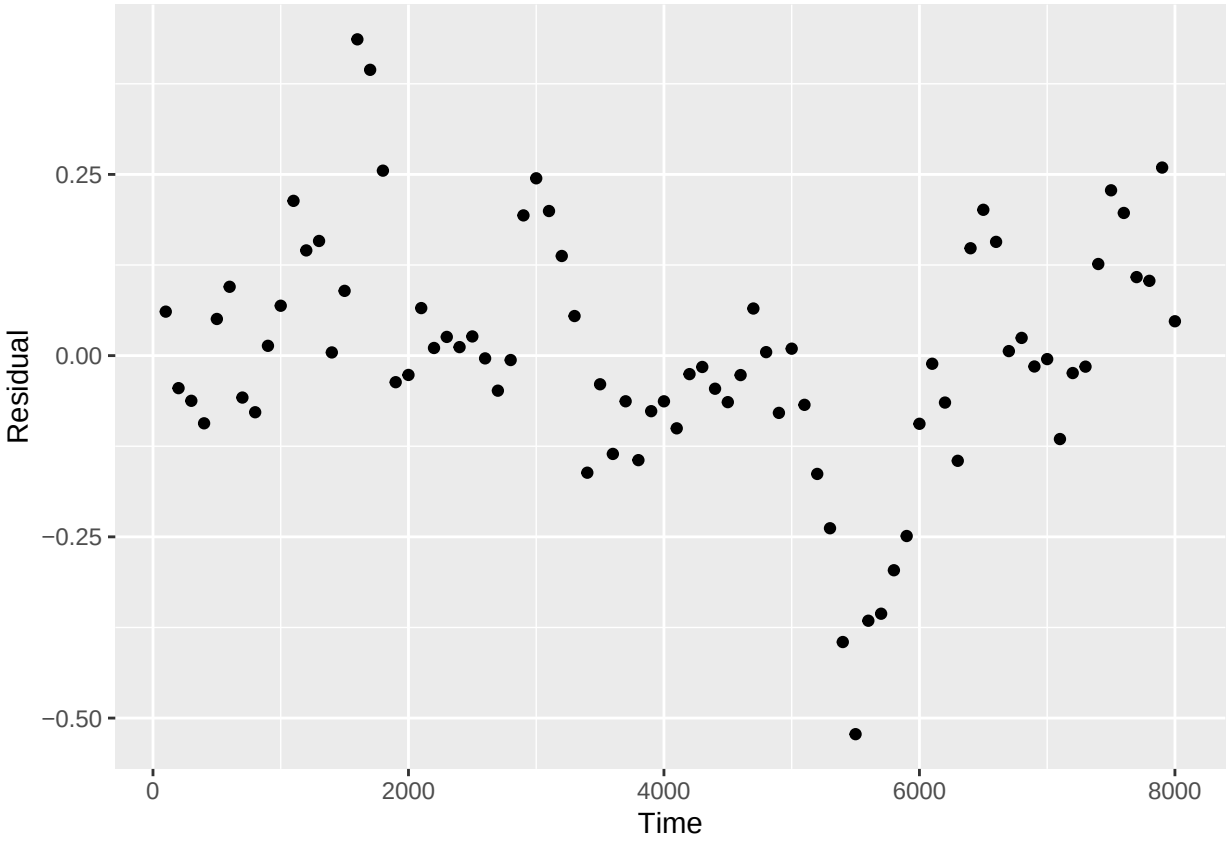

Predicted values of Charcoal
0.5
0.0
−0.5
−1.0
Charcoal
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

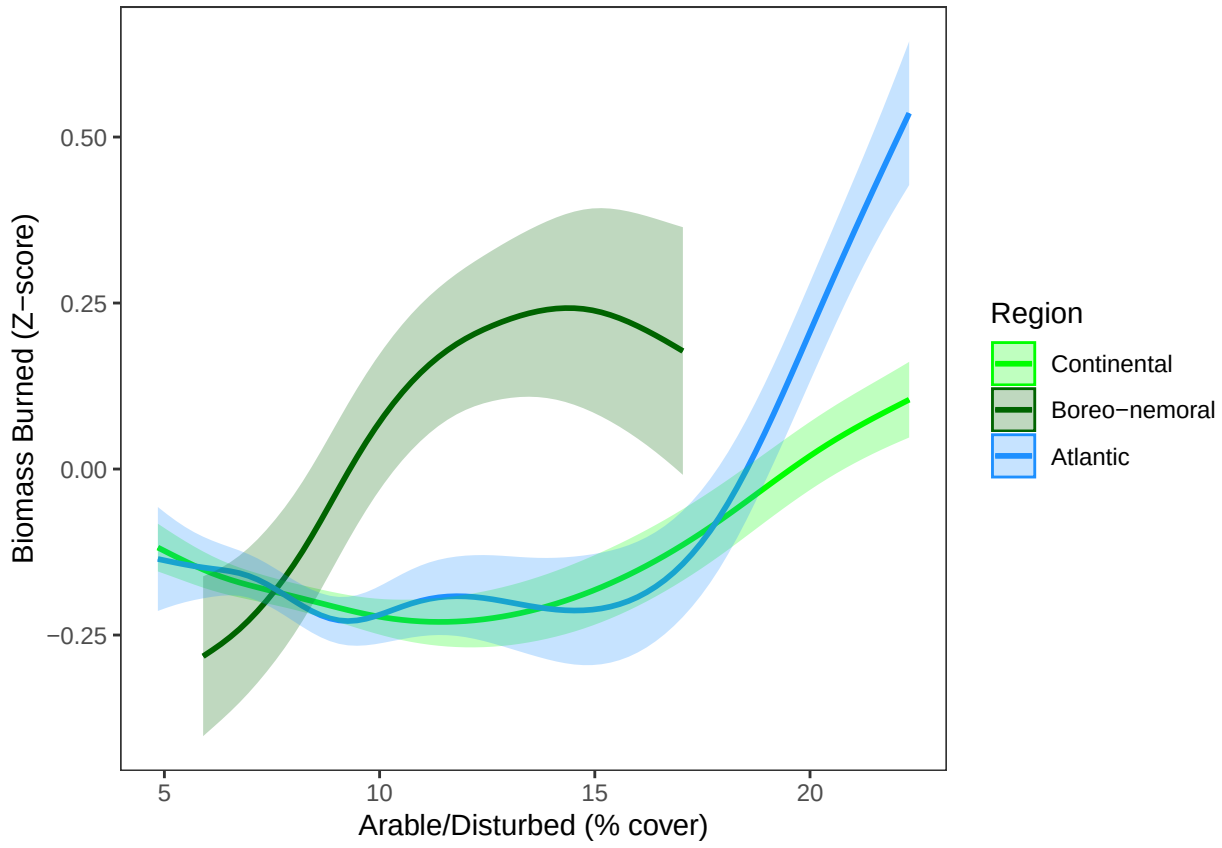



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.53865, p-value = 4.391e-15
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

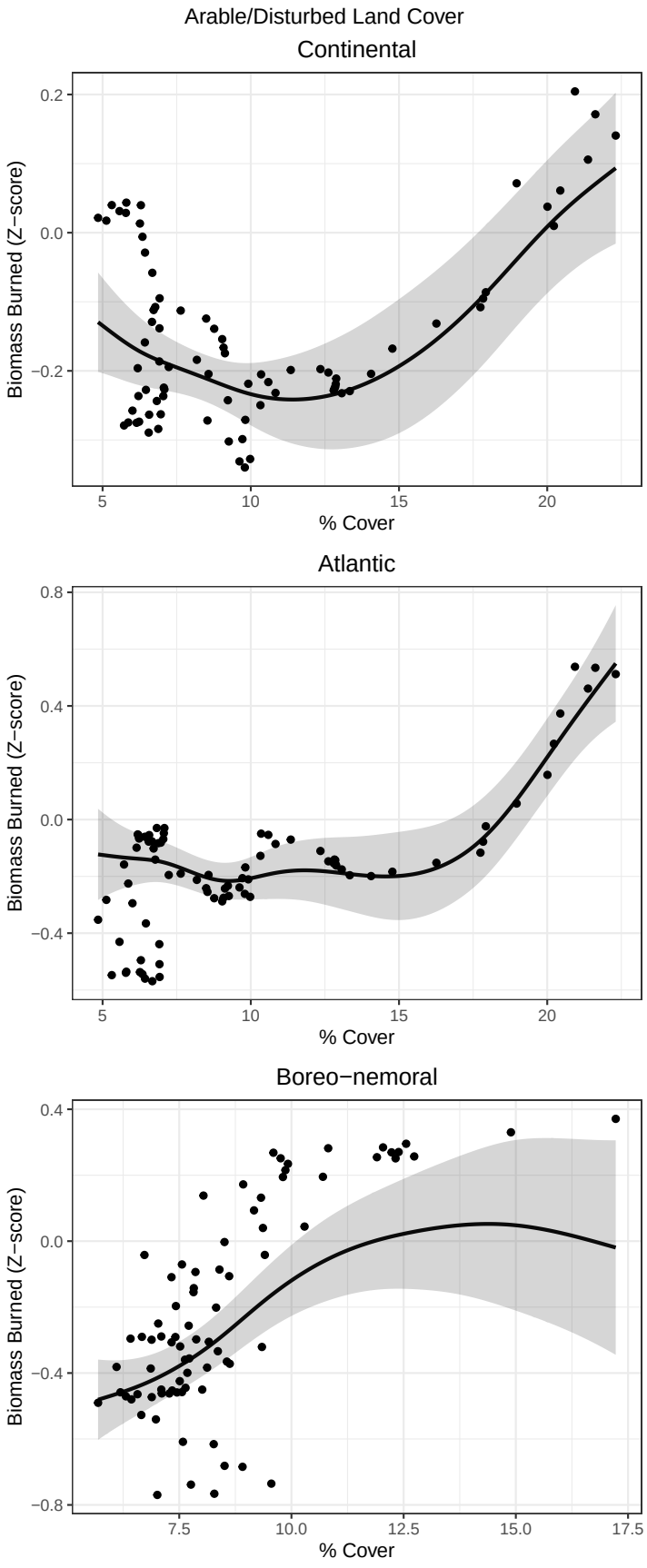


Arable/disturbed land cover plot

Here we show the marginal response of biomass burned to arable and arable cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.


Biomass Burned (Z−score)
0.50
0.25
0.00
−0.25
5
10
15
20
Arable/Disturbed (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```

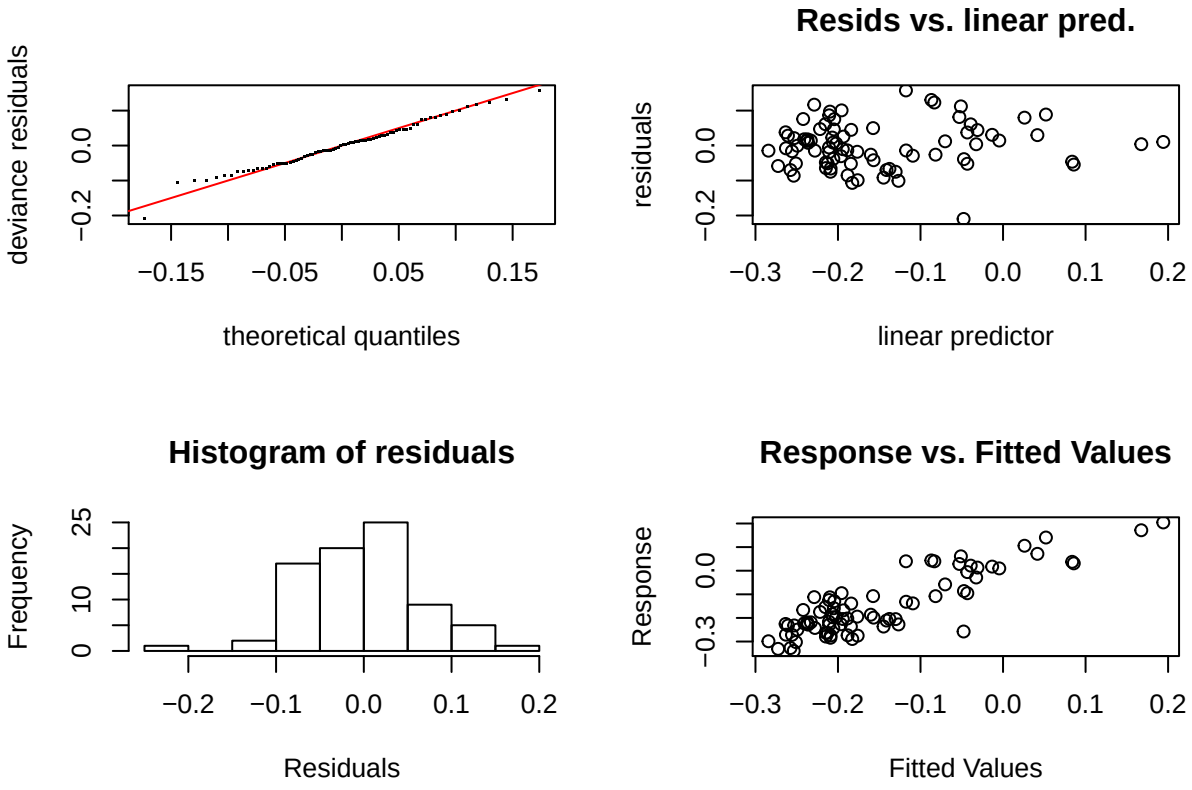

Arable/Disturbed Land Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
5
10
15
20
% Cover
Atlantic
Biomass Burned (Z−score)
0.8
0.4
0.0
−0.4
5
10
15
20
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.4
0.0
−0.4
−0.8
7.5
10.0
12.5
15.0
17.5
% Cover

Grassland/pasture

Grassland/pasture cover, Continental ecoregion

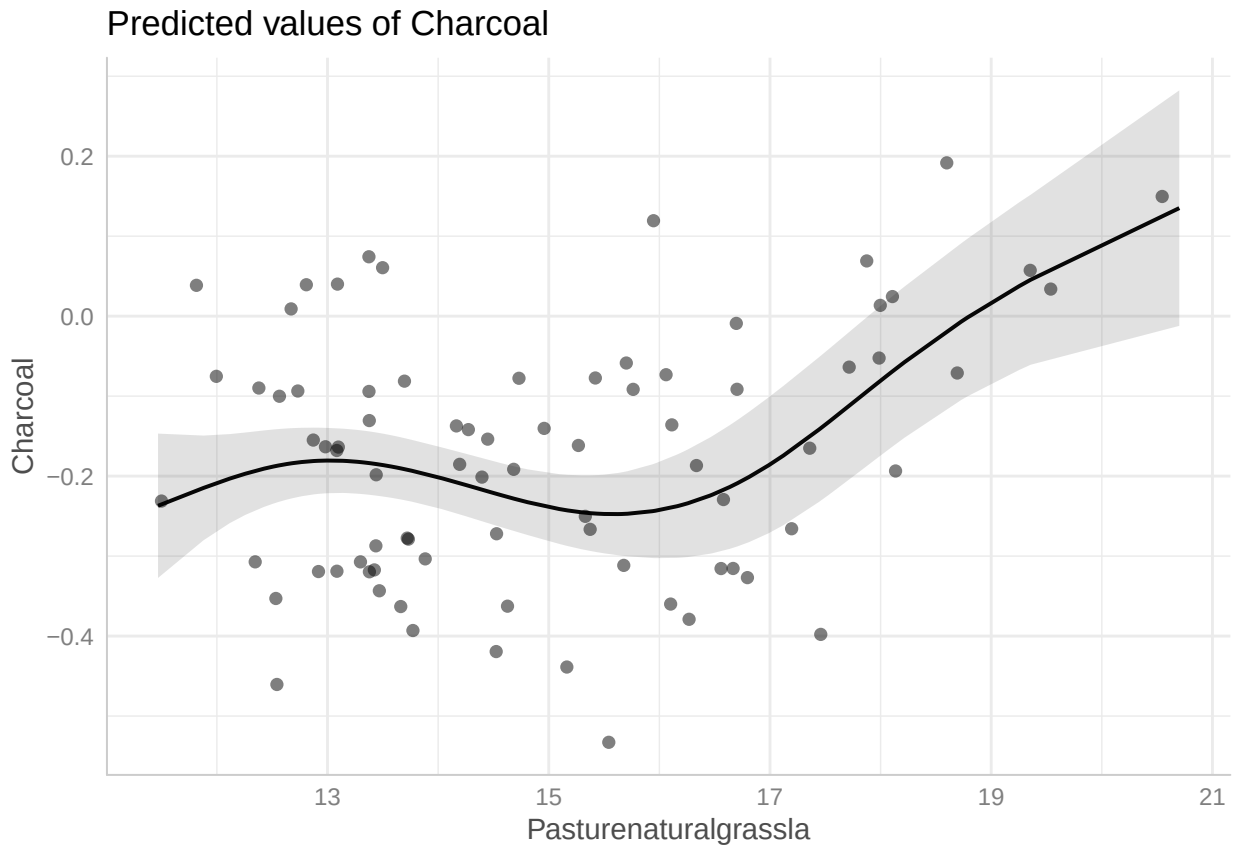
```
pasture.continental <- charcoal.gam(Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature)  + s(P.PET), da
```

```
## [1] "Checking GAM"
```

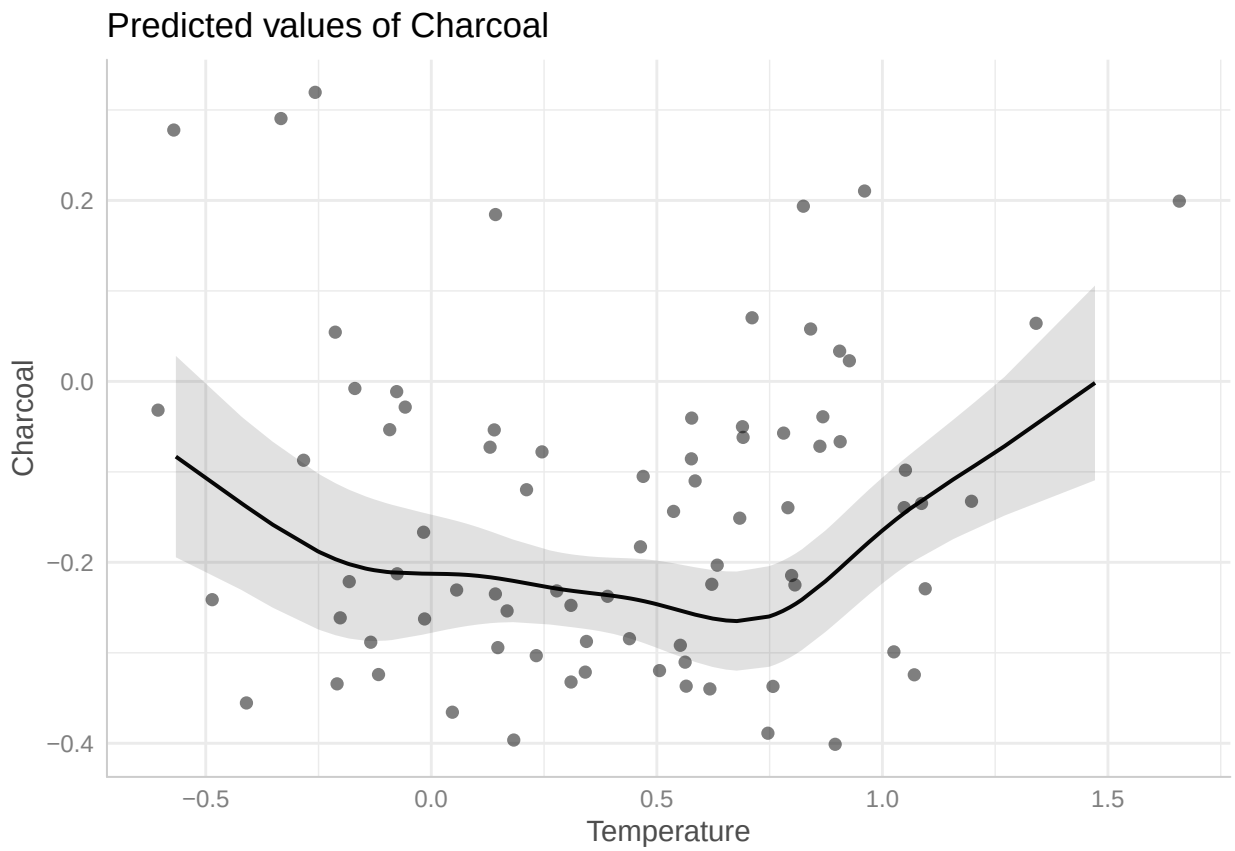



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 12 iterations.
## Gradient range [-2.939047e-05,0.0001116154]
## (score -81.80595 & scale 0.004819602).
## Hessian positive definite, eigenvalue range [1.936251e-06,39.72786].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                              k'   edf k-index p-value
## s(Pasturenaturalgrassla) 9.000 4.567    1.14    0.87
## s(Temperature)           9.000 4.456    1.05    0.61
## s(P.PET)                 9.000 0.842    1.09    0.76
## $mfrow
```

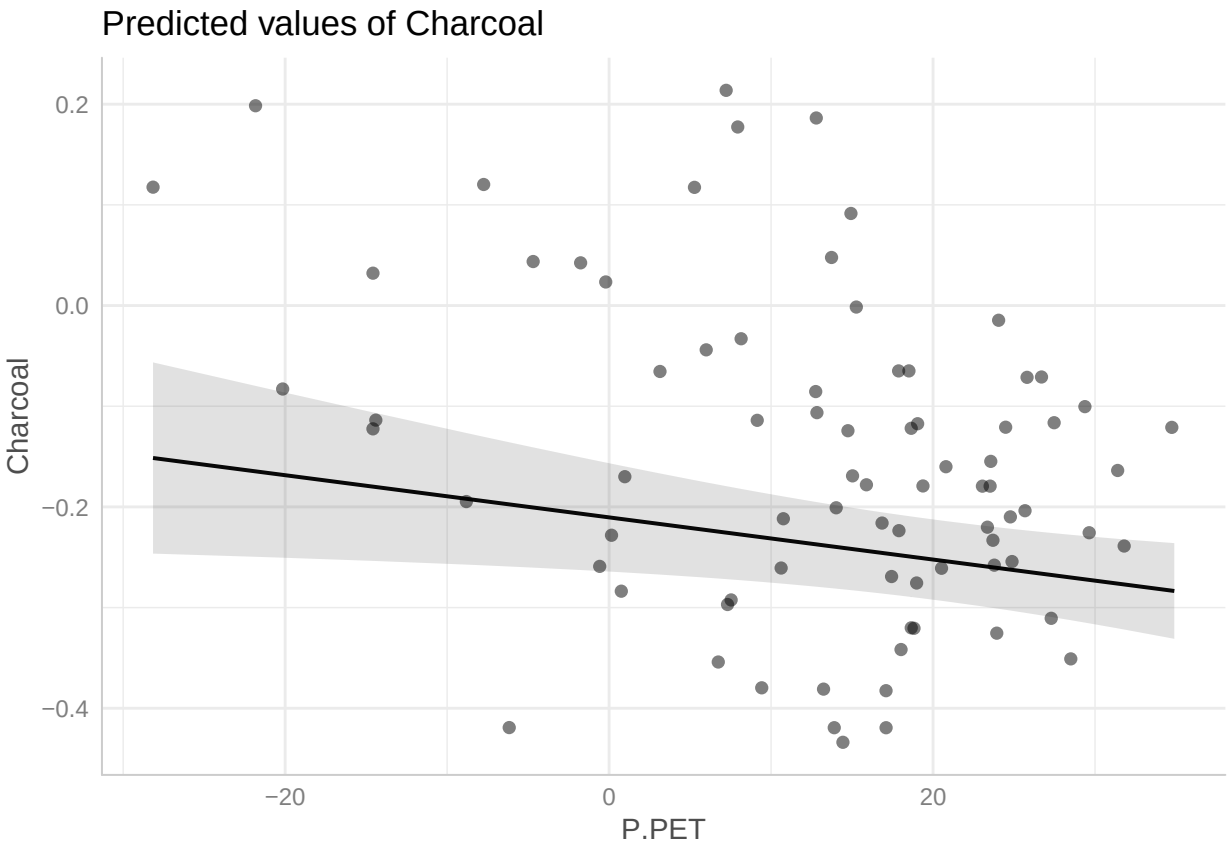
```
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.149423   0.007762  -19.25   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                               edf Ref.df     F  p-value
## s(Pasturenaturalgrassla) 4.5668      9 6.567 1.34e-10 ***
## s(Temperature)           4.4562      9 2.981 3.00e-05 ***
## s(P.PET)                 0.8424      9 0.593   0.0132 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.708   Deviance explained = 74.5%
## -REML = -81.806  Scale est. = 0.0048196  n = 80
## [1] "Plotting predictions"
## $Pasturenaturalgrassla
```

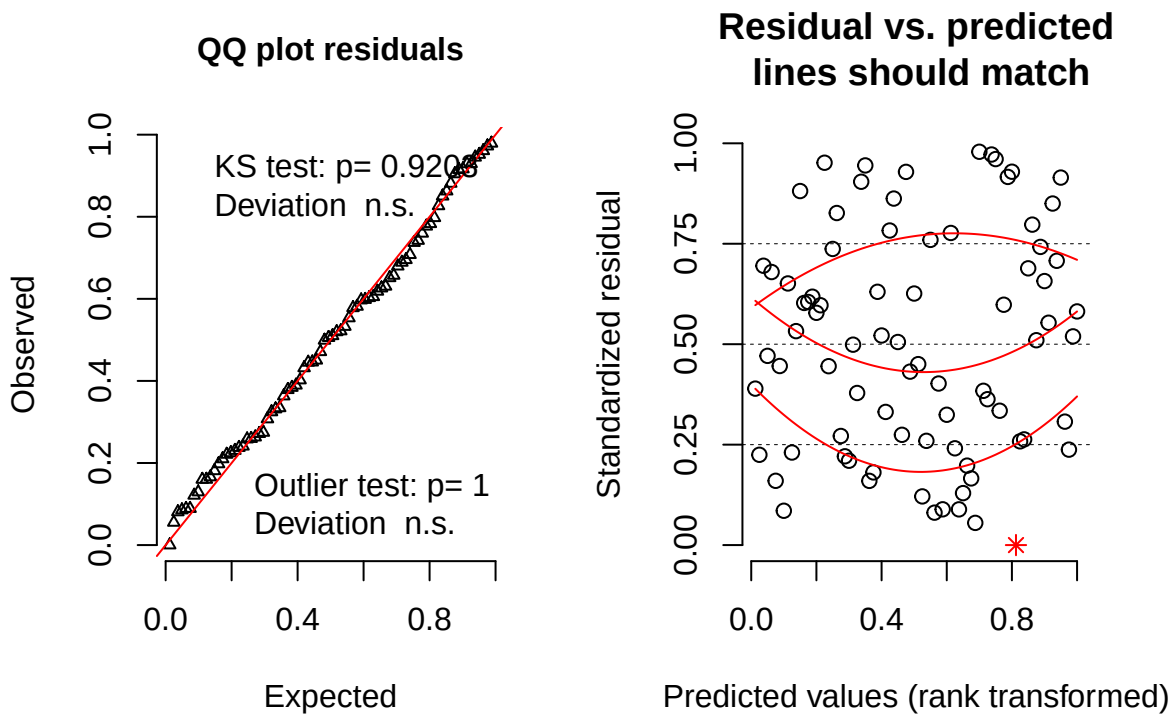



```
##
## $Temperature
```

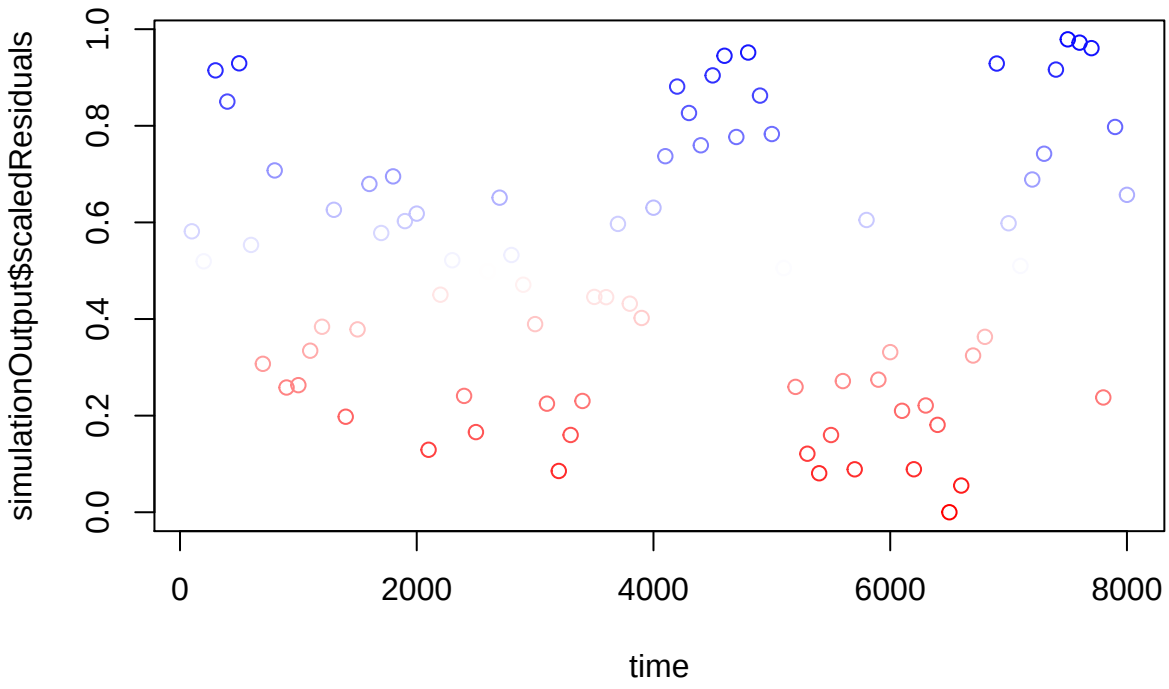

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−0.5
0.0
0.5
1.0
1.5
Temperature

```
##
## $P.PET
```

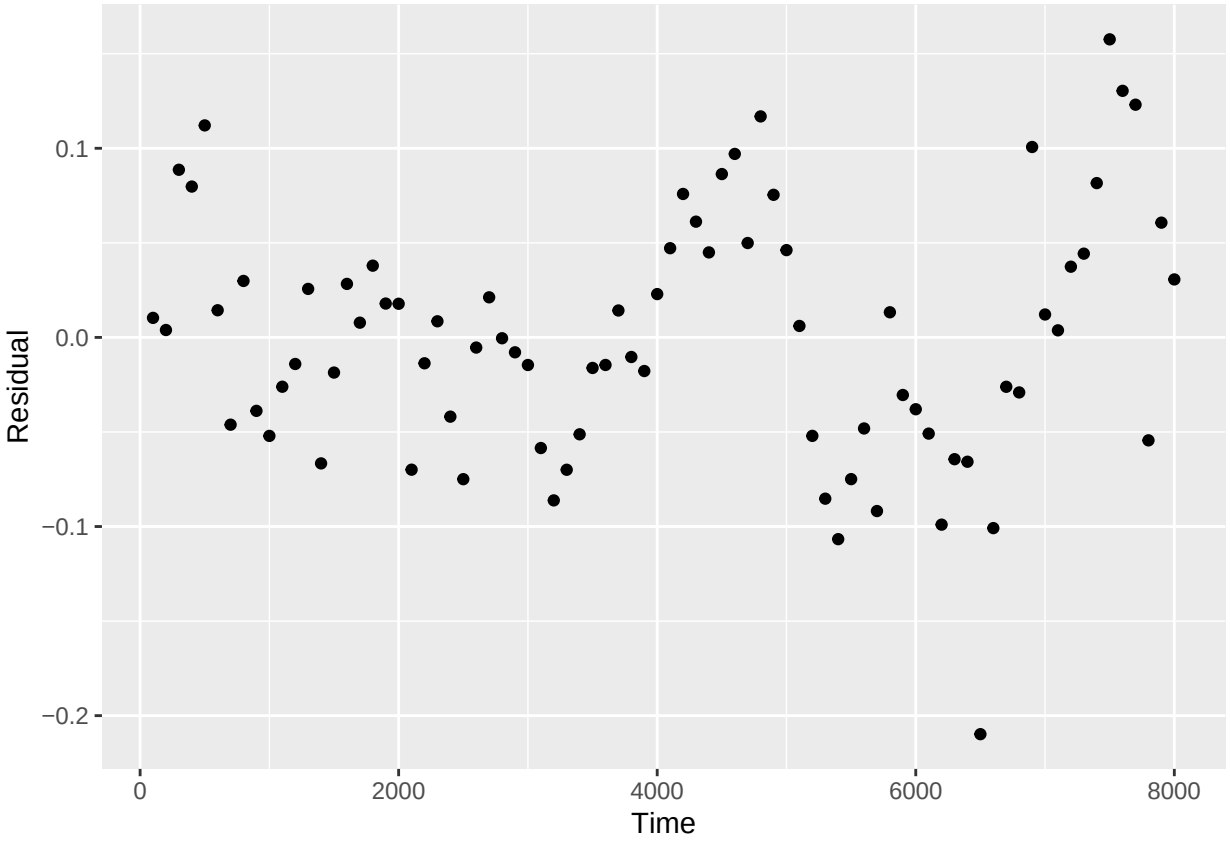

Predicted values of Charcoal
Charcoal
0.2
0.0
−0.2
−0.4
−20
0
20
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



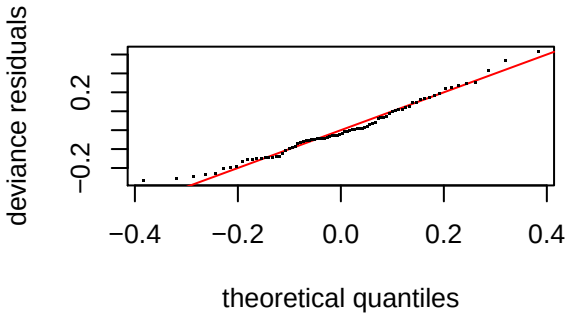

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.69061, p-value = 1.874e-11
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

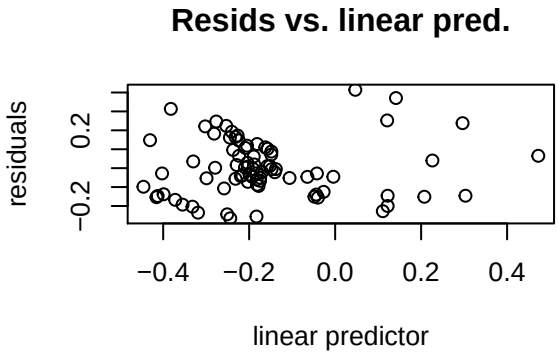


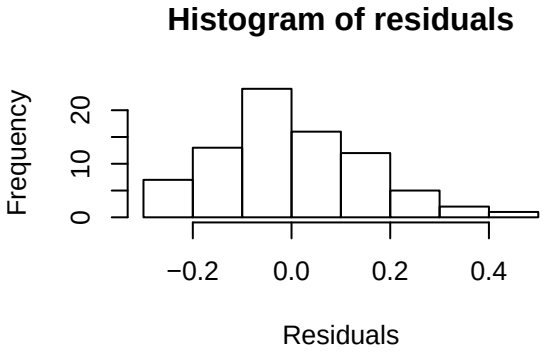
Grassland/pasture cover, Atlantic ecoregion

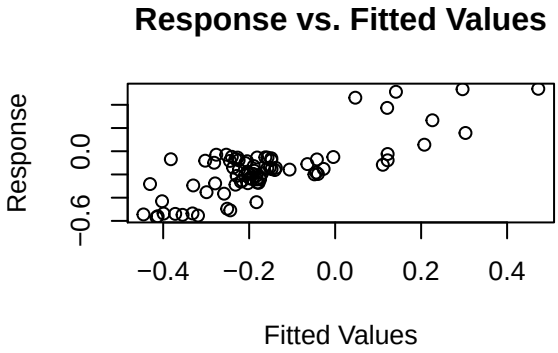
```
pasture.atlantic <- charcoal.gam(Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature)  + s(P.PET), data
```

```
## [1] "Checking GAM"
```



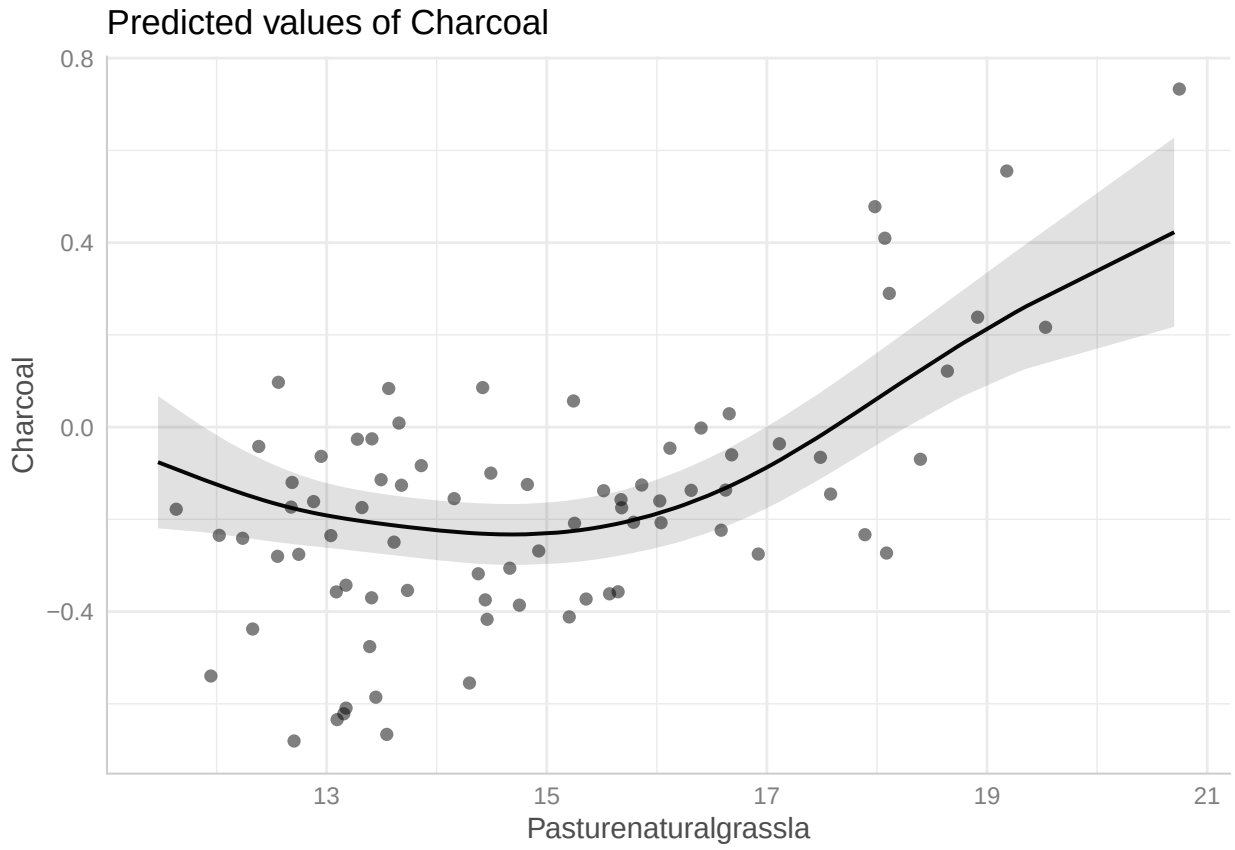




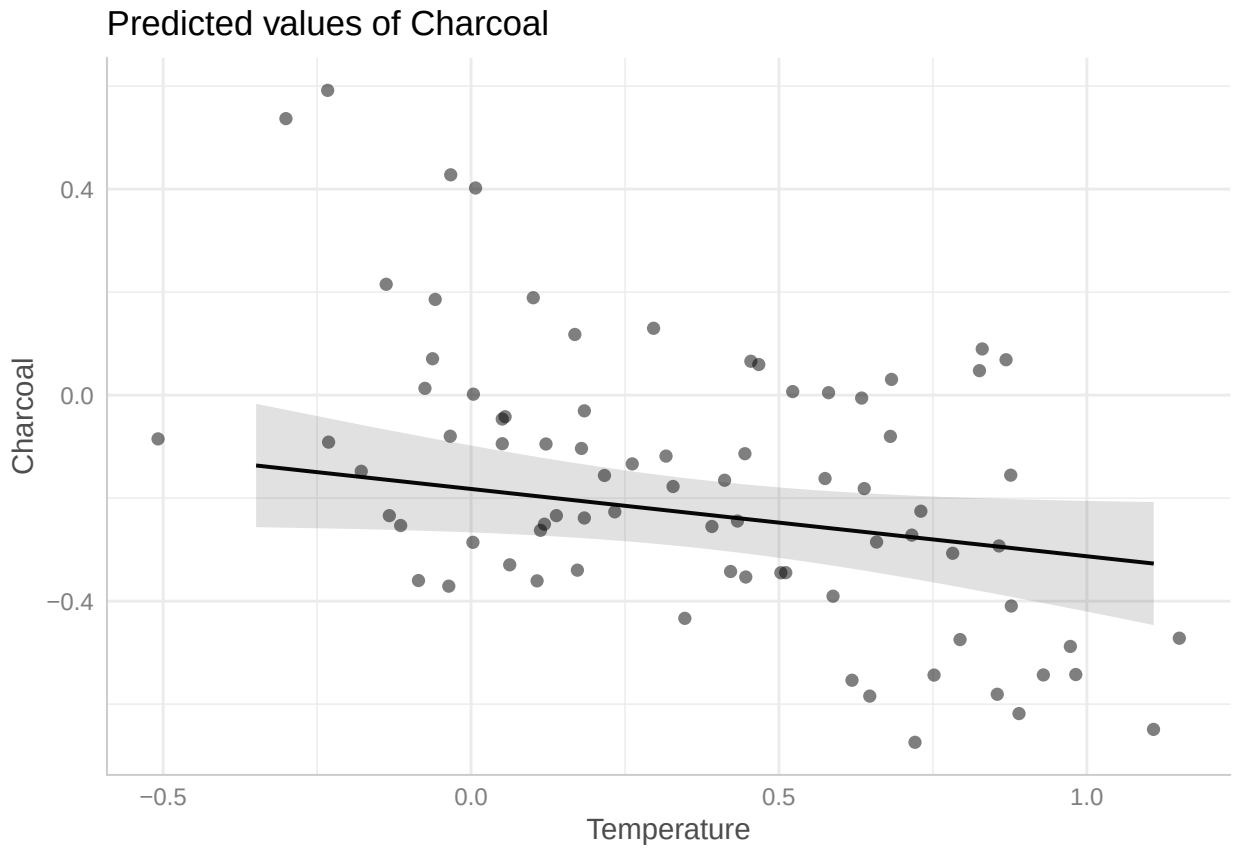



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 14 iterations.
## Gradient range [-4.784537e-05,9.766528e-05]
## (score -26.69937 & scale 0.0235591).
## Hessian positive definite, eigenvalue range [7.398593e-06,39.5824].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                              k'   edf k-index p-value
## s(Pasturenaturalgrassla) 9.000 3.071    1.31    1.00
## s(Temperature)           9.000 0.779    1.10    0.76
## s(P.PET)                 9.000 1.931    1.01    0.47
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

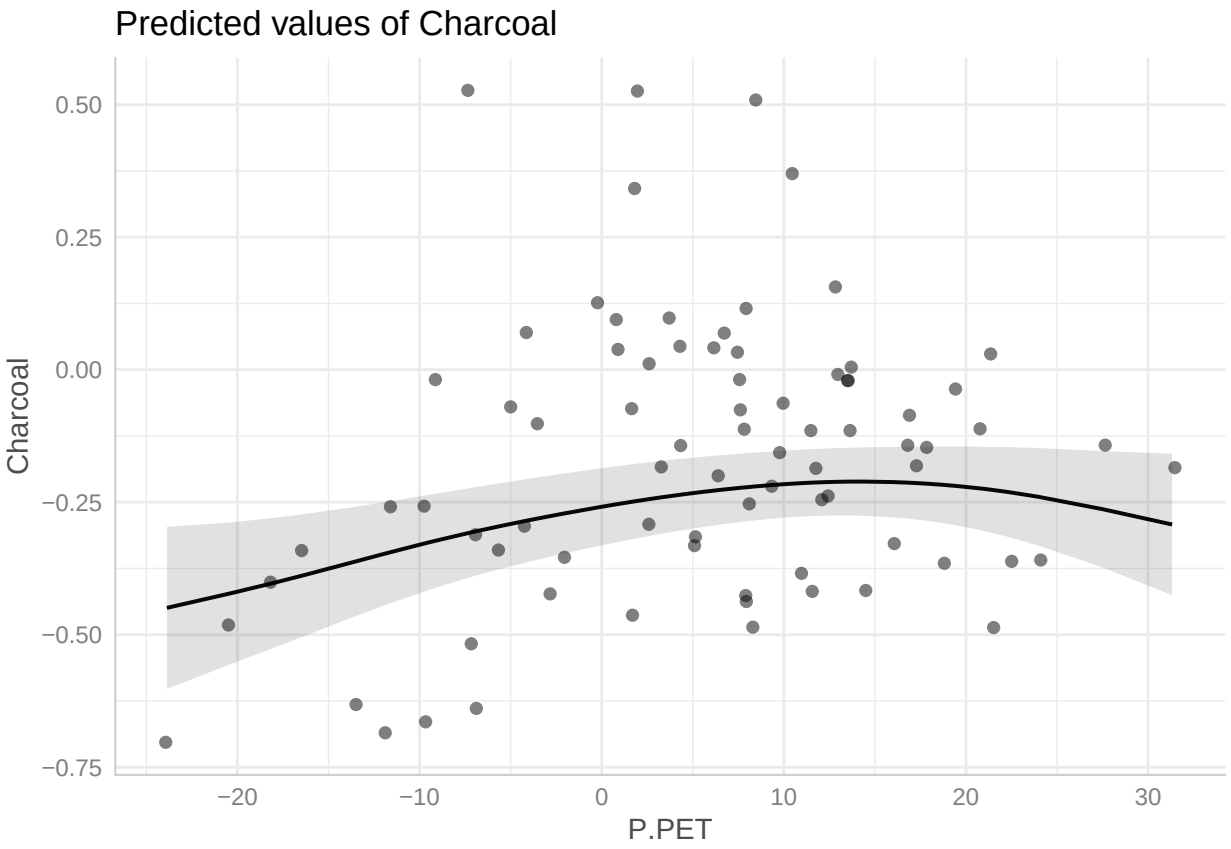
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.01716  -9.417    3e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                              edf Ref.df     F  p-value
## s(Pasturenaturalgrassla) 3.0708      9 4.864 2.89e-09 ***
## s(Temperature)           0.7788      9 0.391  0.03113 *
## s(P.PET)                 1.9307      9 1.050  0.00455 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.583   Deviance explained = 61.4%
## -REML = -26.699  Scale est. = 0.023559  n = 80
## [1] "Plotting predictions"
## $Pasturenaturalgrassla
```

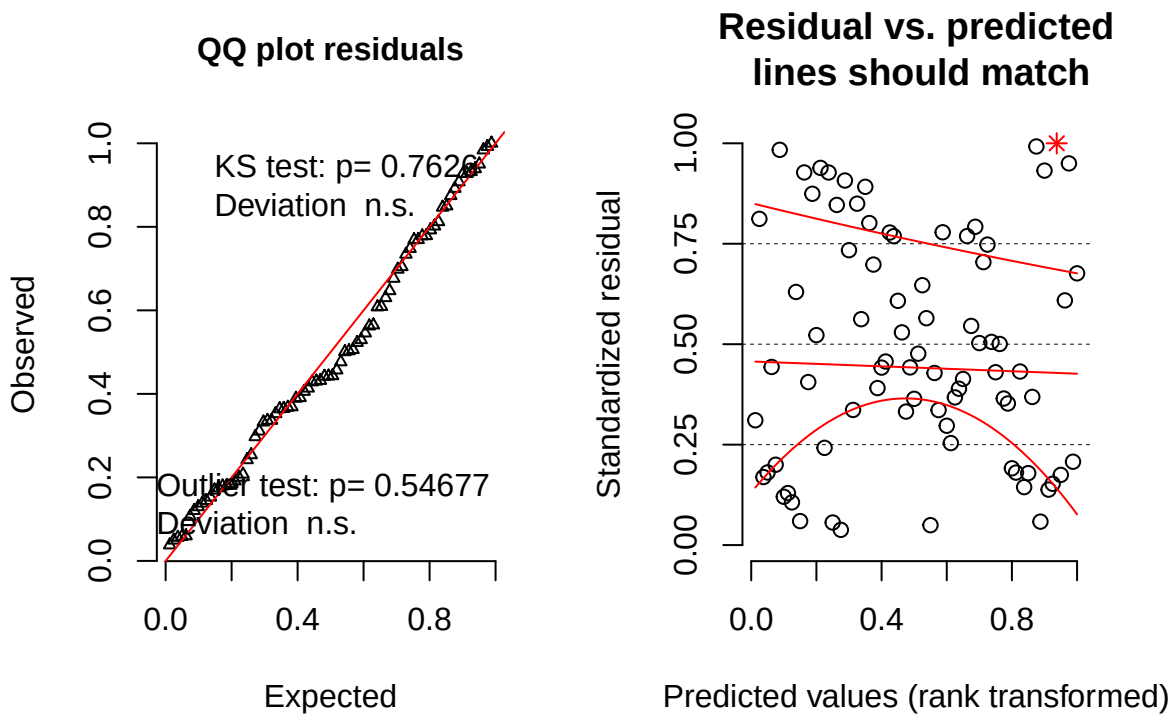



```
##
## $Temperature
```

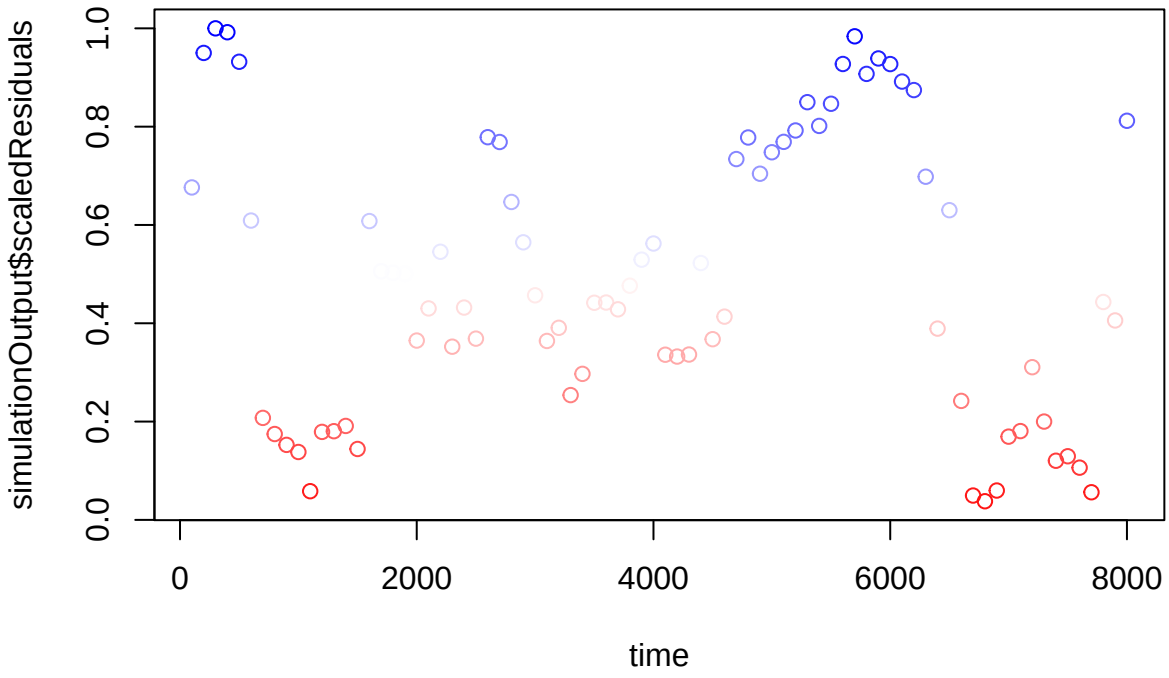

Predicted values of Charcoal
Charcoal
0.4
0.0
−0.4
−0.5
0.0
0.5
1.0
Temperature

```
##
## $P.PET
```

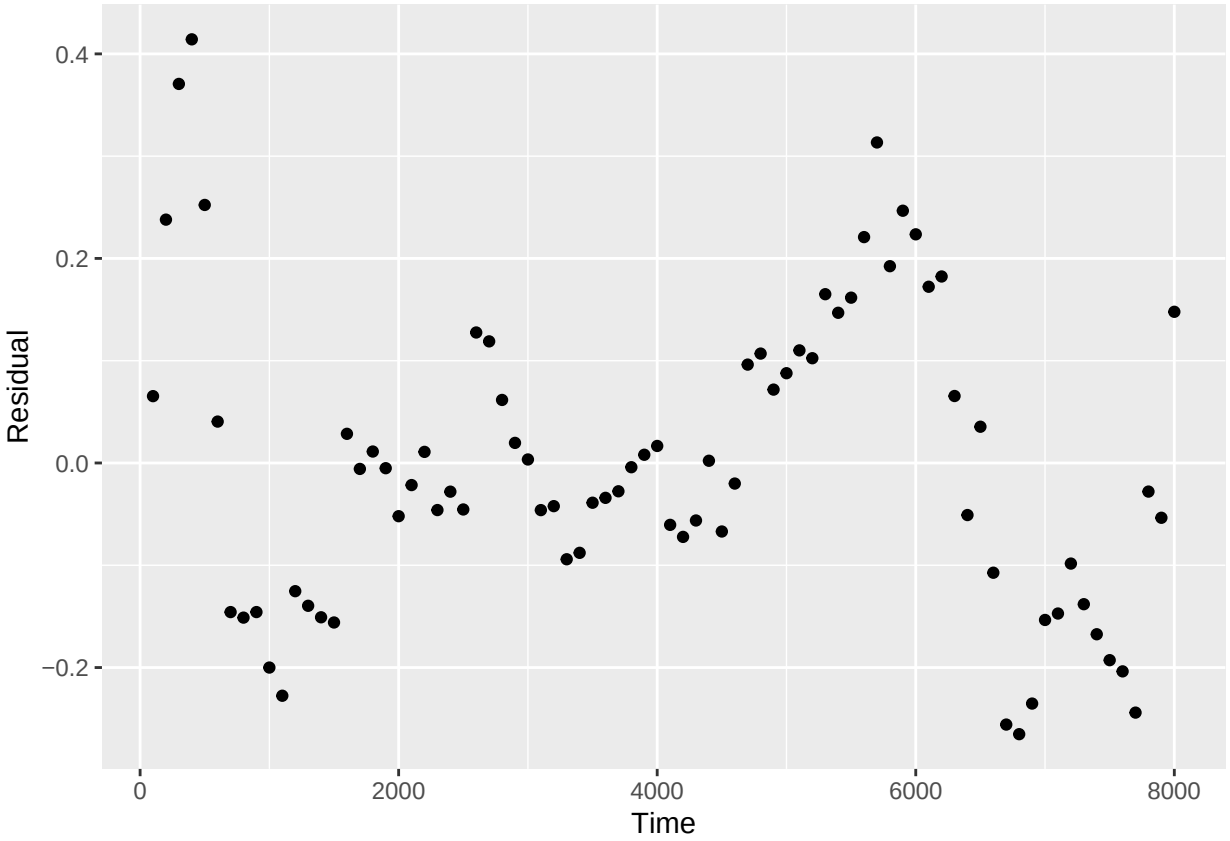

Predicted values of Charcoal
Charcoal
0.50
0.25
0.00
−0.25
−0.50
−0.75
−20
−10
0
10
20
30
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```



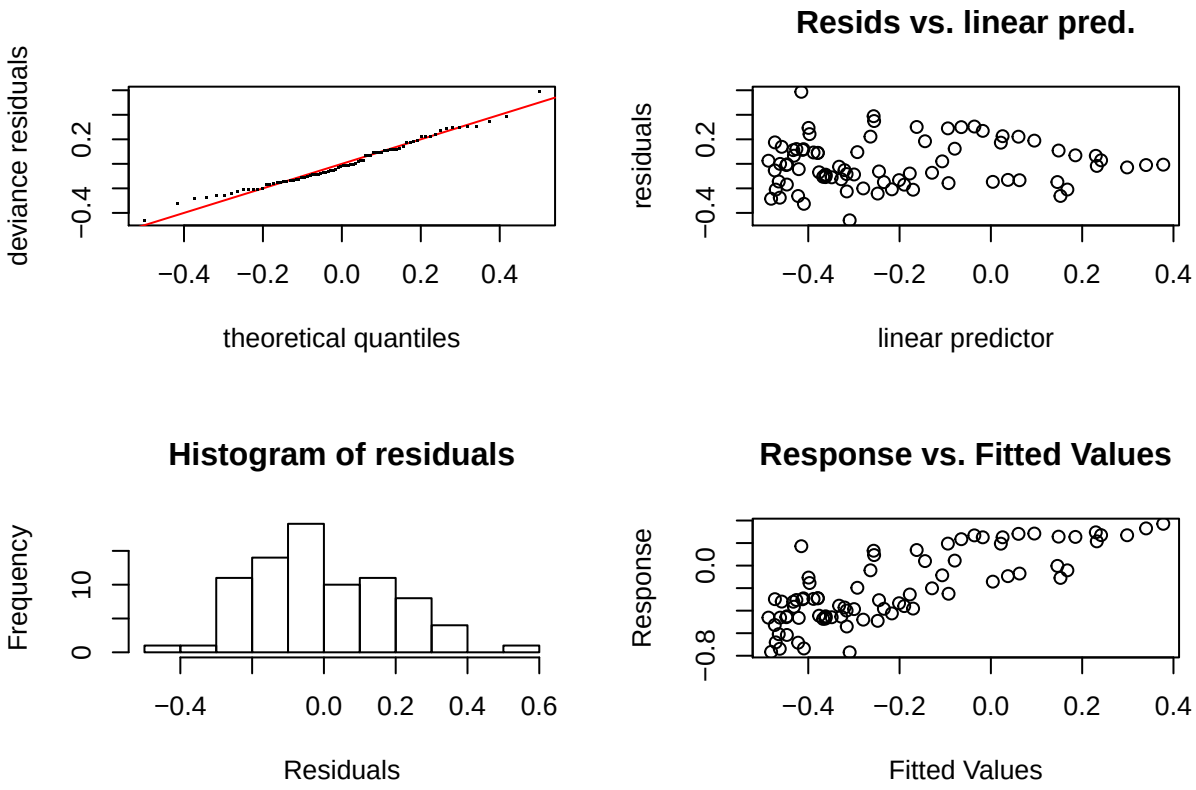

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.3062, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Grassland/pasture cover, Boreo-Nemoral ecoregion

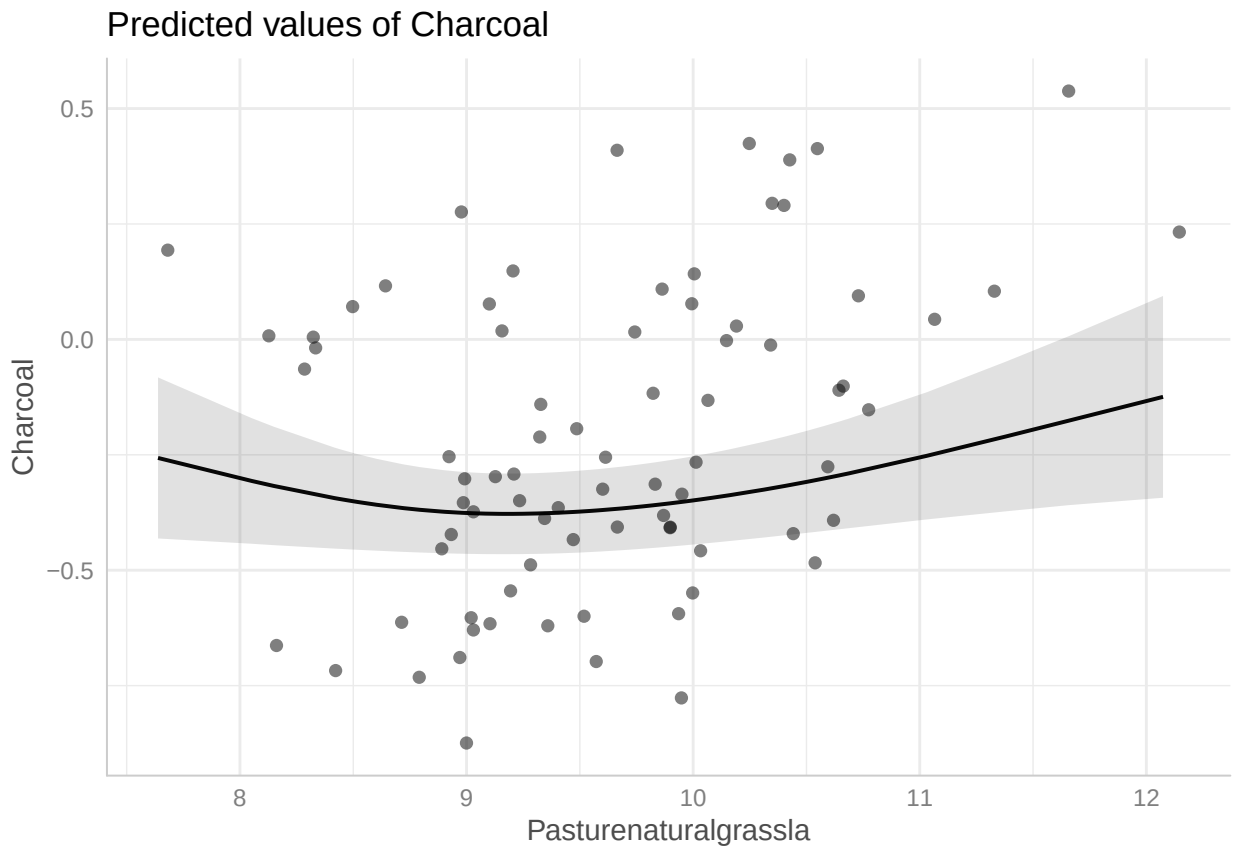
```
pasture.boreonemoral <- charcoal.gam(Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature)  + s(P.PET), c
```

```
## [1] "Checking GAM"
```

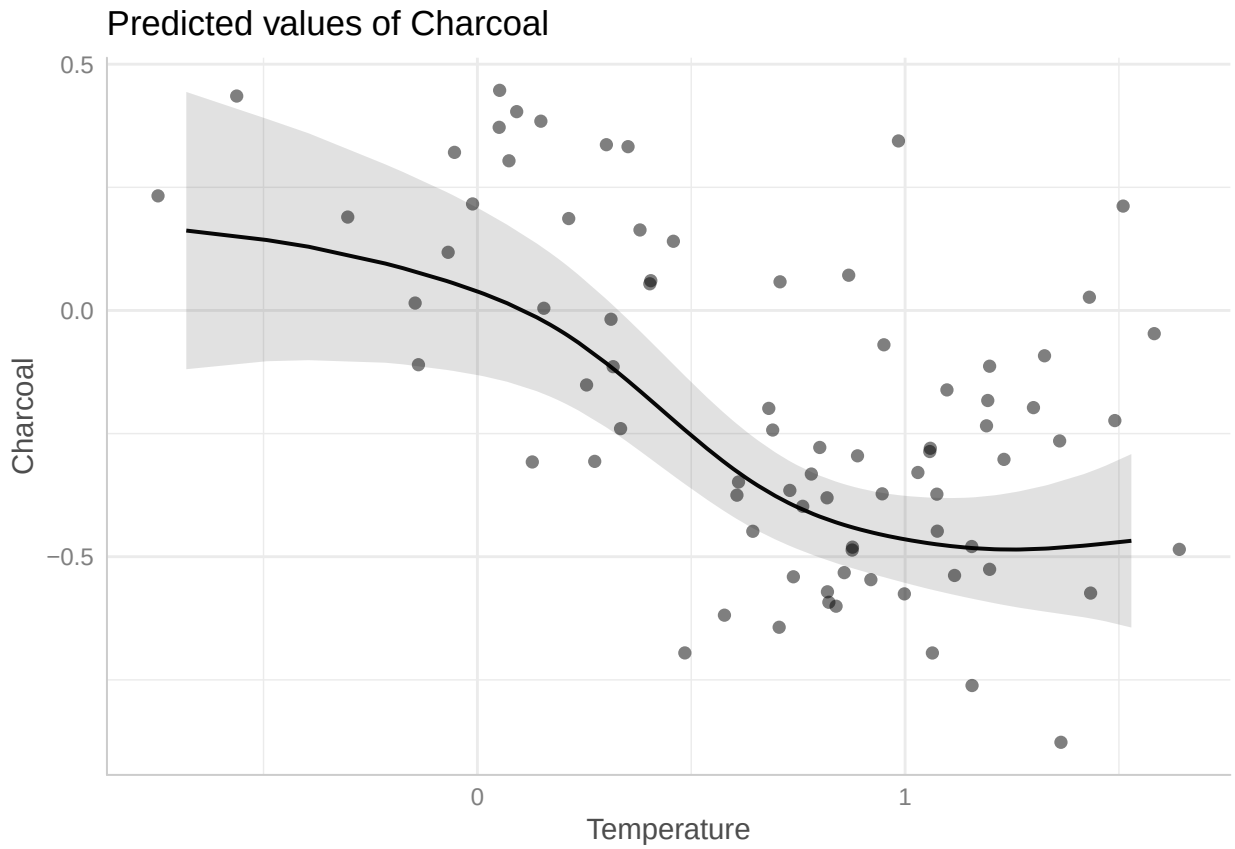



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 10 iterations.
## Gradient range [-1.181911e-06,1.838096e-06]
## (score -4.663647 & scale 0.04010133).
## Hessian positive definite, eigenvalue range [9.603398e-07,39.60802].
## Model rank =  28 / 28
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                            k'  edf k-index p-value
## s(Pasturenaturalgrassla) 9.00 1.77    1.09    0.77
## s(Temperature)           9.00 2.98    0.90    0.15
## s(P.PET)                 9.00 2.17    1.15    0.87
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ s(Pasturenaturalgrassla) + s(Temperature) + s(P.PET)
##
## Parametric coefficients:
```

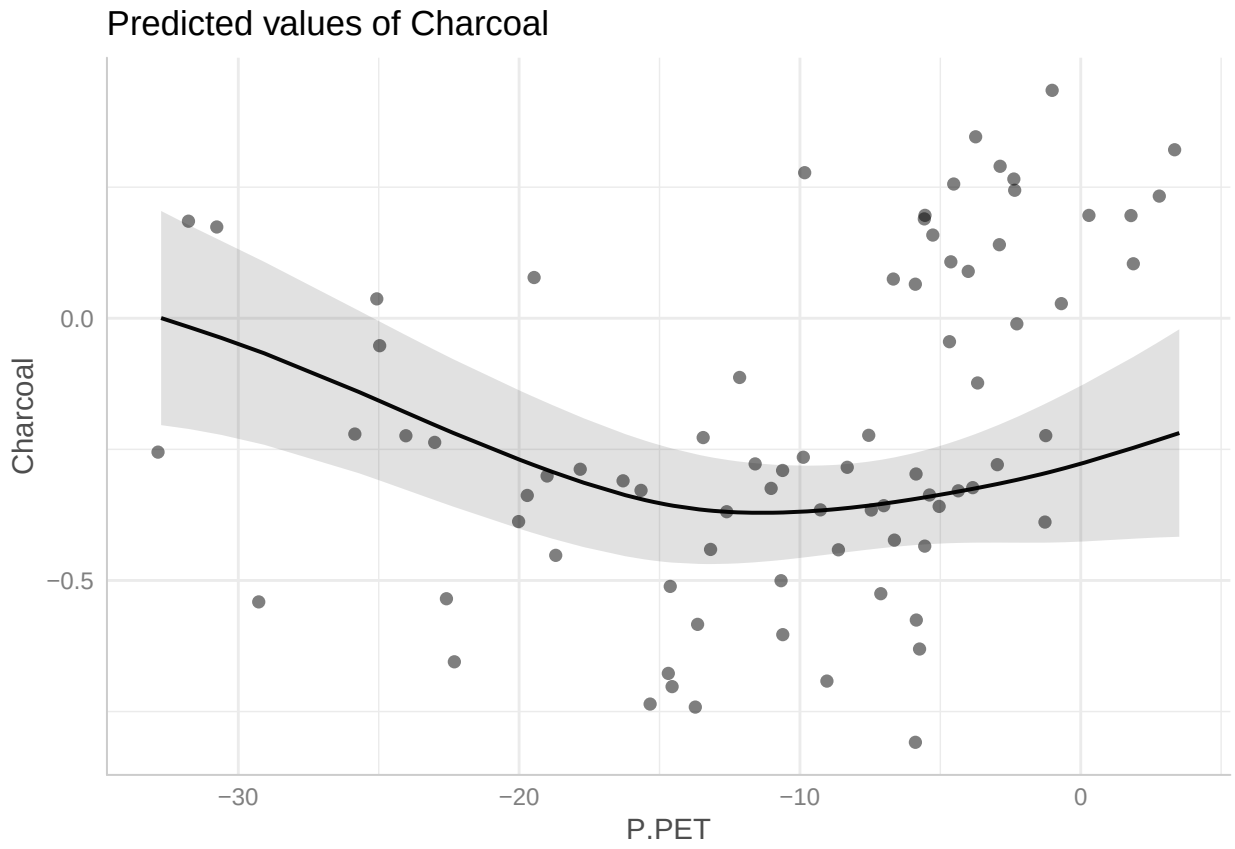
```
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.02239  -9.396  3.8e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                             edf Ref.df     F  p-value
## s(Pasturenaturalgrassla) 1.769      9 0.580 0.042367 *
## s(Temperature)           2.983      9 3.632 2.32e-07 ***
## s(P.PET)                 2.171      9 1.573 0.000592 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.595   Deviance explained = 63.1%
## -REML = -4.6636  Scale est. = 0.040101  n = 80
## [1] "Plotting predictions"
## $Pasturenaturalgrassla
```

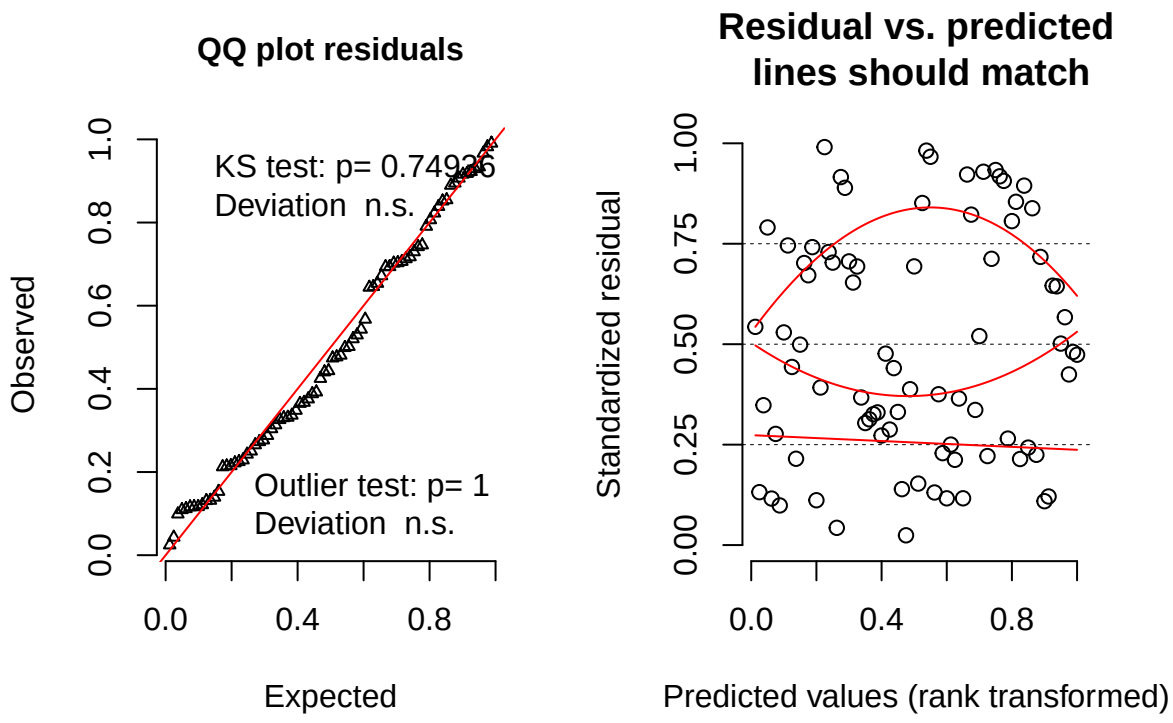



```
##
## $Temperature
```

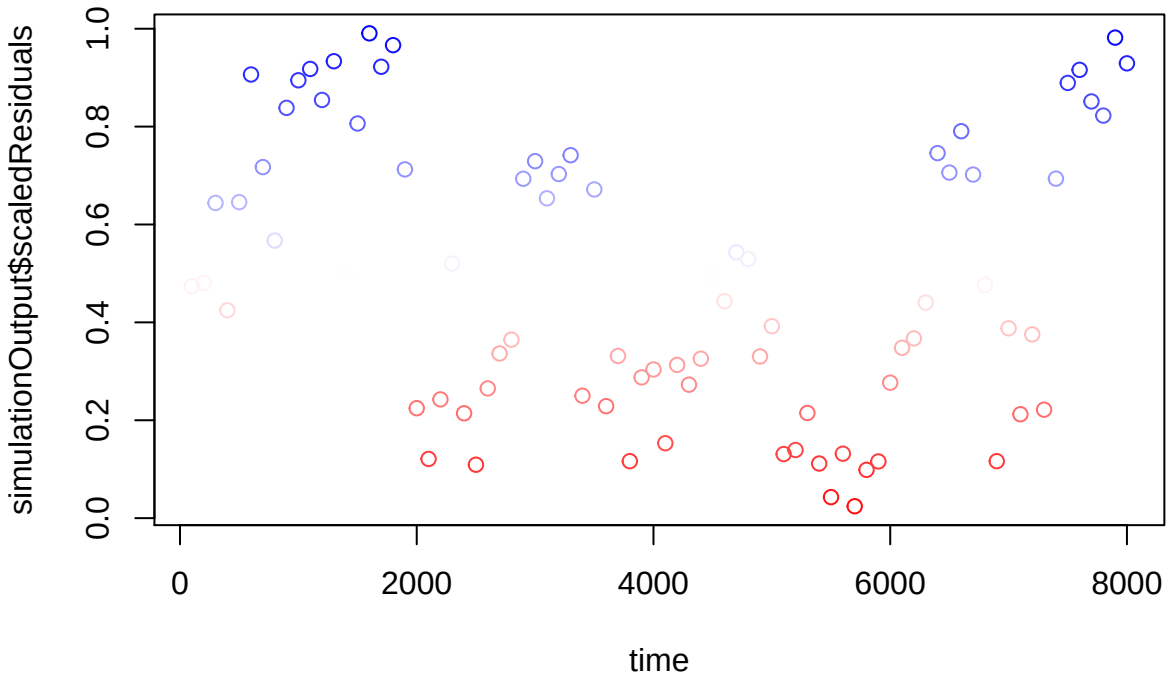

Predicted values of Charcoal
0.5
0.0
−0.5
Charcoal
0
1
Temperature

```
##
## $P.PET
```

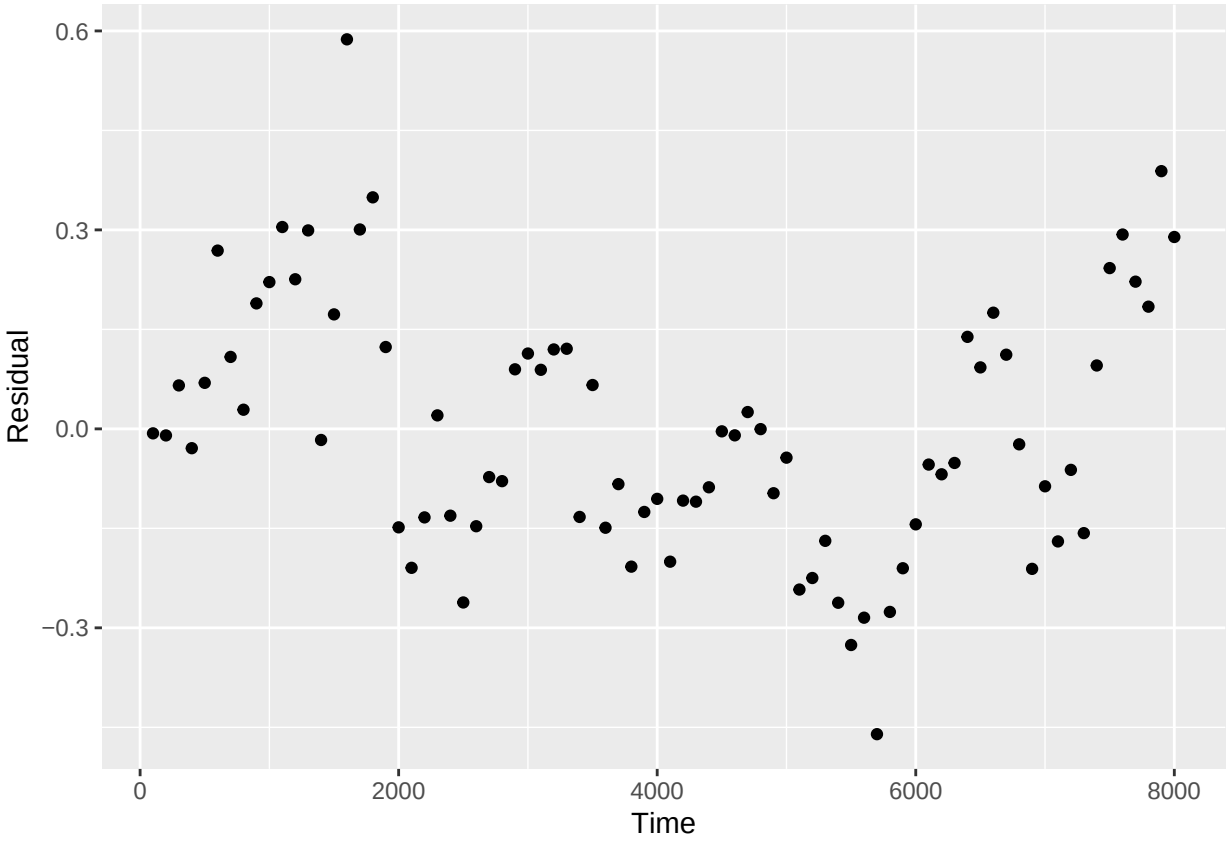

Predicted values of Charcoal
Charcoal
0.0
−0.5
−30
−20
−10
0
P.PET




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

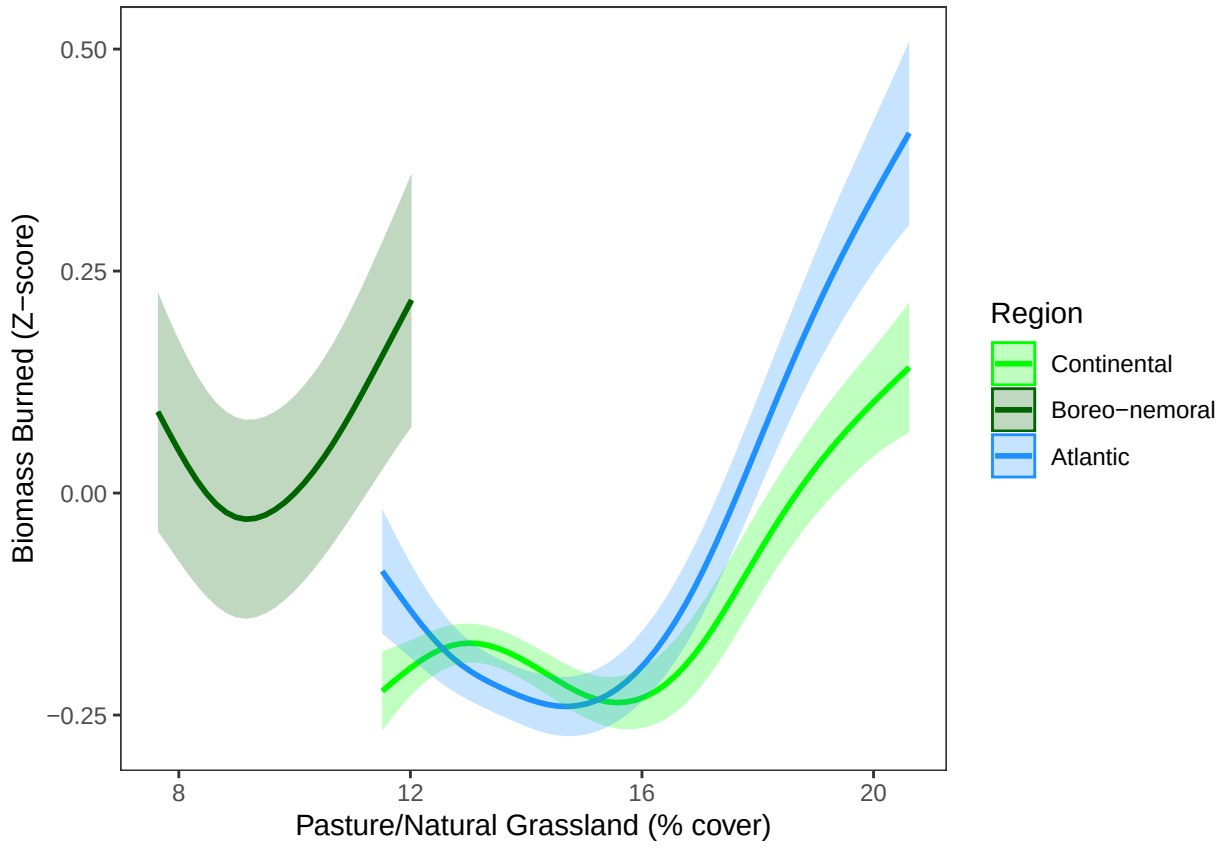



```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.47797, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

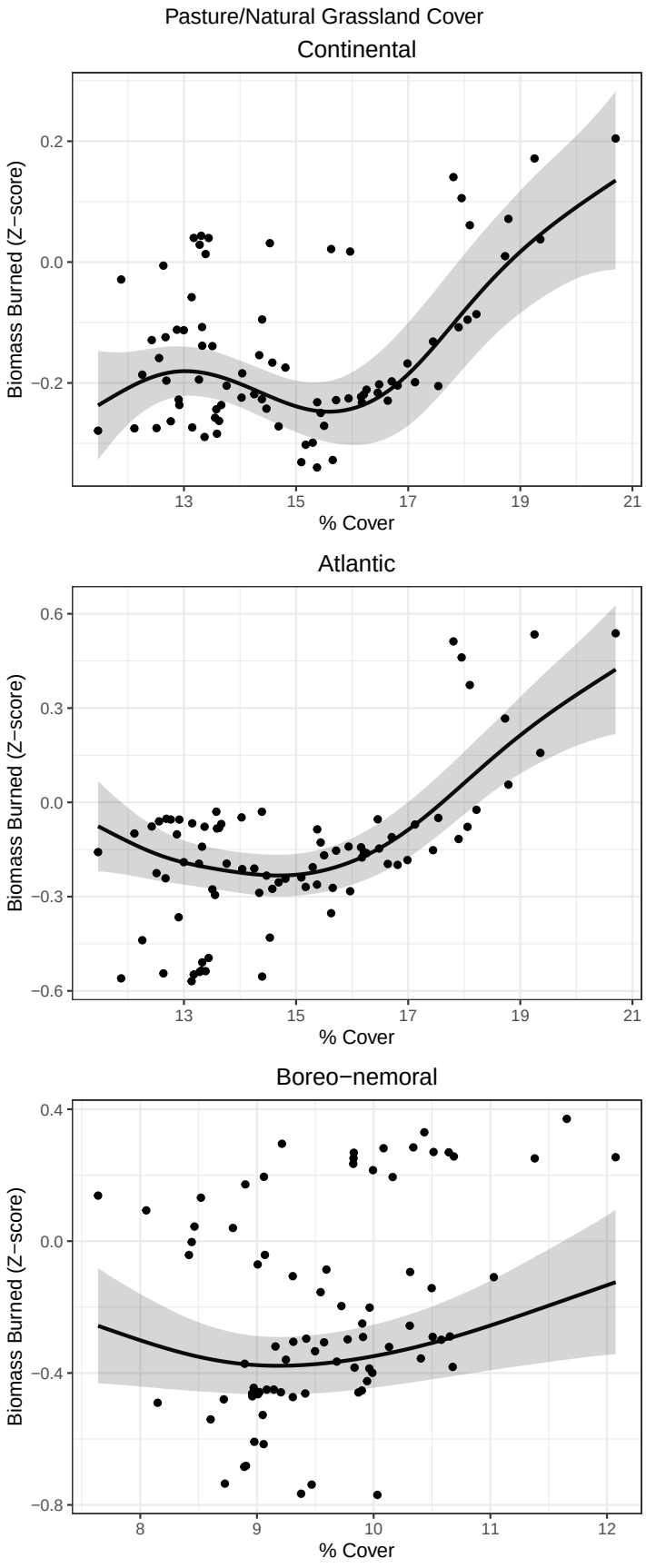


Grassland/pasture cover plot

Here we show the marginal response of biomass burned to grassland/pasture cover in each region, holding the climate variables (temperature and P-PET) constant at their average value over each region.

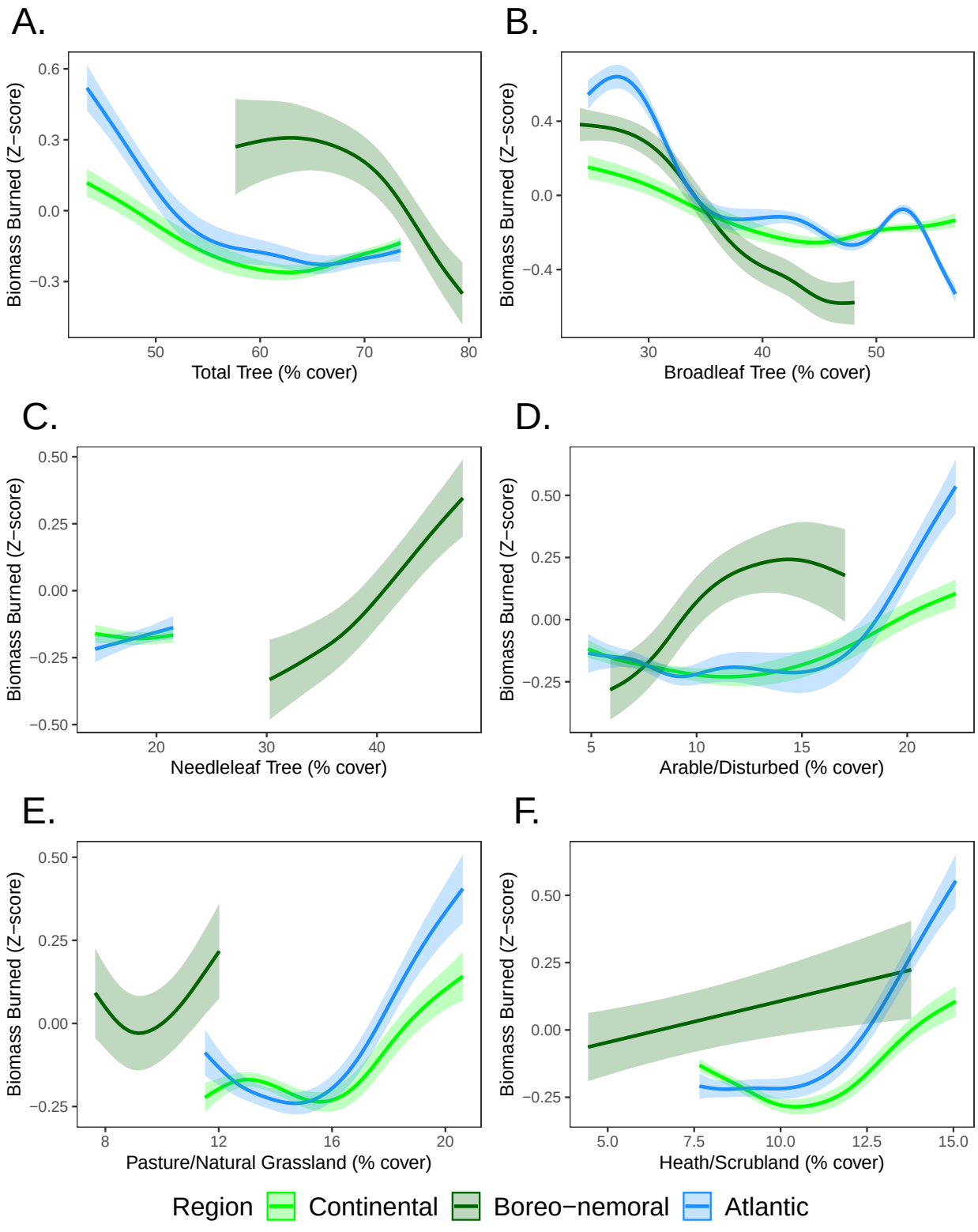

0.50
0.25
0.00
−0.25
Biomass Burned (Z−score)
8
12
16
20
Pasture/Natural Grassland (% cover)
Region
Continental
Boreo−nemoral
Atlantic

```
## pdf
##   2
```


Pasture/Natural Grassland Cover
Continental
Biomass Burned (Z−score)
0.2
0.0
−0.2
13
15
17
19
21
% Cover
Atlantic
Biomass Burned (Z−score)
0.6
0.3
0.0
−0.3
−0.6
13
15
17
19
21
% Cover
Boreo−nemoral
Biomass Burned (Z−score)
0.4
0.0
−0.4
−0.8
8
9
10
11
12
% Cover

Plot the six landcover GAMs together (main manuscript figure)

```
## pdf
##   2
```



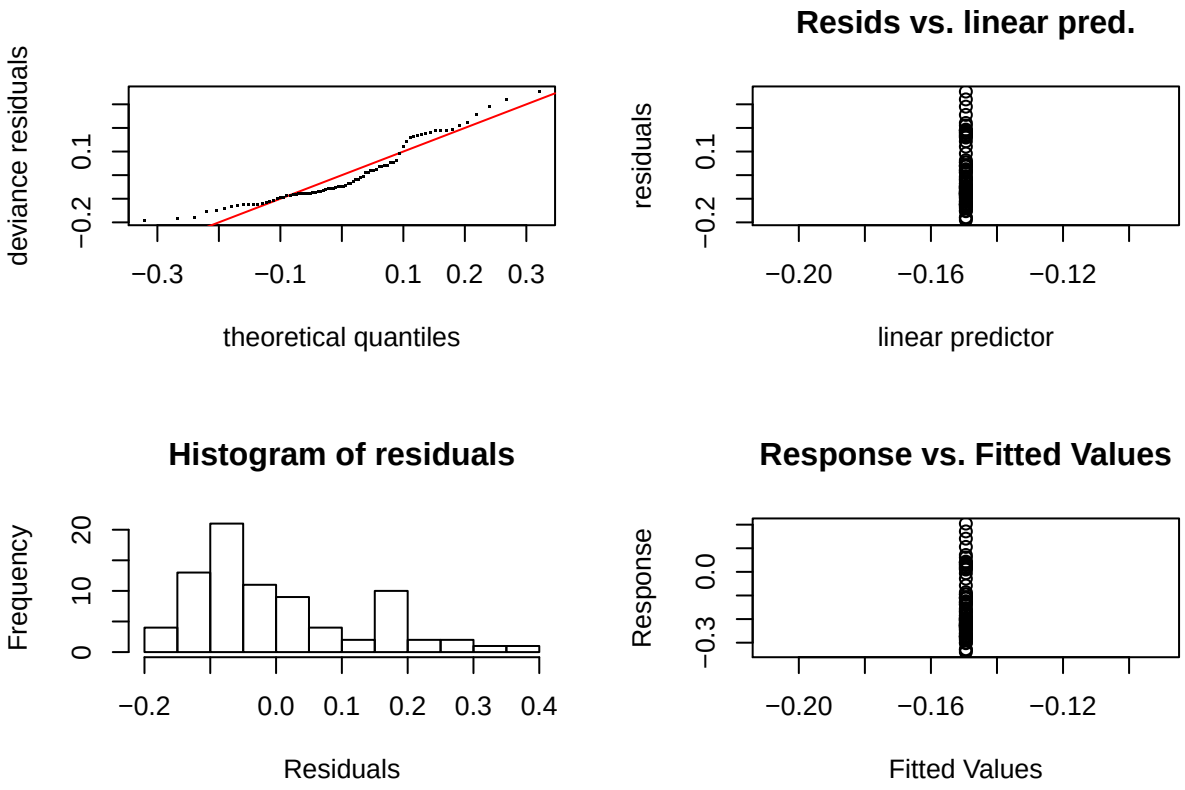
```
## pdf
##   2
```

Model selection by region

First, we built some intercept-only GAMs to use in the AIC tables. These models basically represent a model with no explanatory variable, and are used as a baseline to indicate what we should expect about charcoal burned if our predictors were fundamentally uninformative.

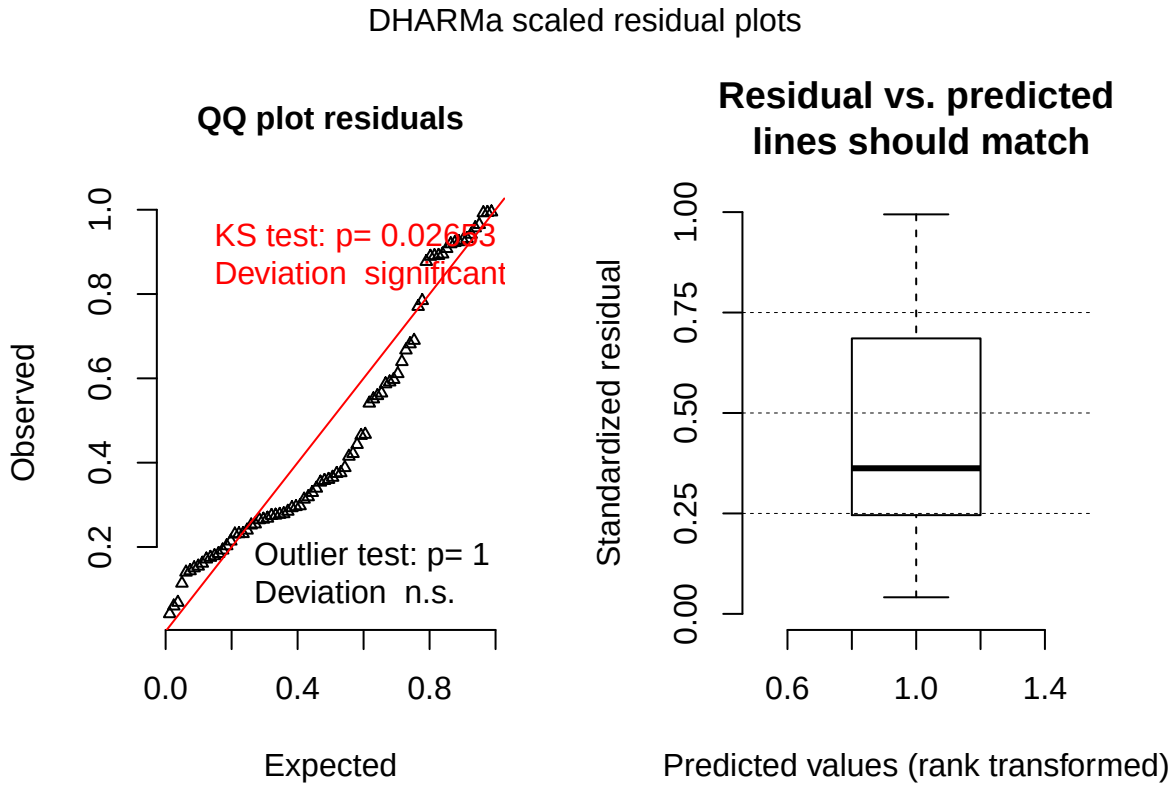
```
intercept.continental <- charcoal.gam(Charcoal ~ 1, data = AllEurope, region = "Continental")
```

```
## [1] "Checking GAM"
```

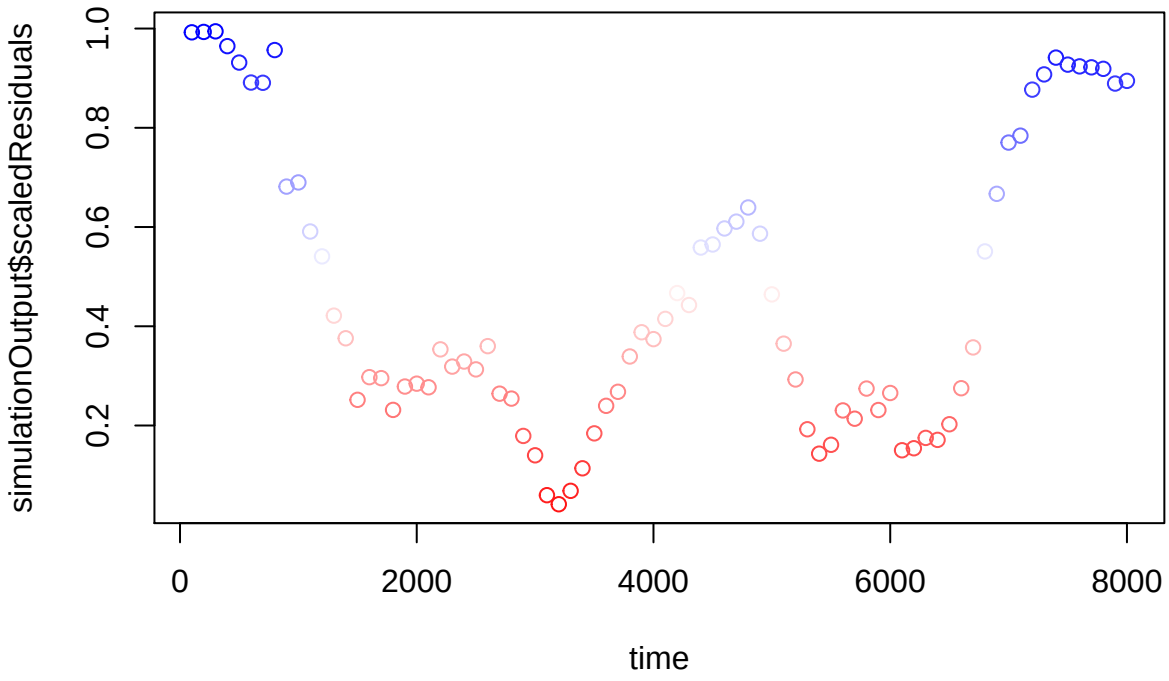



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 6 iterations.
## Gradient range [-2.17948e-07,-2.17948e-07]
## (score -47.79346 & scale 0.01651797).
## Hessian positive definite, eigenvalue range [39.5,39.5].
## Model rank =  1 / 1
##
## $mfrow
## [1] 2 2
```

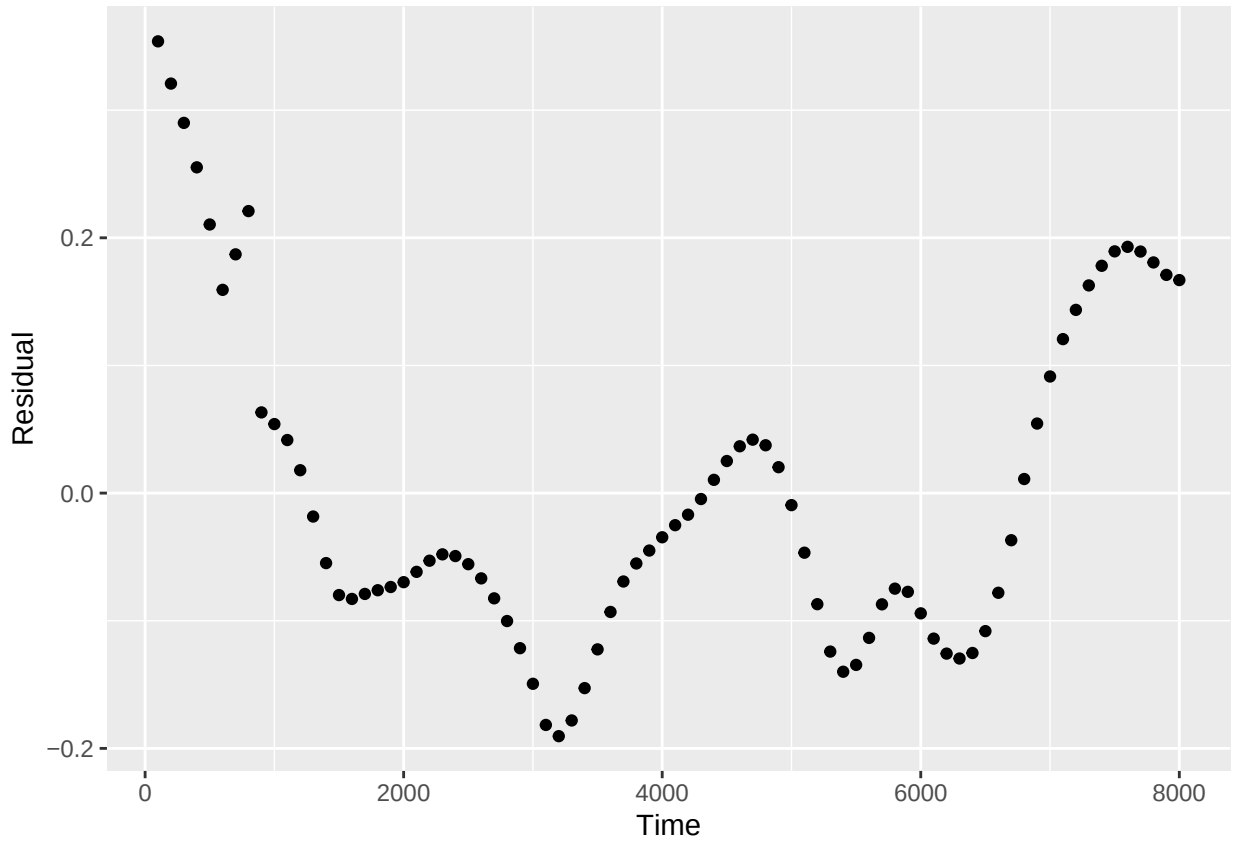
```
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ 1
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.14942    0.01437   -10.4   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =      0   Deviance explained =    0%
## -REML = -47.793  Scale est. = 0.016518  n = 80
## [1] "Plotting predictions"
## list()
```




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

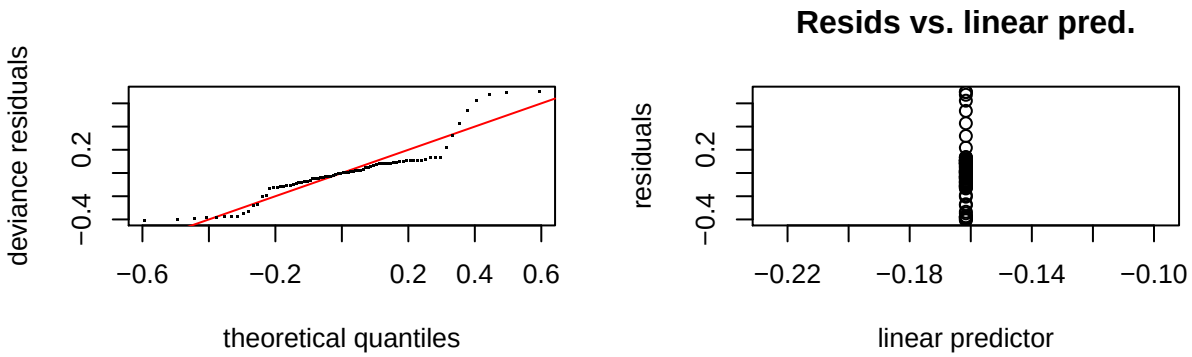


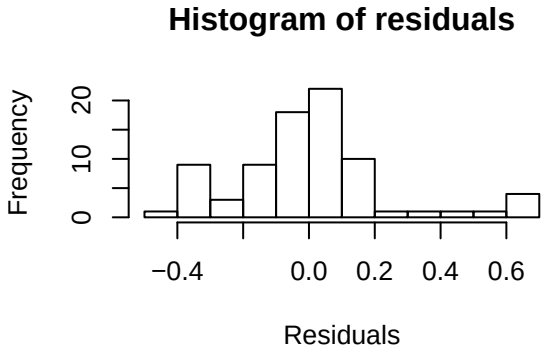

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.055027, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

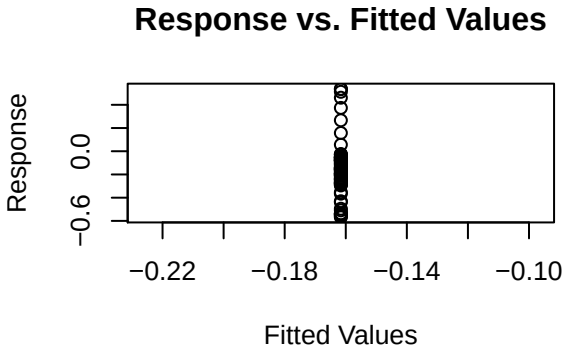



```
intercept.atlantic <- charcoal.gam(Charcoal ~ 1, data = AllEurope, region = "Atlantic")
```

```
## [1] "Checking GAM"
```

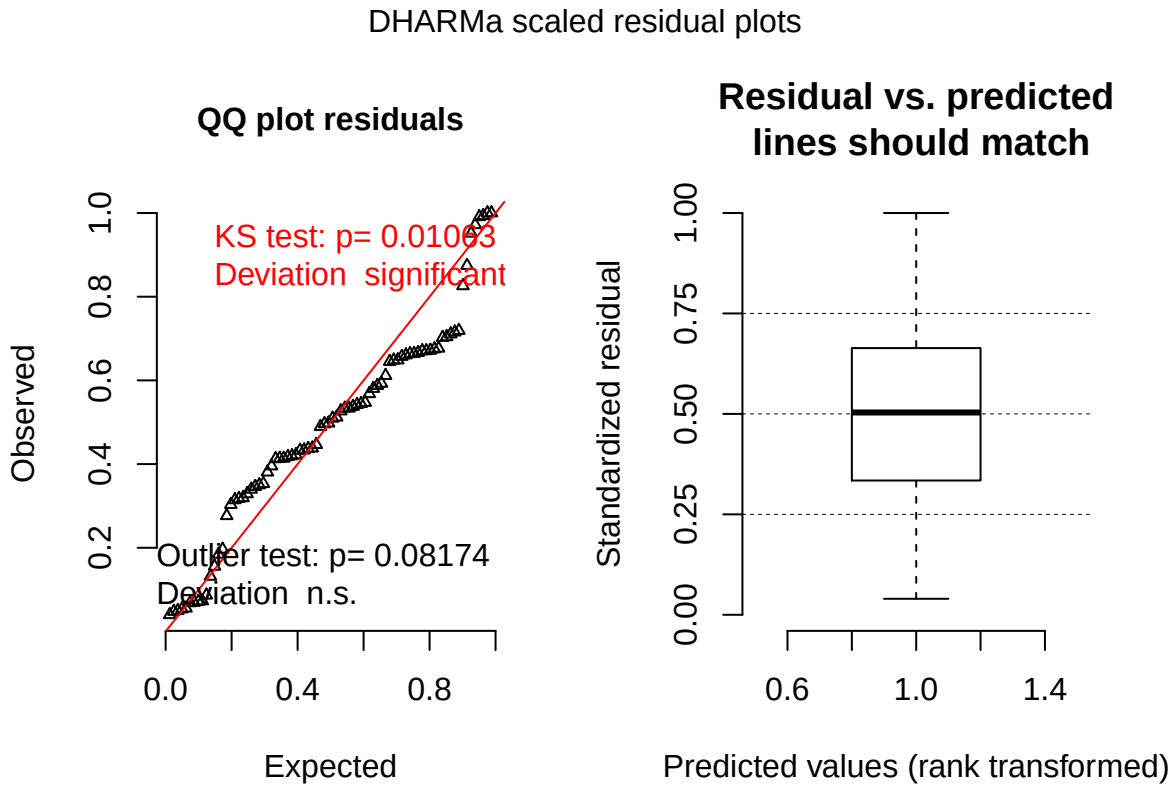




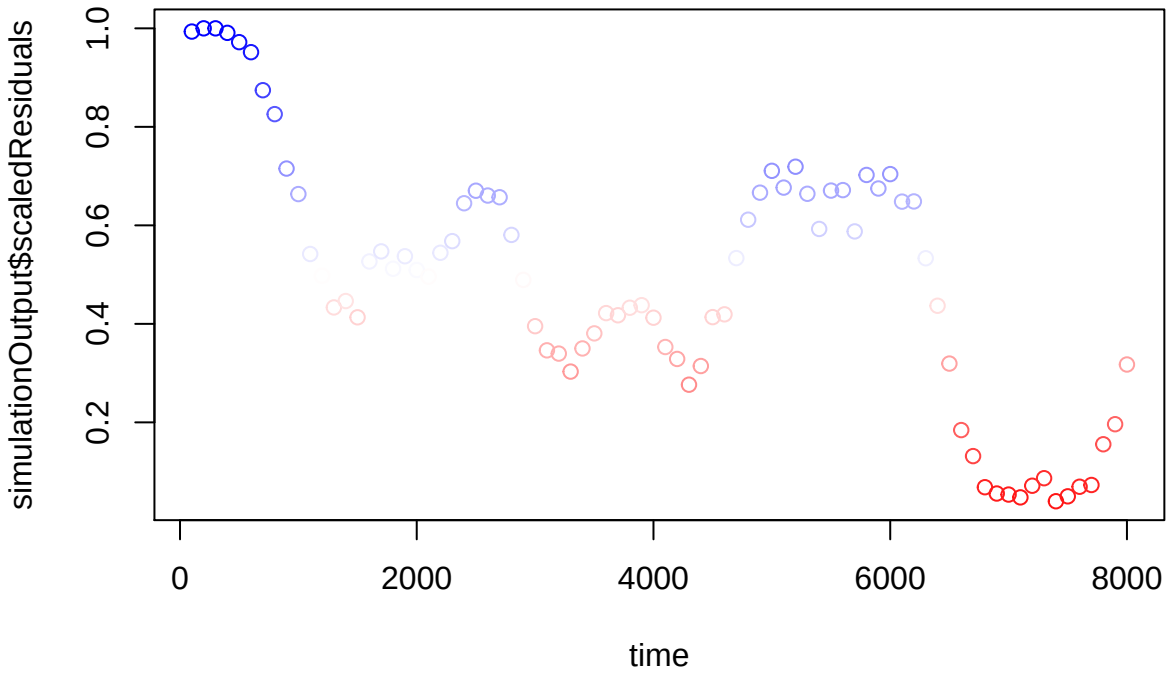



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 6 iterations.
## Gradient range [-2.17948e-07,-2.17948e-07]
## (score 0.8077092 & scale 0.05653488).
## Hessian positive definite, eigenvalue range [39.5,39.5].
## Model rank =  1 / 1
##
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ 1
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.16160    0.02658  -6.079 4.04e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =      0   Deviance explained =    0%
```

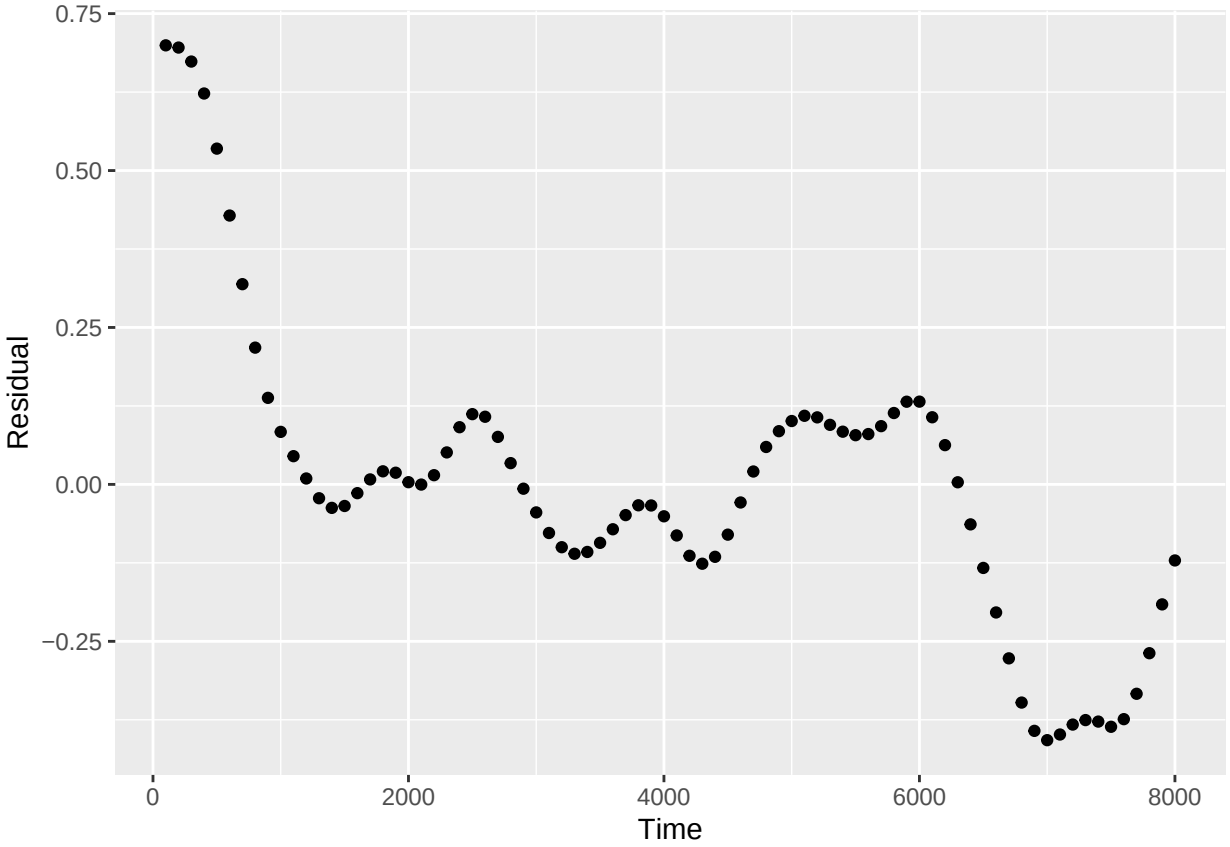
```
## -REML = 0.80771  Scale est. = 0.056535  n = 80
## [1] "Plotting predictions"
## list()
```




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```

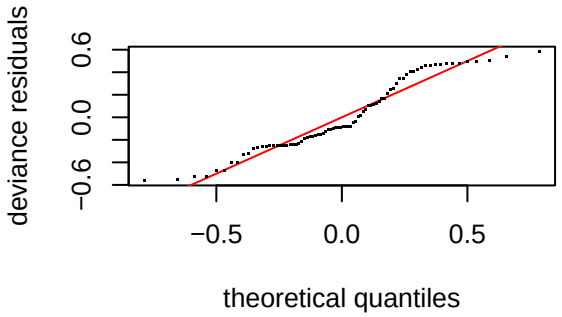


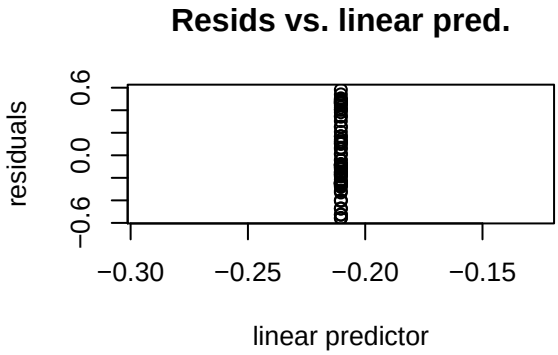

```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.055072, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```

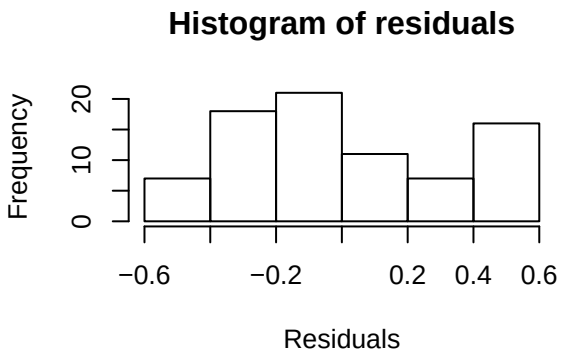


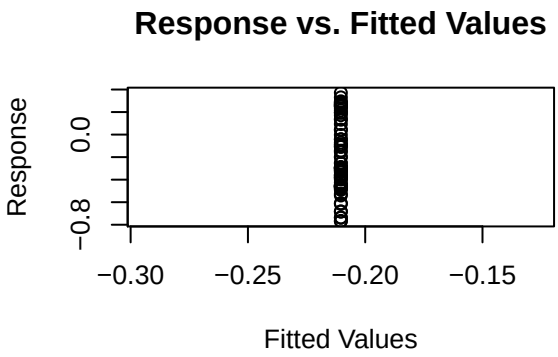

```
intercept.boreonemoral <- charcoal.gam(Charcoal ~1, data = AllEurope, region = "Boreo-nemoral")
```

```
## [1] "Checking GAM"
```



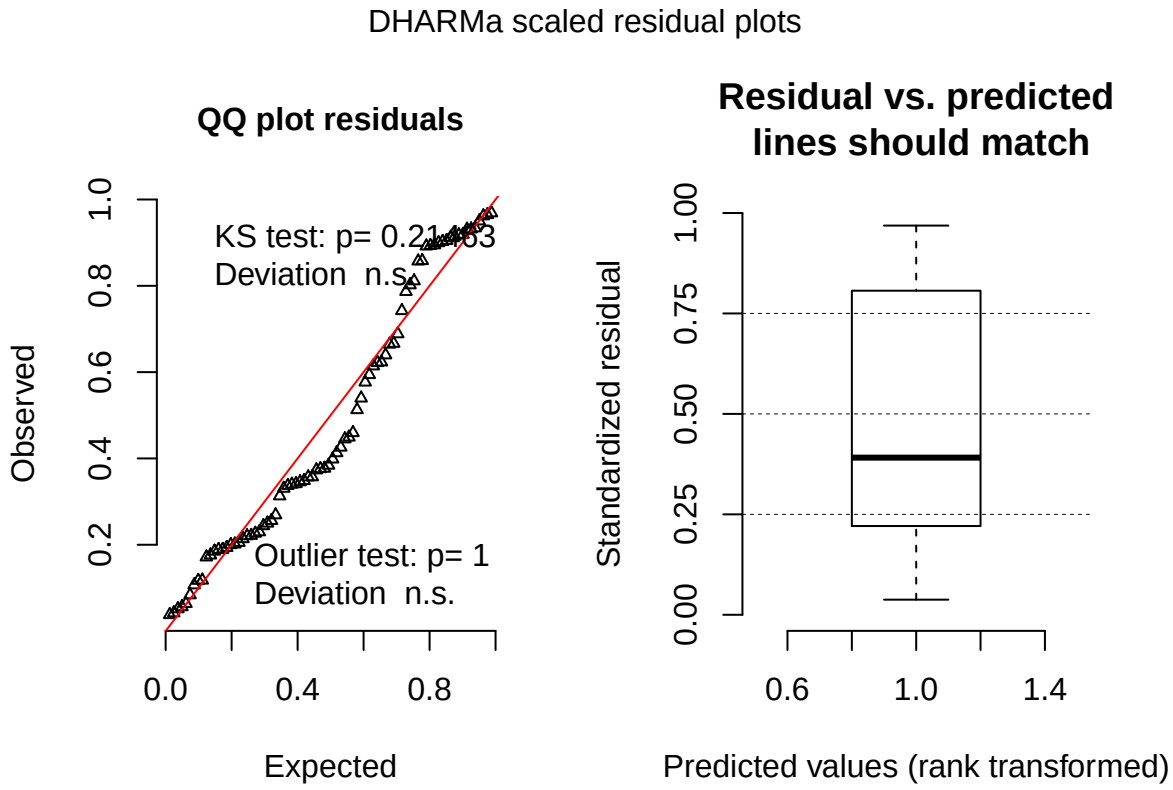




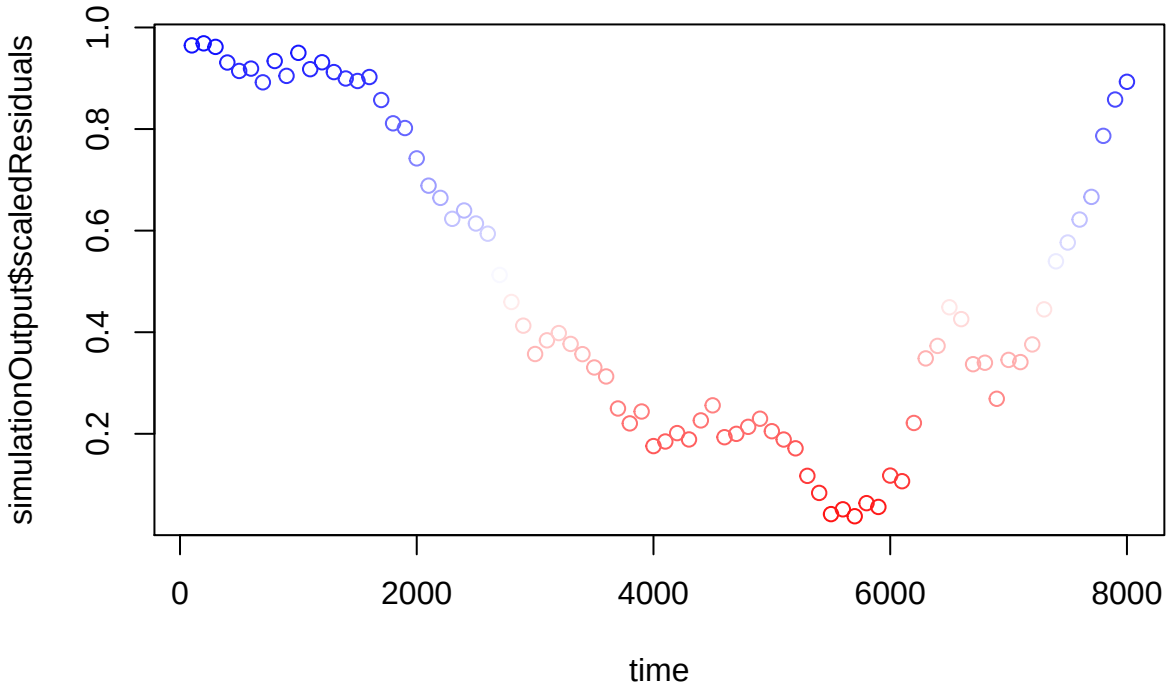



```
##
## Method: REML   Optimizer: outer newton
## full convergence after 6 iterations.
## Gradient range [-2.17948e-07,-2.17948e-07]
## (score 22.97567 & scale 0.09909432).
## Hessian positive definite, eigenvalue range [39.5,39.5].
## Model rank =  1 / 1
##
## $mfrow
## [1] 2 2
##
##
## Family: gaussian
## Link function: identity
##
## Formula:
## Charcoal ~ 1
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.21038    0.03519  -5.977 6.21e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =      0   Deviance explained =    0%
```

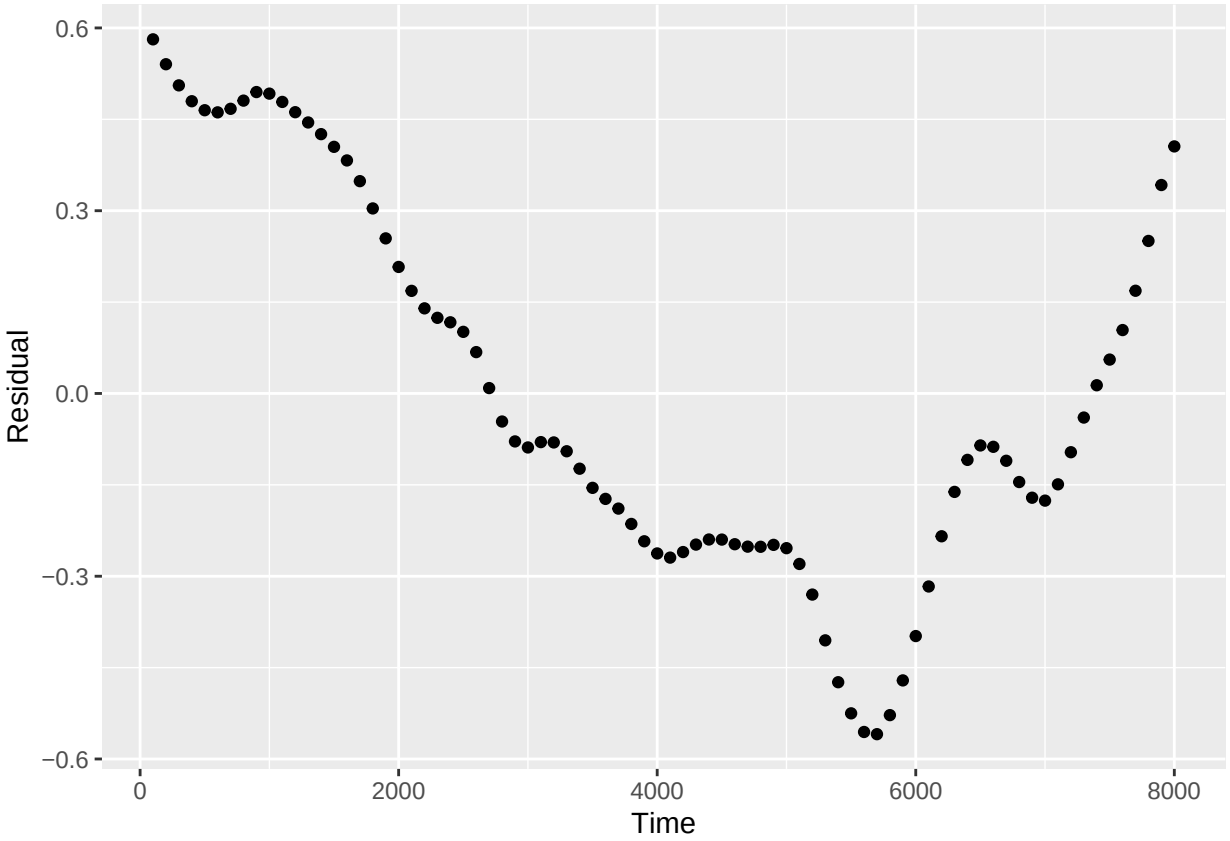
```
## -REML = 22.976  Scale est. = 0.099094  n = 80
## [1] "Plotting predictions"
## list()
```




```
## $mfrow
## [1] 1 2
##
## $oma
## [1] 0 1 2 1
```




```
##
##  Durbin-Watson test
##
## data:  simulationOutput$scaledResiduals ~ 1
## DW = 0.022883, p-value < 2.2e-16
## alternative hypothesis: true autocorrelation is not 0
##
## [1] "Time series of residuals"
```



Here we group models by region and get AIC values and AIC weights for each set of predictors over that region.

Atlantic ecoregion

```
atlantic.models <- list(climate.atlantic = late.climate.atlantic,
                        needleleaf.atlantic = needle.atlantic,
                        scrub.atlantic = scrub.atlantic,
                        broadleaf.atlantic = broad.atlantic,
                        totaltree.atlantic = totaltree.atlantic,
                        arable.atlantic = arable.atlantic,
                        pasture.atlantic = pasture.atlantic,
                        intercept.atlantic = intercept.atlantic)
atlantic.aic.df <- data.frame(Model = names(atlantic.models),
                              AIC = sapply(atlantic.models, function(x) x$aic),
                              akaike.weights(sapply(atlantic.models, function(x) x$aic)))

atlantic.aic.df <- atlantic.aic.df[order(atlantic.aic.df$AIC),]
atlantic.aic.df$Cumulative.Weight <- cumsum(atlantic.aic.df$weights)

kable(atlantic.aic.df, row.names = FALSE)
```

Model	AIC	deltaAIC	rel.LL	weights	Cumulative.Weight
broadleaf.atlantic	-154.0558978	0.00000	1	1	1
arable.atlantic	-94.8110940	59.24480	0	0	1
totaltree.atlantic	-86.2392459	67.81665	0	0	1
scrub.atlantic	-77.5731477	76.48275	0	0	1
pasture.atlantic	-64.3536747	89.70222	0	0	1
needleleaf.atlantic	-33.5075403	120.54836	0	0	1
climate.atlantic	-33.1322949	120.92360	0	0	1
intercept.atlantic	0.1920688	154.24797	0	0	1

```
write.csv(atlantic.aic.df, file = "atlantic.aic.csv")
```

Continental ecoregion

```
continental.models <- list(climate.continental = late.climate.continental,
                           needleleaf.continental = needle.continental,
                           scrub.continental = scrub.continental,
                           broadleaf.continental = broad.continental,
                           totaltree.continental = totaltree.continental,
                           arable.continental = arable.continental,
                           pasture.continental = pasture.continental,
                           intercept.continental = intercept.continental)
continental.aic.df <- data.frame(Model = names(continental.models),
                                 AIC = sapply(continental.models, function(x) x$aic),
                                 akaike.weights(sapply(continental.models, function(x) x$aic)))

continental.aic.df <- continental.aic.df[order(continental.aic.df$AIC),]
continental.aic.df$Cumulative.Weight <- cumsum(continental.aic.df$weights)

kable(continental.aic.df, row.names = FALSE)
```

Model	AIC	deltaAIC	rel.LL	weights	Cumulative.Weight
totaltree.continental	-206.67043	0.000000	1.0000000	0.9197937	0.9197937
broadleaf.continental	-200.84680	5.823633	0.0543769	0.0500155	0.9698092
scrub.continental	-199.67135	6.999087	0.0302112	0.0277881	0.9975973
arable.continental	-194.71565	11.954779	0.0025354	0.0023321	0.9999294
pasture.continental	-187.72188	18.948548	0.0000768	0.0000706	1.0000000
needleleaf.continental	-145.18921	61.481222	0.0000000	0.0000000	1.0000000
climate.continental	-144.96485	61.705585	0.0000000	0.0000000	1.0000000
intercept.continental	-98.24067	108.429762	0.0000000	0.0000000	1.0000000

```
write.csv(continental.aic.df, file = "continental.aic.csv")
```

Boreo-Nemoral ecoregion

```
boreonemoral.models <- list(climate.boreonemoral = late.climate.boreonemoral,
                            needleleaf.boreonemoral = needle.boreonemoral,
                            scrub.boreonemoral = scrub.boreonemoral,
                            broadleaf.boreonemoral = broad.boreonemoral,
                            totaltree.boreonemoral = totaltree.boreonemoral,
                            arable.boreonemoral = arable.boreonemoral,
                            pasture.boreonemoral = pasture.boreonemoral,
                            intercept.boreonemoral = intercept.boreonemoral)
boreonemoral.aic.df <- data.frame(Model = names(boreonemoral.models),
                                  AIC = sapply(boreonemoral.models, function(x) x$aic),
                                  akaike.weights(sapply(boreonemoral.models, function(x) x$aic)))
boreonemoral.aic.df <- boreonemoral.aic.df[order(boreonemoral.aic.df$AIC),]
boreonemoral.aic.df$Cumulative.Weight <- cumsum(boreonemoral.aic.df$weights)

kable(boreonemoral.aic.df, row.names = FALSE)
```

Model	AIC	deltaAIC	rel.LL	weights	Cumulative.Weight
broadleaf.boreonemoral	-89.19857	0.00000	1	1	1
arable.boreonemoral	-45.28533	43.91325	0	0	1
needleleaf.boreonemoral	-40.63121	48.56736	0	0	1
totaltree.boreonemoral	-36.77012	52.42845	0	0	1
pasture.boreonemoral	-20.77414	68.42443	0	0	1
scrub.boreonemoral	-19.43688	69.76169	0	0	1
climate.boreonemoral	-17.53115	71.66743	0	0	1
intercept.boreonemoral	45.08921	134.28778	0	0	1

```
write.csv(boreonemoral.aic.df, file = "boreonemoral.aic.csv")
```

Summary

Although some of the land cover classes are highly correlated (arable and pastures vs. total tree cover and broadleaf tree vs. total tree cover) comparison of AIC scores shows differences in their explanatory power for patterns of biomass burning. Evaluation of the models using AIC scores and weights shows that broadleaf cover produces the best fitting model in determining biomass burning in all ecoregions: ATL, BNE, CON (Table 1). Most of the explanatory power (including > 0.99 of the total cumulative AIC weight) comes from models that include broadleaf cover alone for the BNE and ATL ecoregions and the joint effects of broadleaf, total tree and arable cover for the CON ecoregion (Table 1, Fig. SUPPLEMENT HTML FILE).

The contrast between models including land cover and climate vs. those including climate alone demonstrates that most of the explanatory power in these sets of candidate models is coming from the land cover variables, not from the climate variables.