

# THE INFLUENCE OF VITORIA EDDY IN THE ABUNDANCE OF SEABOB SHRIMP *Xiphopenaeus* spp. (HELLER) IN THE BRAZILIAN EAST COAST

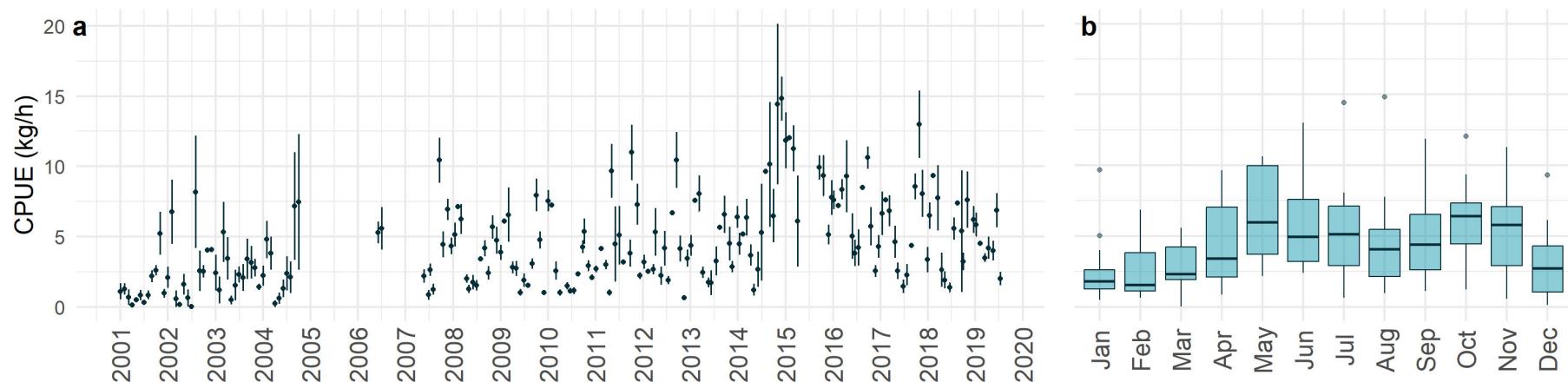
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2026-01-19

## Exploratory descriptive analysis of variables

### CPUE

#### Descriptive statistics



#### Measures of central tendency and dispersion

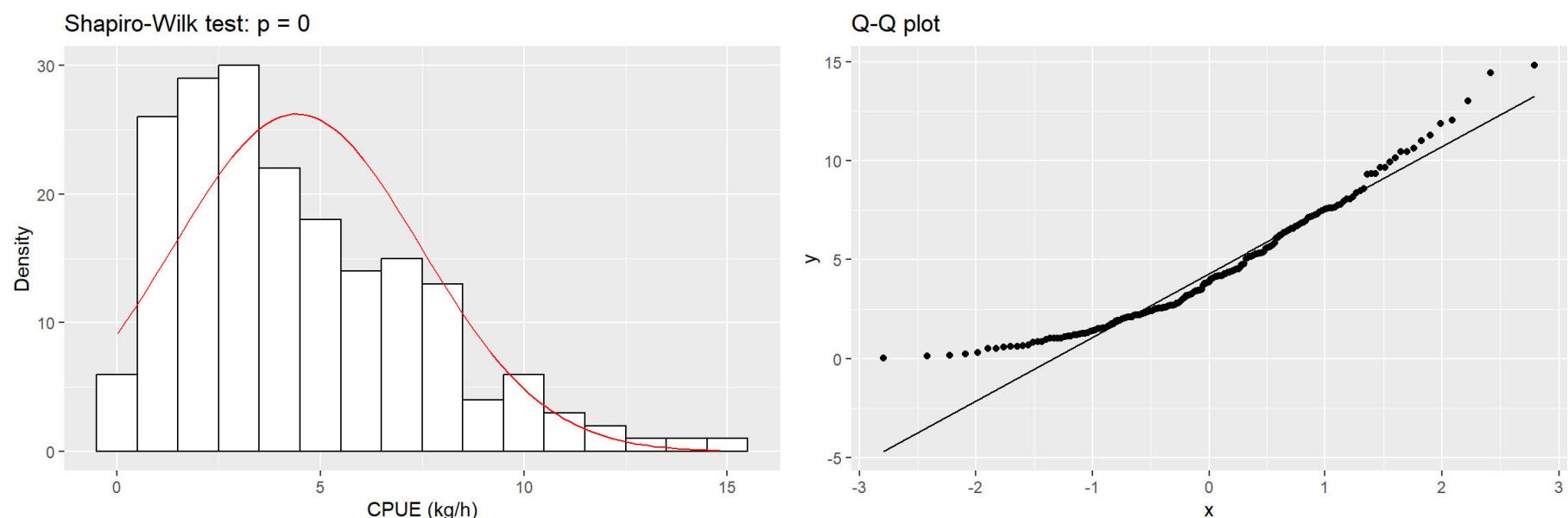
```
##      Min.    1st Qu.     Median      Mean    3rd Qu.      Max.    NA's 
## 0.008571 2.109195 3.882664 4.421113 6.444444 14.820000      32
```

```
## [1] "N = 191"
```

year	annual_mean	se
2001	0.8	0.3
2002	1.9	0.6
2003	3.0	0.6
2004	2.4	0.4
2005	3.5	0.9
2006		
2007	5.4	0.1
2008	4.5	0.8
2009	3.7	0.5
2010	3.5	0.8
2011	2.6	0.4
2012	5.0	0.8
2013	4.7	0.8
2014	4.4	0.5
2015	8.8	1.3
2016	8.1	0.4
2017	5.9	0.7
2018	5.8	1.0
2019	4.7	0.6
2020	4.3	1.4
month	monthly_mean	se
1	2.5	0.5
2	2.4	0.4
3	2.8	0.4

month	monthly_mean	se
4	4.5	0.7
5	6.4	0.8
6	5.8	0.7
7	5.4	0.8
8	4.5	0.8
9	4.9	0.6
10	5.9	0.7
11	5.2	0.7
12	3.1	0.6

### Shapiro-Wilk Normality Test



### Seasonal variation (Kruskal-Wallis and Dunn's Test)

```
## 
## Kruskal-Wallis rank sum test
## 
## data: data$CPUE and data$month
## Kruskal-Wallis chi-squared = 45.83, df = 11, p-value = 3.465e-06
```

### Dunn's Test to compare monthly means

	01	02	03	04	05	06	07	08	09	10	11	12
01	1	0.4715	0.2587	0.0136	0	2e-04	9e-04	0.0221	0.0032	1e-04	0.0011	0.1896
02	0.4715	1	0.2793	0.015	0	2e-04	0.001	0.0244	0.0035	1e-04	0.0012	0.2058
03	0.2587	0.2793	1	0.0544	4e-04	0.0017	0.0059	0.08	0.0168	0.001	0.0069	0.4031
04	0.0136	0.015	0.0544	1	0.0465	0.1036	0.1876	0.4234	0.3163	0.078	0.2108	0.0896
05	0	0	4e-04	0.0465	1	0.3353	0.218	0.0303	0.1109	0.3953	0.1866	0.0011
06	2e-04	2e-04	0.0017	0.1036	0.3353	1	0.3592	0.0725	0.2129	0.4365	0.3209	0.0041
07	9e-04	0.001	0.0059	0.1876	0.218	0.3592	1	0.1401	0.3362	0.3023	0.4613	0.0124
08	0.0221	0.0244	0.08	0.4234	0.0303	0.0725	0.1401	1	0.25	0.0532	0.1586	0.1257
09	0.0032	0.0035	0.0168	0.3163	0.1109	0.2129	0.3362	0.25	1	0.1695	0.3703	0.032
10	1e-04	1e-04	0.001	0.078	0.3953	0.4365	0.3023	0.0532	0.1695	1	0.2659	0.0025
11	0.0011	0.0012	0.0069	0.2108	0.1866	0.3209	0.4613	0.1586	0.3703	0.2659	1	0.0145
12	0.1896	0.2058	0.4031	0.0896	0.0011	0.0041	0.0124	0.1257	0.032	0.0025	0.0145	1

### Temporal Model

```
## ---- Model summary ----
```

```

## 
## Family: Tweedie(p=1.567)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + s(month, k = 12, bs = "cc") + s(year,
##   k = 8, bs = "cr") + ti(year, month, k = c(10, 12), bs = c("cr",
##   "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.3620    0.1412   9.645 <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(grid)      4.110     7 2.173 0.000686 ***
## s(month)     5.435    10 7.059 < 2e-16 ***
## s(year)      2.603     7 54.965 0.008100 **
## ti(year,month) 1.512    90 0.018 0.355958
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.522 Deviance explained = 55.1%
## -REML = 277.62 Scale est. = 0.45904 n = 132

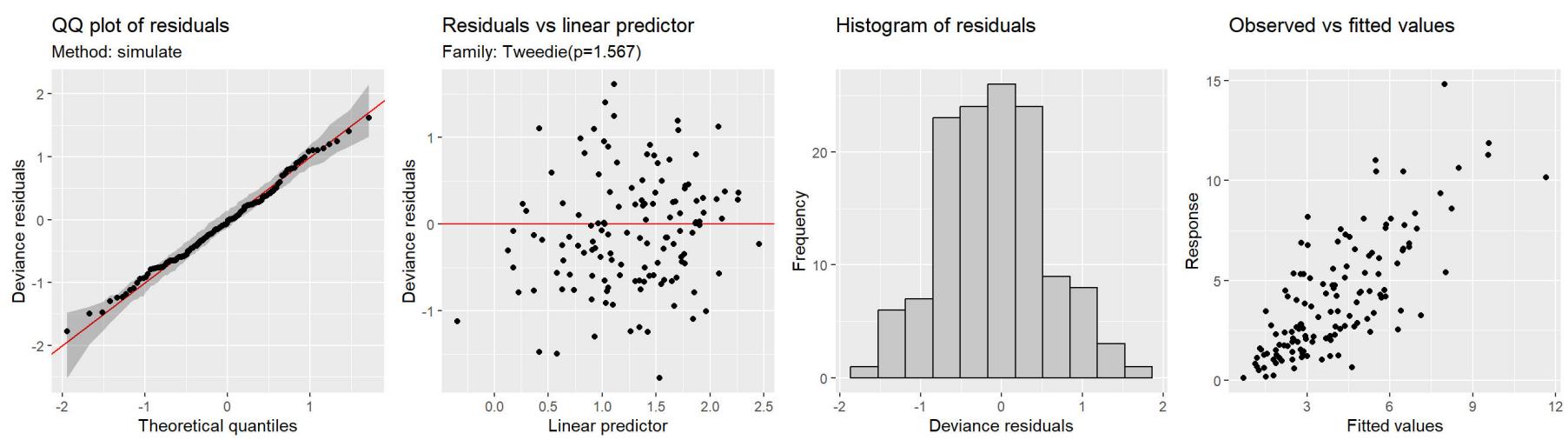
```

```
## ---- k check ----
```

```

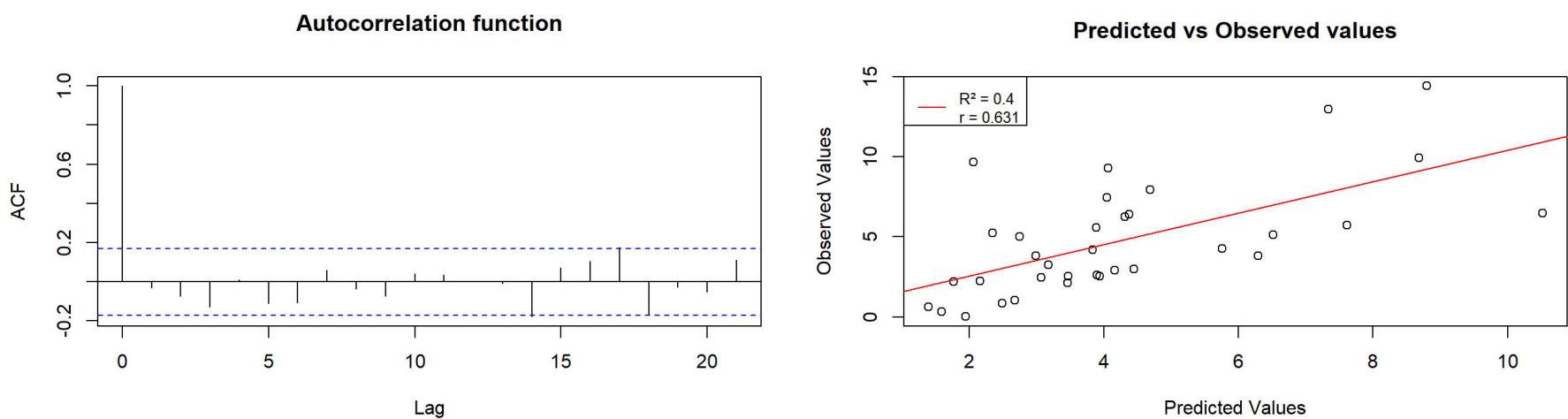
##          k'      edf  k-index p-value
## s(grid)    8 4.109585      NA      NA
## s(month)   10 5.435242 1.0122406  0.6600
## s(year)     7 2.602523 0.8849365  0.1200
## ti(year,month) 90 1.512307 1.0466381  0.8175

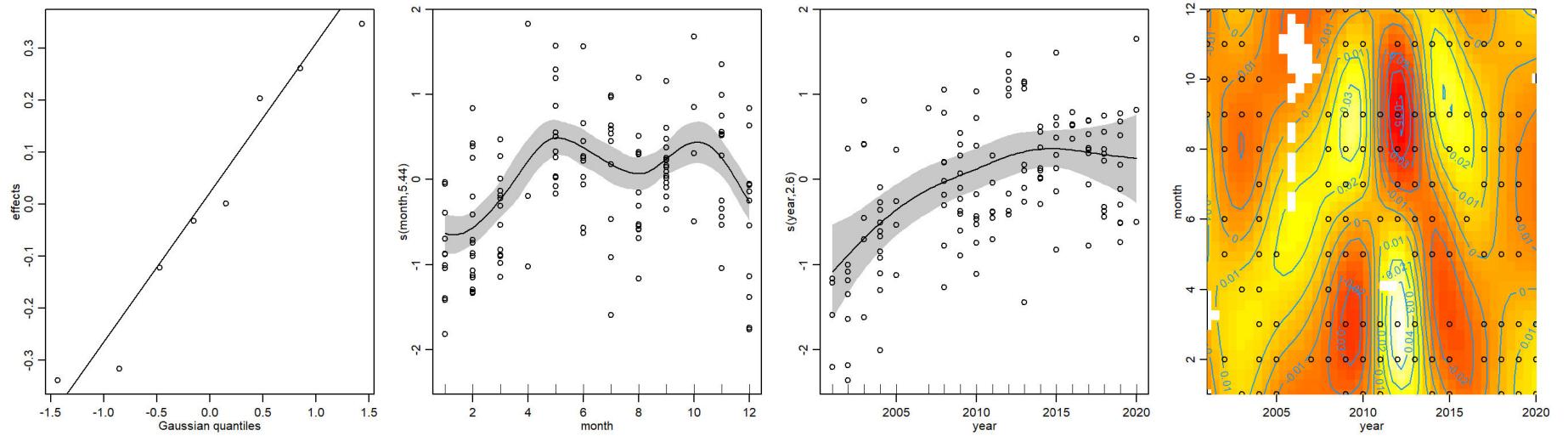
```



```
## Average percentage deviation = 1.29 %
```

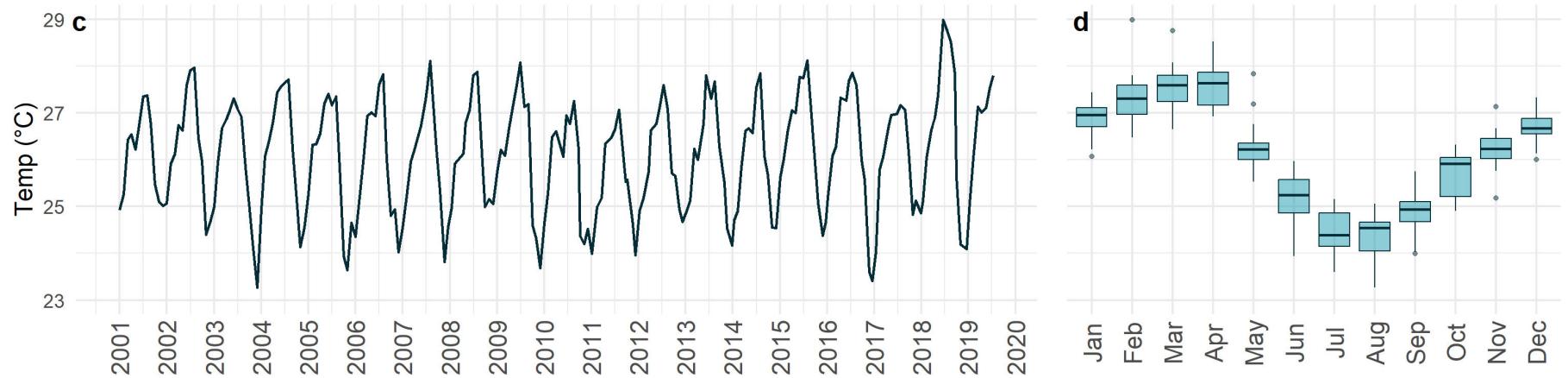
```
## AIC = 543.8606
```





## Sea bottom temperature

### Descriptive statistics



### Measures of central tendency and dispersion

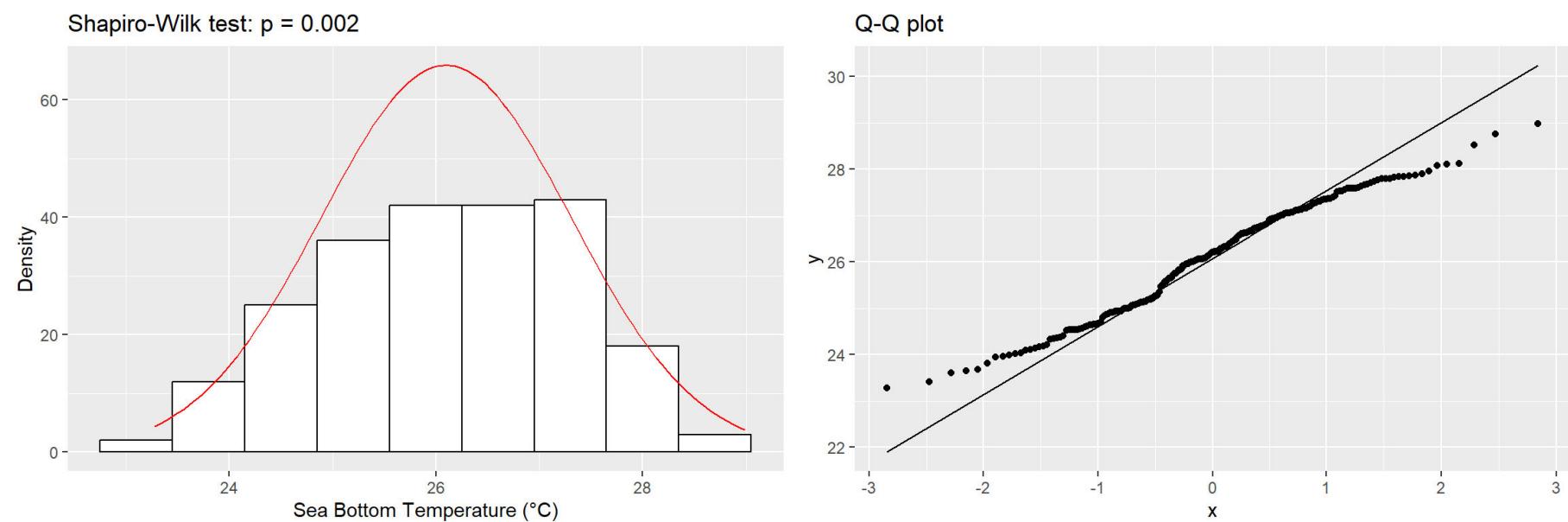
```
##      Min. 1st Qu. Median   Mean 3rd Qu.   Max.
## 23.27 25.08 26.21 26.10 27.06 28.99
```

```
## [1] "N = 223"
```

year	annual_mean	se
2001	25.8	0.4
2002	26.2	0.2
2003	26.3	0.3
2004	25.9	0.4
2005	26.2	0.4
2006	25.8	0.4
2007	25.9	0.4
2008	26.1	0.4
2009	26.3	0.3
2010	26.1	0.4
2011	25.6	0.3
2012	25.7	0.3
2013	26.0	0.3
2014	26.0	0.4
2015	26.2	0.3
2016	26.3	0.4
2017	26.0	0.5
2018	26.2	0.3
2019	26.7	0.5
2020	27.5	0.2
month	monthly_mean	se
1	26.9	0.1
2	27.3	0.1
3	27.5	0.1

month	monthly_mean	se
4	27.6	0.1
5	26.3	0.1
6	25.2	0.1
7	24.4	0.1
8	24.4	0.1
9	24.9	0.1
10	25.7	0.1
11	26.2	0.1
12	26.7	0.1

### Shapiro-Wilk Normality Test



### Seasonal variation (Kruskal-Wallis and Dunn's Test)

```
## 
## Kruskal-Wallis rank sum test
## 
## data: data$temp and data$month
## Kruskal-Wallis chi-squared = 193.9, df = 11, p-value < 2.2e-16
```

### Dunn's Test to compare monthly means

	01	02	03	04	05	06	07	08	09	10	11	12
01	1	0.1197	0.0365	0.0296	0.0366	0	0	0	0	3e-04	0.0239	0.2415
02	0.1197	1	0.2689	0.2341	0.0016	0	0	0	0	0	8e-04	0.0302
03	0.0365	0.2689	1	0.4531	2e-04	0	0	0	0	0	1e-04	0.0063
04	0.0296	0.2341	0.4531	1	1e-04	0	0	0	0	0	1e-04	0.005
05	0.0366	0.0016	2e-04	1e-04	1	0.003	0	0	4e-04	0.0547	0.4365	0.1357
06	0	0	0	0	0.003	1	0.074	0.0569	0.2804	0.1191	0.0044	1e-04
07	0	0	0	0	0	0.074	1	0.4466	0.1882	0.0041	0	0
08	0	0	0	0	0	0.0569	0.4466	1	0.1537	0.0027	0	0
09	0	0	0	0	4e-04	0.2804	0.1882	0.1537	1	0.0371	6e-04	0
10	3e-04	0	0	0	0.0547	0.1191	0.0041	0.0027	0.0371	1	0.072	0.0031
11	0.0239	8e-04	1e-04	1e-04	0.4365	0.0044	0	0	6e-04	0.072	1	0.1008
12	0.2415	0.0302	0.0063	0.005	0.1357	1e-04	0	0	0	0.0031	0.1008	1

### Temporal Model

```
## ---- Model summary ----
```

```

## 
## Family: gaussian
## Link function: identity
##
## Formula:
## temp ~ s(month, k = 12, bs = "cc") + s(year, k = 6, bs = "cr") +
##      ti(year, month, k = c(6, 12), bs = c("cr", "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 26.06764    0.03458   753.9 <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(month)     7.013    10 107.11 < 2e-16 ***
## s(year)      2.582      5  3.07 0.000396 ***
## ti(year,month) 4.235     50  0.14 0.086555 .
## ---
## Signif. codes:  0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.863  Deviance explained = 87.4%
## -REML = 132.88  Scale est. = 0.21004 n = 178

```

```

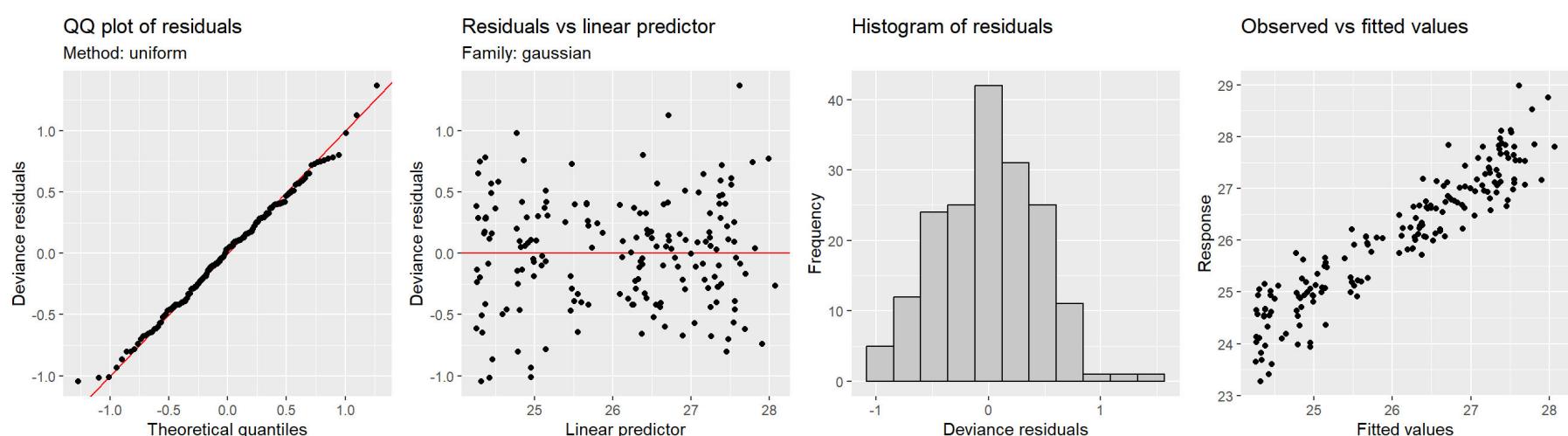
## ---- k check ----

```

```

##          k'      edf  k-index p-value
## s(month) 10 7.012960 1.0581273 0.7200
## s(year)   5 2.582434 0.8786807 0.0425
## ti(year,month) 50 4.234904 0.9333749 0.1000

```



```

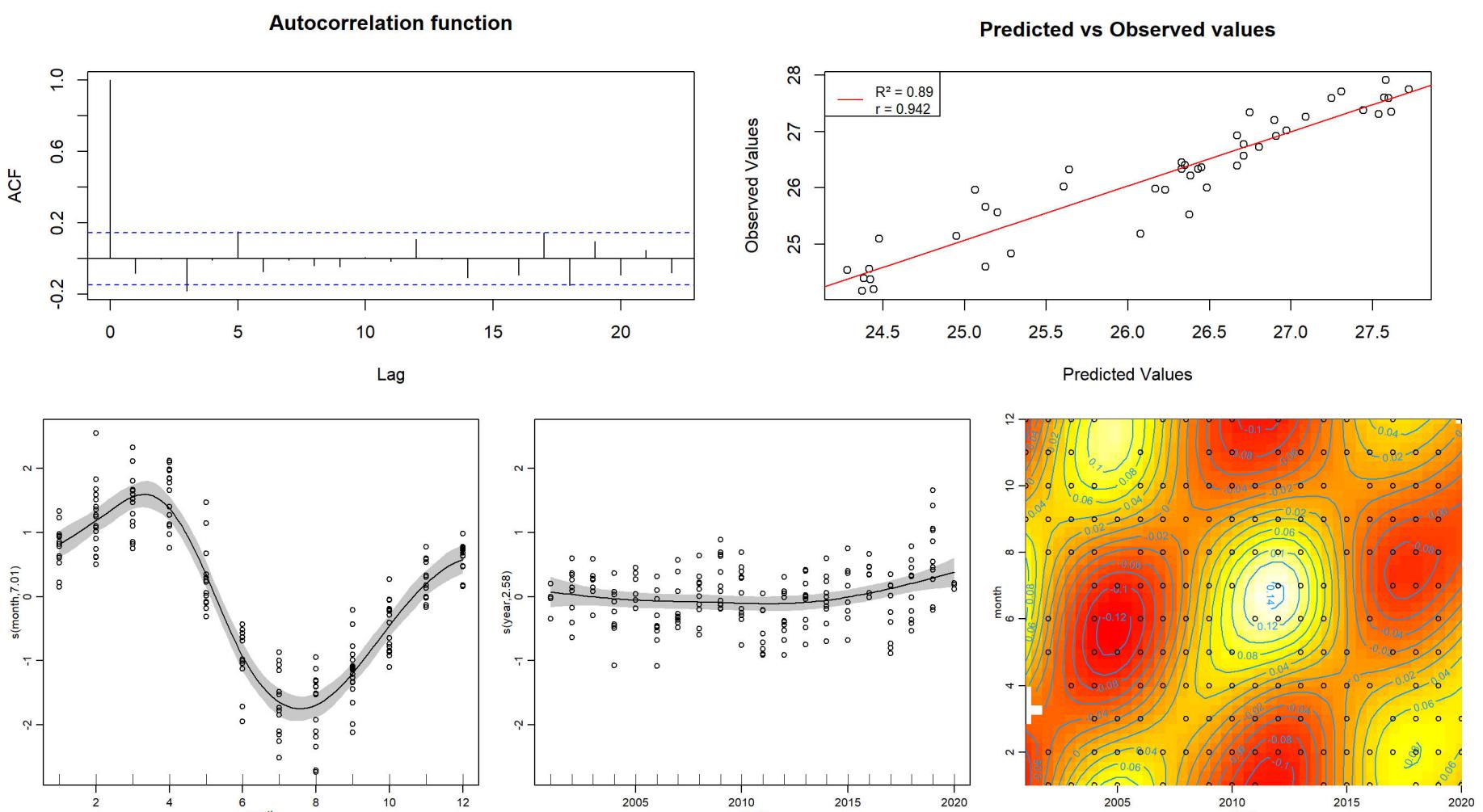
## Average percentage deviation = 0 %

```

```

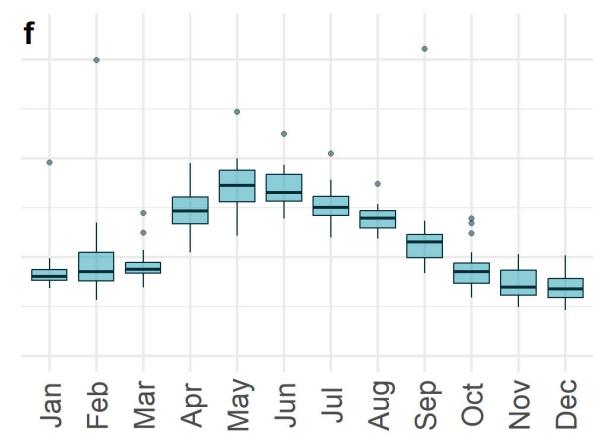
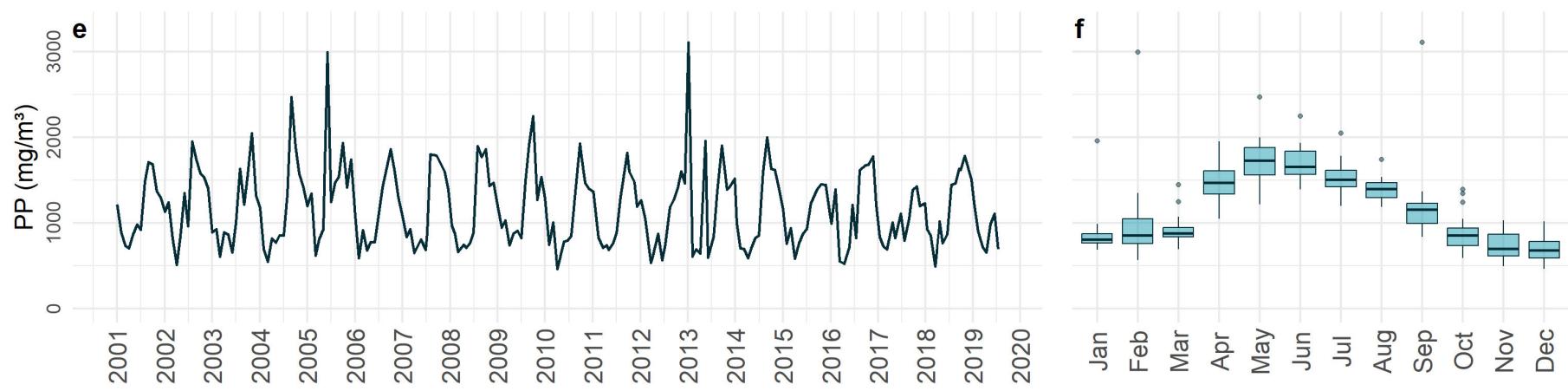
## AIC = 250.2187

```



# PP

## Descriptive statistics



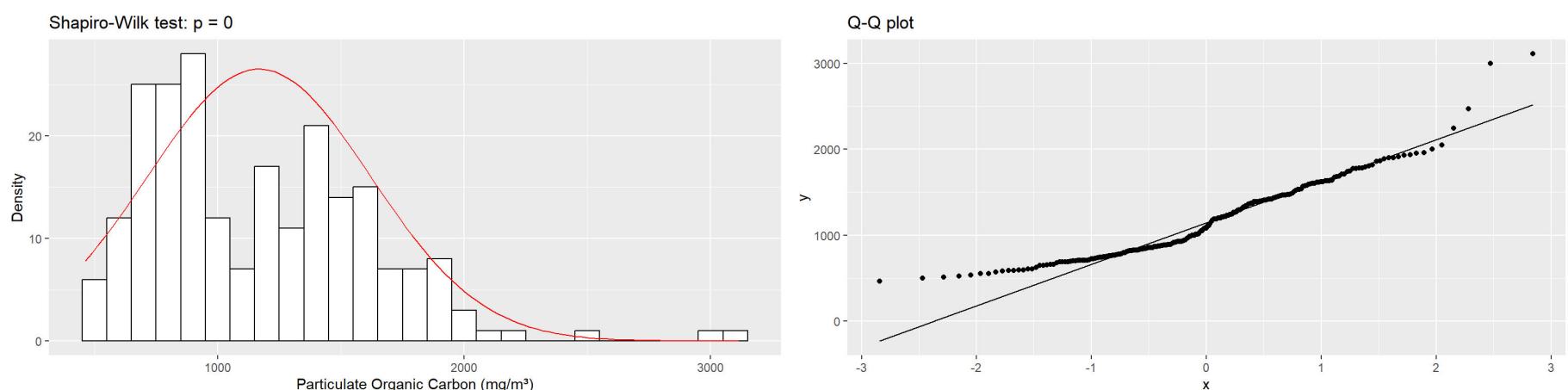
## Measures of central tendency and dispersion

```
##      Min. 1st Qu. Median   Mean 3rd Qu.   Max.
##  462.9   814.5 1080.9 1167.7 1467.7 3113.8
```

```
## [1] "N = 223"
```

year	annual_mean	se
2001	885	118
2002	1168	105
2003	1223	122
2004	1130	131
2005	1262	155
2006	1377	190
2007	1163	115
2008	1160	133
2009	1226	129
2010	1215	149
2011	1167	125
2012	1096	120
2013	1181	205
2014	1165	142
2015	1172	133
2016	1061	98
2017	1164	122
2018	1027	77
2019	1216	118
2020	927	124
month	monthly_mean	se
1	869	63
2	984	121
3	921	40
4	1481	56
5	1710	70
6	1685	52
7	1537	47
8	1388	34
9	1217	110
10	890	52
11	731	38
12	703	36

## Shapiro-Wilk Normality Test



## Seasonal variation (Kruskal-Wallis and Dunn's Test)

```
## 
## Kruskal-Wallis rank sum test
## 
## data: data$PP and data$month
## Kruskal-Wallis chi-squared = 162.28, df = 11, p-value < 2.2e-16
```

## Dunn's Test to compare monthly means

	01	02	03	04	05	06	07	08	09	10	11	12
01	1	0.3227	0.2399	0	0	0	0	0	0.0064	0.3911	0.1242	0.0696
02	0.3227	1	0.4027	0	0	0	0	2e-04	0.0214	0.4272	0.0532	0.0263
03	0.2399	0.4027	1	0	0	0	0	4e-04	0.0375	0.3336	0.0314	0.0144
04	0	0	0	1	0.1246	0.1199	0.3406	0.2884	0.0158	0	0	0
05	0	0	0	0.1246	1	0.4907	0.2292	0.0436	5e-04	0	0	0
06	0	0	0	0.1199	0.4907	1	0.2222	0.0415	4e-04	0	0	0
07	0	0	0	0.3406	0.2292	0.2222	1	0.1663	0.0051	0	0	0
08	0	2e-04	4e-04	0.2884	0.0436	0.0415	0.1663	1	0.0565	1e-04	0	0
09	0.0064	0.0214	0.0375	0.0158	5e-04	4e-04	0.0051	0.0565	1	0.0135	1e-04	0
10	0.3911	0.4272	0.3336	0	0	0	0	1e-04	0.0135	1	0.0763	0.0396
11	0.1242	0.0532	0.0314	0	0	0	0	0	1e-04	0.0763	1	0.3728
12	0.0696	0.0263	0.0144	0	0	0	0	0	0	0.0396	0.3728	1

## Temporal Model

```
## ---- Model summary ----
```

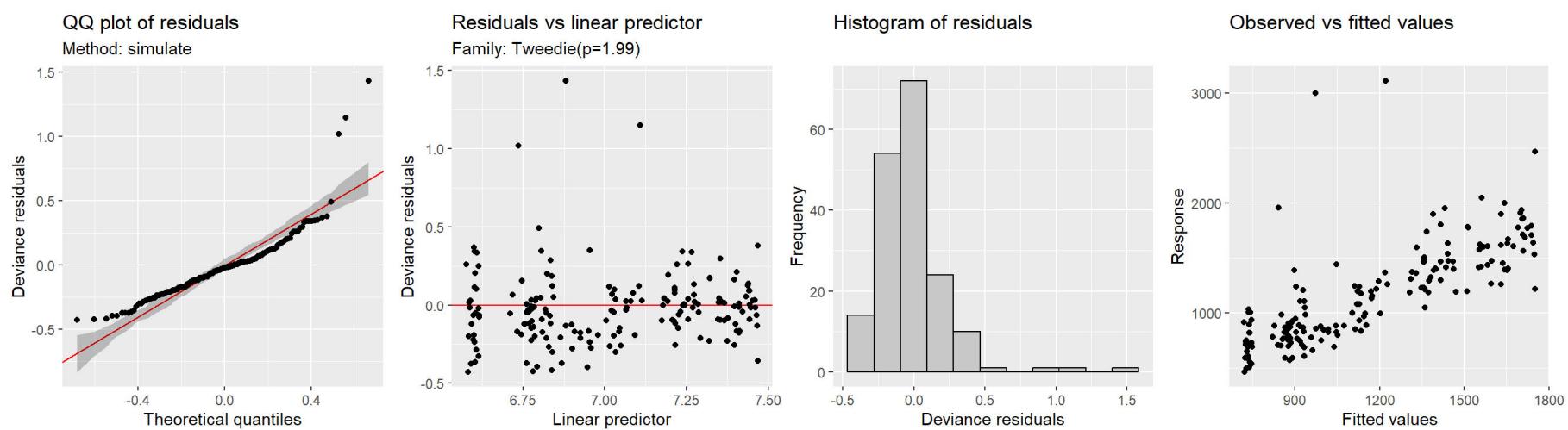
```
## 
## Family: Tweedie(p=1.99)
## Link function: log
## 
## Formula:
## PP ~ s(month, k = 12, bs = "cc") + s(year, k = 10, bs = "cr") +
##     ti(year, month, k = c(10, 12), bs = c("cr", "cc"))
## 
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 7.01703   0.01809   387.9   <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(month)      5.7837    10 25.738   <2e-16 ***
## s(year)       0.4076     9  0.077   0.190    
## ti(year,month) 3.9233    90  0.065   0.109    
## ---      
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## R-sq.(adj) =  0.544  Deviance explained = 61.7%
## -REML = 1258  Scale est. = 0.061638 n = 178
```

```
## ---- k check ----
```

```

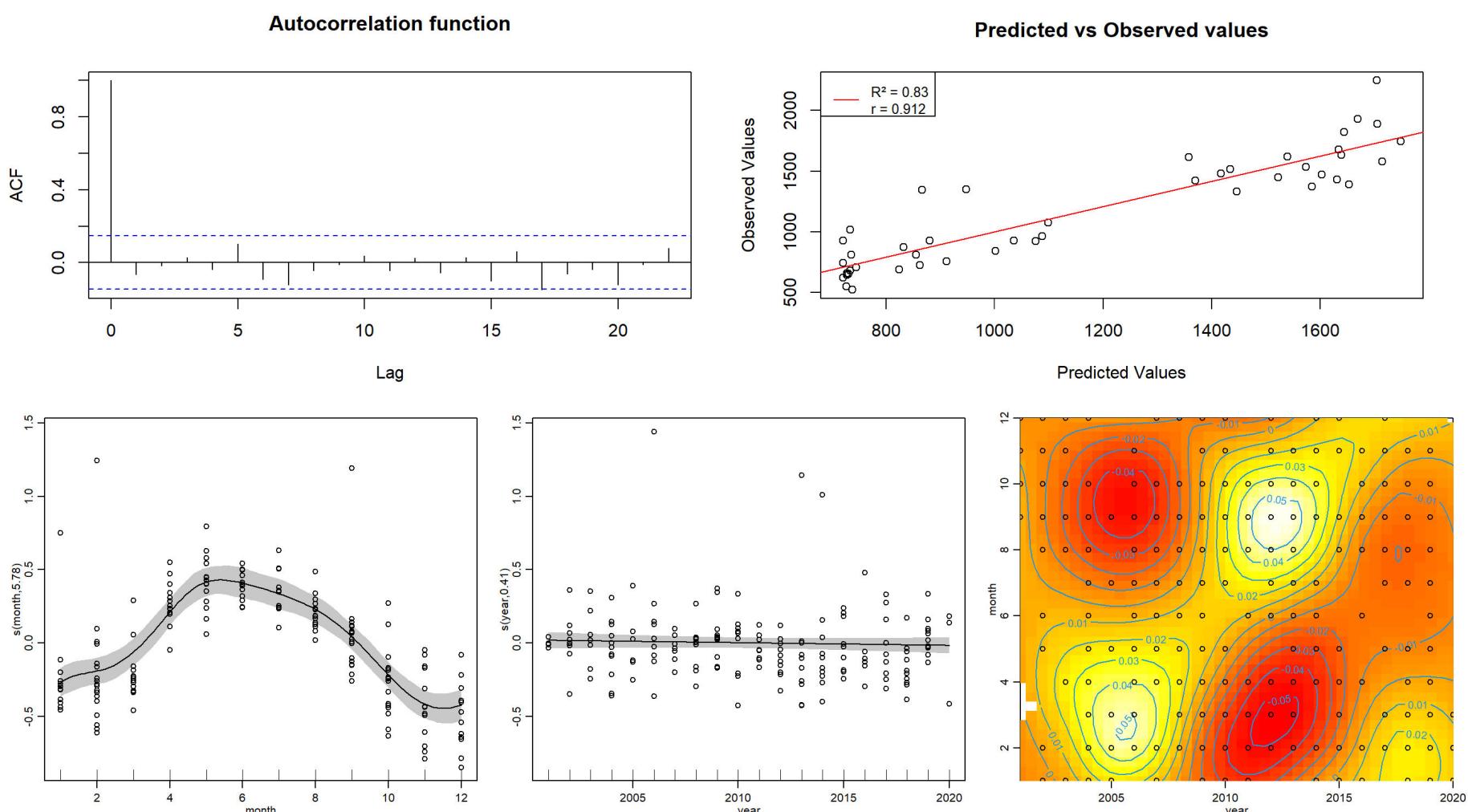
##          k'      edf  k-index p-value
## s(month) 10 5.783709 1.001848 0.5075
## s(year)   9 0.407577 1.055474 0.7775
## ti(year,month) 90 3.923331 1.030778 0.6750

```



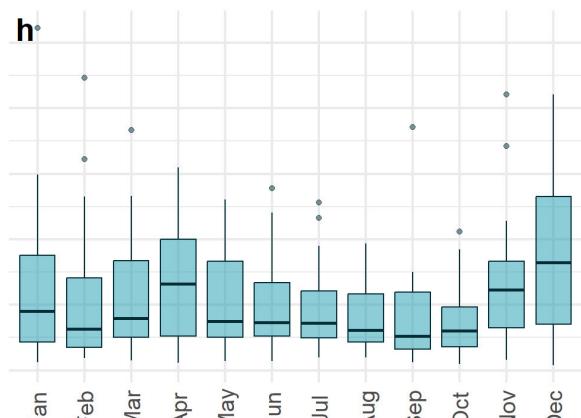
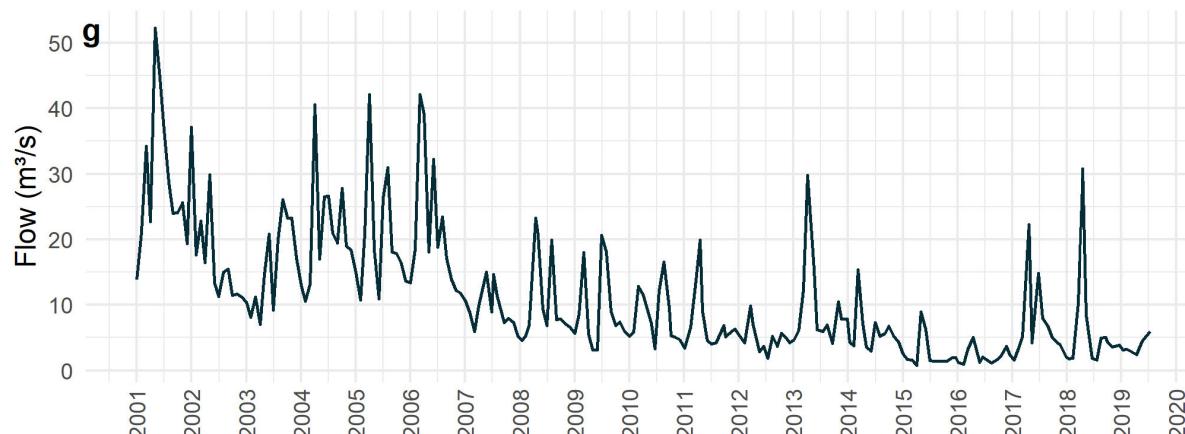
```
## Average percentage deviation = 0.3 %
```

```
## AIC = 2512.55
```



## River flow

### Descriptive statistics



### Measures of central tendency and dispersion

```

##      Min. 1st Qu. Median Mean 3rd Qu. Max.
## 0.754 4.415 7.854 11.382 16.534 52.274

```

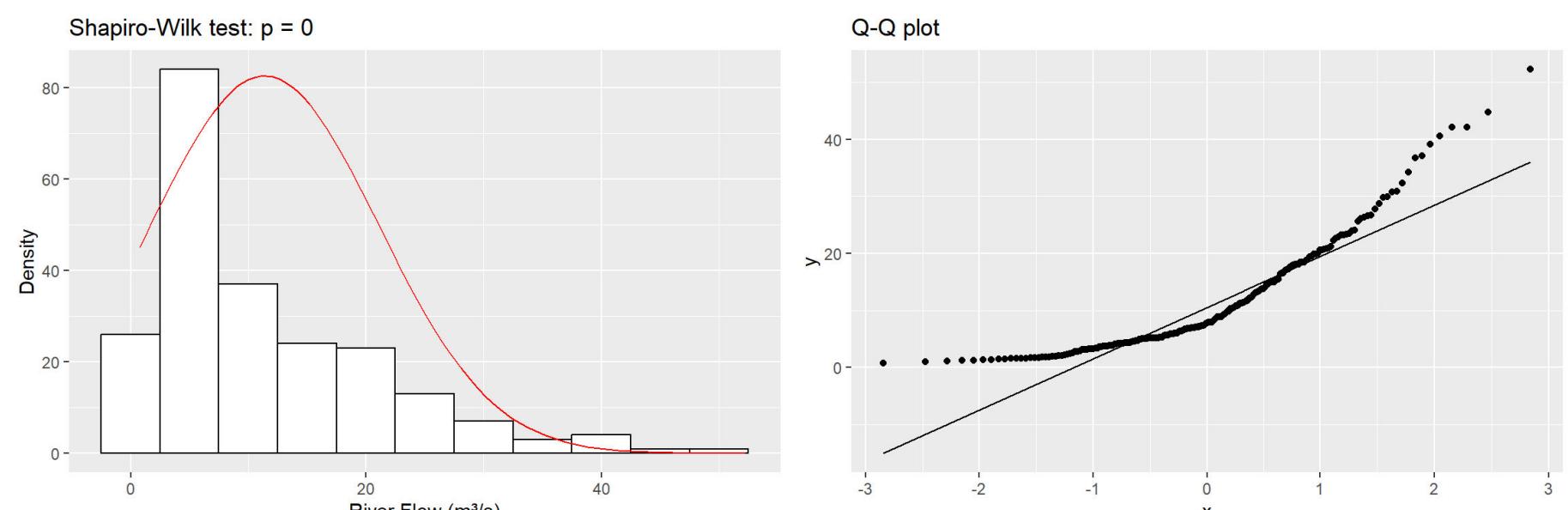
```
## [1] "N = 223"
```

year	annual_mean	se
2001	23.0	4.2

year	annual_mean	se
2002	29.1	3.2
2003	13.0	1.7
2004	19.3	2.5
2005	22.0	2.3
2006	22.1	3.0
2007	15.3	2.1
2008	9.8	1.6
2009	10.3	1.6
2010	9.1	1.6
2011	8.9	1.6
2012	6.0	0.5
2013	7.1	2.2
2014	7.9	1.1
2015	4.0	0.6
2016	2.9	0.7
2017	4.0	1.7
2018	7.8	2.4
2019	3.8	0.5
2020	5.2	0.4

month	monthly_mean	se
1	13.4	2.8
2	11.6	2.7
3	11.6	2.3
4	13.4	2.2
5	10.4	1.8
6	10.4	1.9
7	9.6	1.7
8	8.2	1.3
9	8.2	1.9
10	7.7	1.3
11	13.8	2.4
12	18.1	3.1

### Shapiro-Wilk Normality Test



### Seasonal variation (Kruskal-Wallis and Dunn's Test)

```
## 
## Kruskal-Wallis rank sum test
## 
## data: data$flow and data$month
## Kruskal-Wallis chi-squared = 15.338, df = 11, p-value = 0.1675
```

### Dunn's Test to compare monthly means

	01	02	03	04	05	06	07	08	09	10	11	12
01	1	0.2318	0.3465	0.3881	0.2941	0.3096	0.2359	0.101	0.0438	0.064	0.3281	0.1242
02	0.2318	1	0.3676	0.1569	0.428	0.4106	0.4987	0.2902	0.1646	0.2149	0.1194	0.0296
03	0.3465	0.3676	1	0.2502	0.4395	0.4571	0.3706	0.1877	0.0945	0.1297	0.2005	0.0607
04	0.3881	0.1569	0.2502	1	0.2075	0.2203	0.1609	0.0618	0.0244	0.037	0.4386	0.1966
05	0.2941	0.428	0.4395	0.2075	1	0.4825	0.4303	0.2343	0.1264	0.1685	0.1634	0.0465
06	0.3096	0.4106	0.4571	0.2203	0.4825	1	0.4131	0.2211	0.1174	0.1575	0.1746	0.051
07	0.2359	0.4987	0.3706	0.1609	0.4303	0.4131	1	0.2915	0.1671	0.2171	0.1233	0.0316
08	0.101	0.2902	0.1877	0.0618	0.2343	0.2211	0.2915	1	0.3411	0.4107	0.0432	0.0079
09	0.0438	0.1646	0.0945	0.0244	0.1264	0.1174	0.1671	0.3411	1	0.4262	0.0156	0.0021
10	0.064	0.2149	0.1297	0.037	0.1685	0.1575	0.2171	0.4107	0.4262	1	0.0246	0.0037
11	0.3281	0.1194	0.2005	0.4386	0.1634	0.1746	0.1233	0.0432	0.0156	0.0246	1	0.2391
12	0.1242	0.0296	0.0607	0.1966	0.0465	0.051	0.0316	0.0079	0.0021	0.0037	0.2391	1

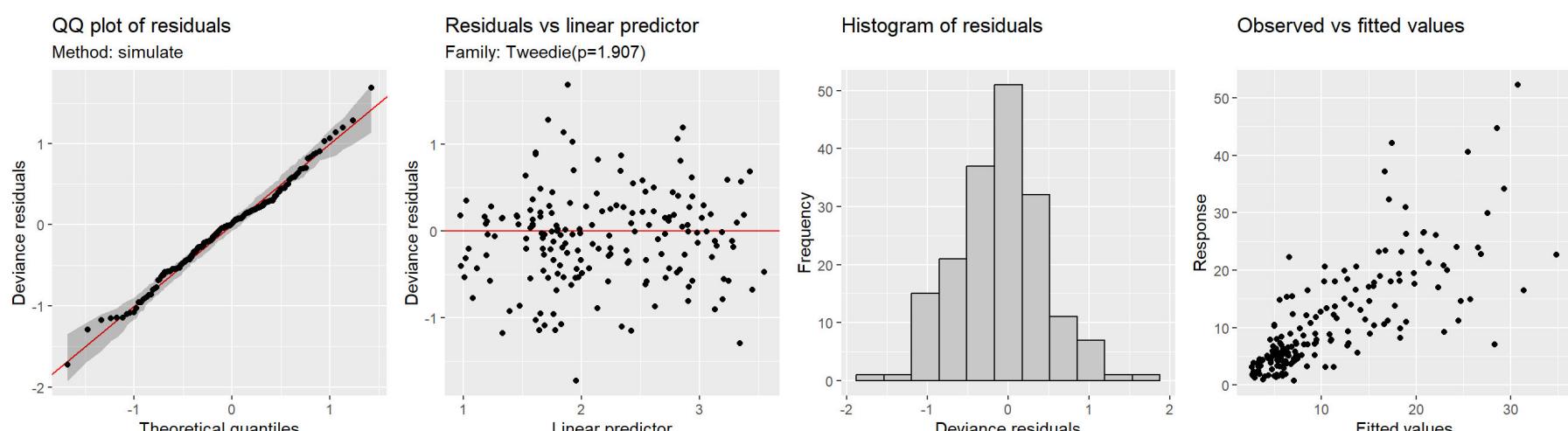
### Temporal Model

```
## ---- Model summary ----
```

```
##
## Family: Tweedie(p=1.907)
## Link function: log
##
## Formula:
## flow ~ s(month, k = 12, bs = "cc") + s(year, k = 6, bs = "cr") +
##      ti(year, month, k = c(6, 12), bs = c("cr", "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 2.17140   0.03757 57.79 <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(month)    4.364    10 4.266 <2e-16 ***
## s(year)     2.984     5 53.785 <2e-16 ***
## ti(year,month) 3.514    50 0.107 0.127
## ---
## Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.563 Deviance explained = 64.6%
## -REML = 516.25 Scale est. = 0.30364 n = 178
```

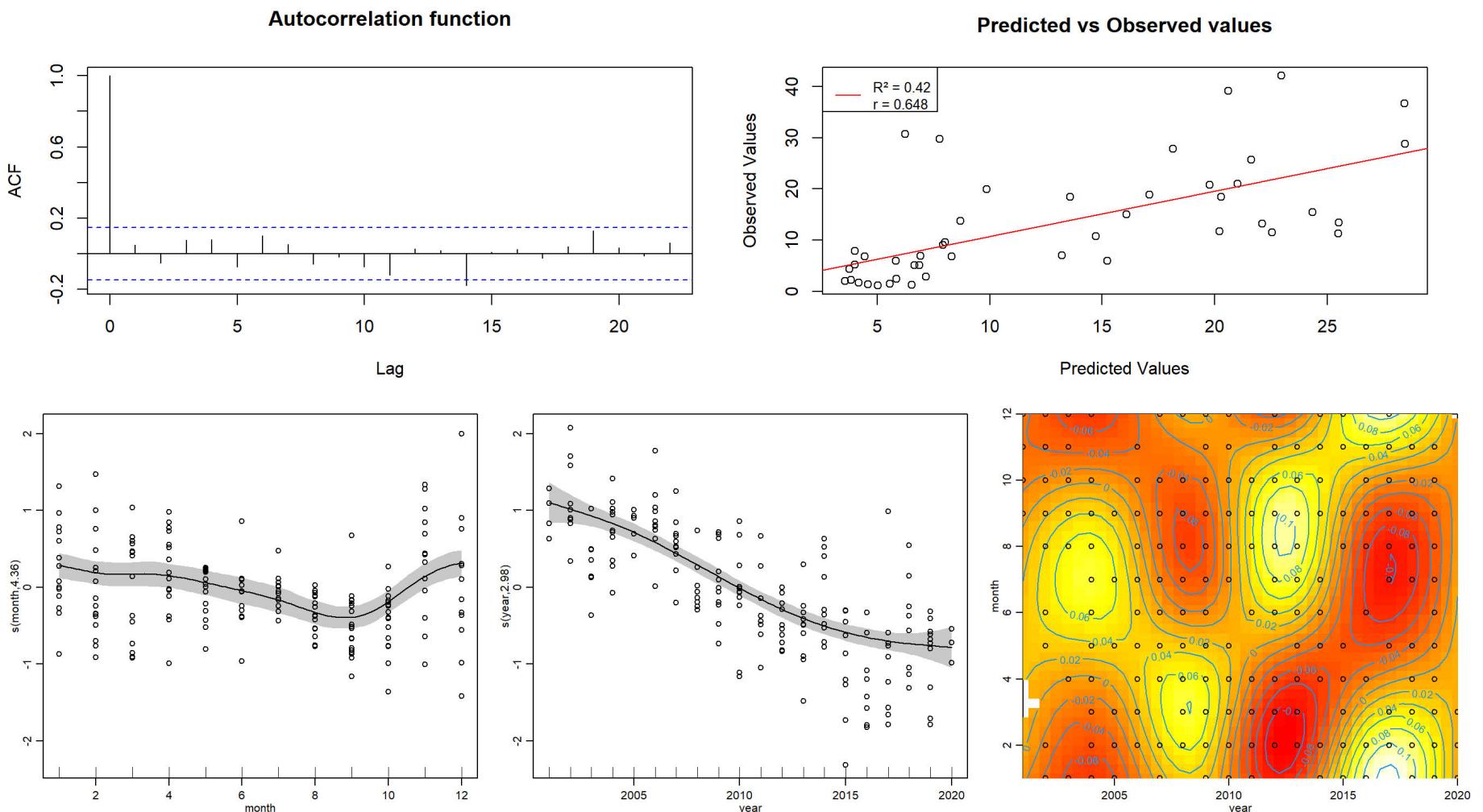
```
## ---- k check ----
```

```
##          k'      edf k-index p-value
## s(month) 10 4.363630 0.8931291 0.105
## s(year)   5 2.984212 0.9161145 0.195
## ti(year,month) 50 3.514208 0.8957897 0.100
```



```
## Average percentage deviation = 0.58 %
```

```
## AIC = 1027.612
```



## CPUE models

### Sea bottom temperature

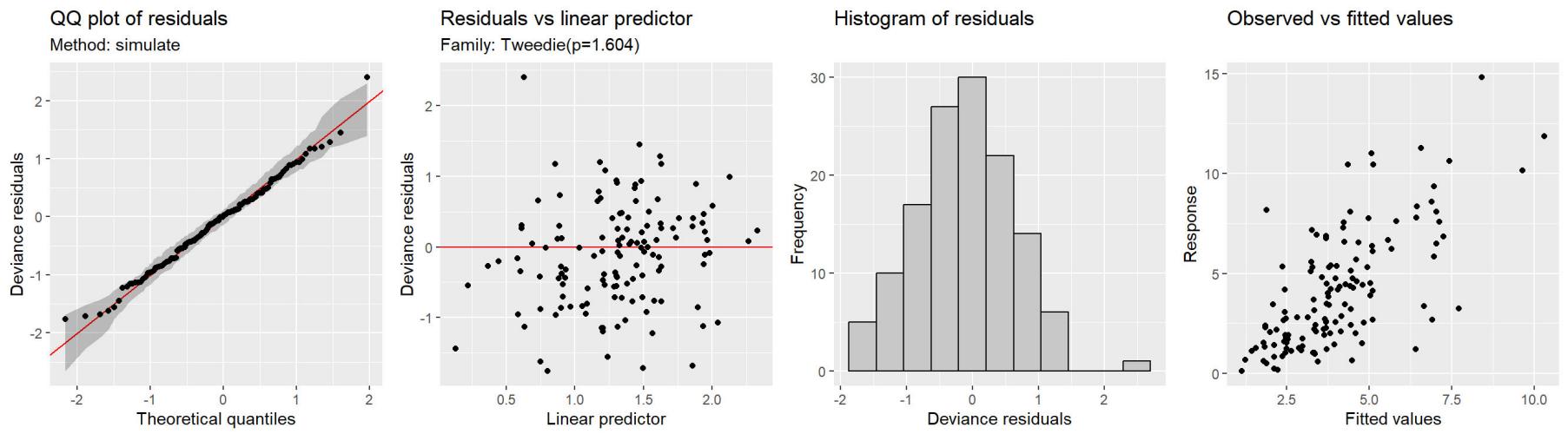
CPUE model as function of isolated factors

```
## ---- Model summary ----
```

```
##
## Family: Tweedie(p=1.604)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + s(temp, k = 8, bs = "tp")
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.2275    0.2144   5.725 7.64e-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(grid) 5.950    7 7.881 < 2e-16 ***
## s(temp) 3.901    7 8.103 2.07e-05 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.415 Deviance explained = 41.9%
## -REML = 245.43 Scale est. = 0.55157 n = 132
```

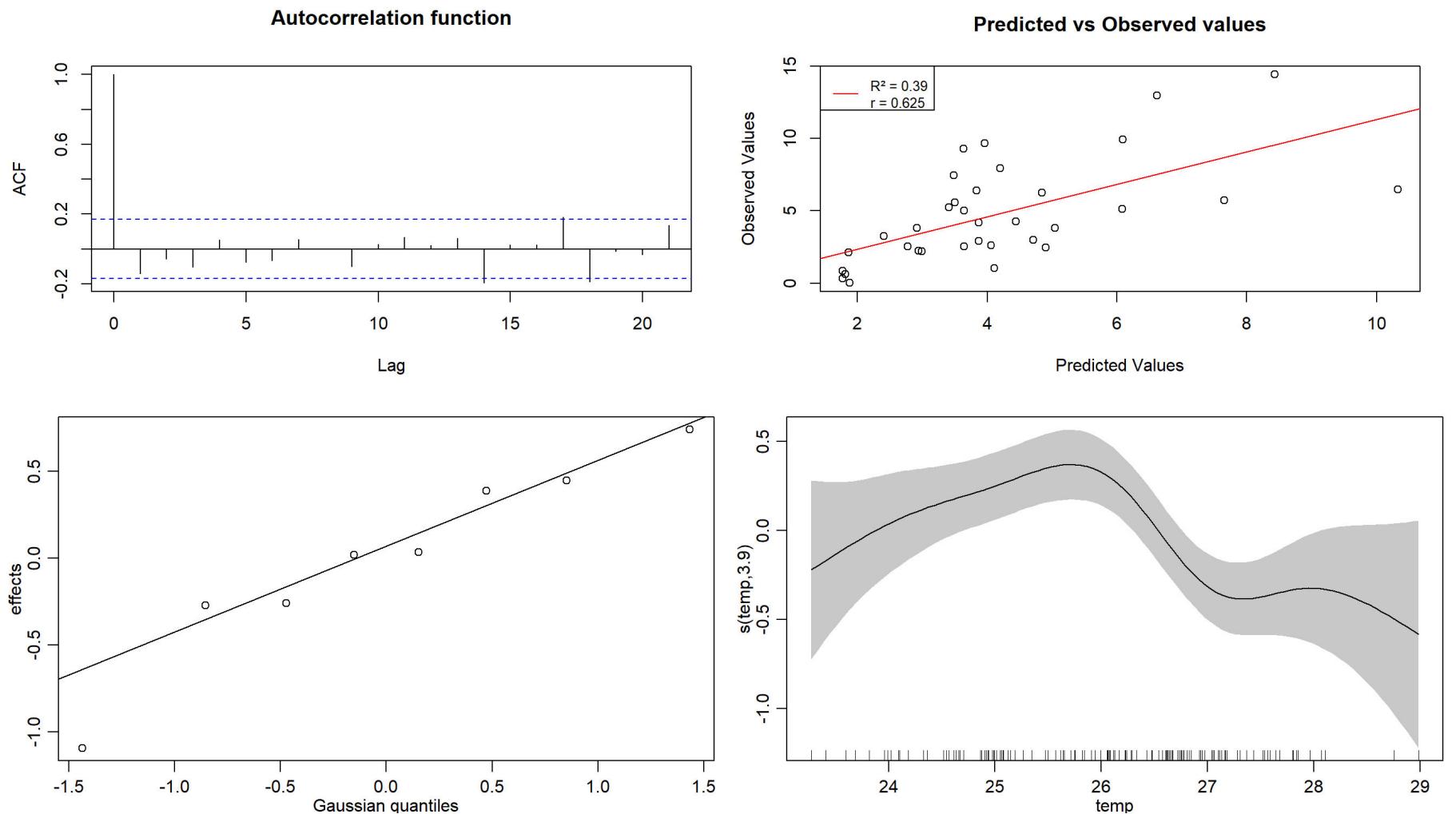
```
## ---- k check ----
```

```
##      k'     edf  k-index p-value
## s(grid) 8 5.950011      NA      NA
## s(temp) 7 3.901257 0.9309283 0.2925
```



```
## Average percentage deviation = 1.62 %
```

```
## AIC = 566.6132
```



### CPUE model as function of tensor product of variables and months

```
## ---- Model summary ----
```

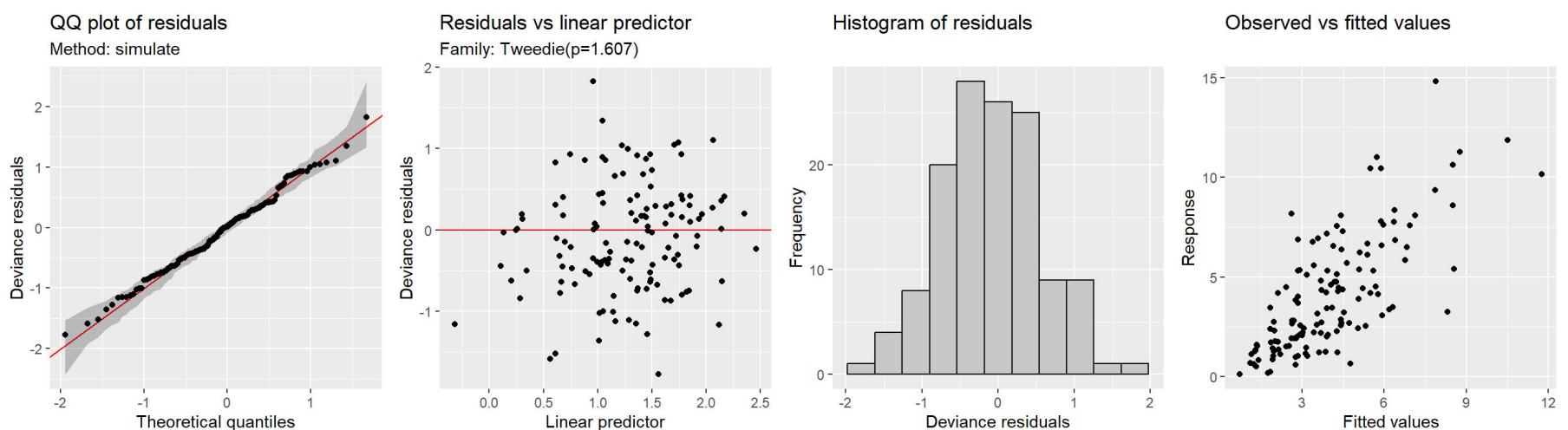
```
##
## Family: Tweedie(p=1.607)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + te(temp, month, k = c(12, 12), bs = c("tp",
##     "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.1951     0.2628   4.548 1.32e-05 ***
## ---
## Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##             edf Ref.df    F p-value
## s(grid)      6.33     7 10.66 <2e-16 ***
## te(temp,month) 6.07    93  0.96 <2e-16 ***
## ---
## Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.49 Deviance explained = 52.5%
## -REML = 280.93 Scale est. = 0.45821 n = 132
```

```
## ---- k check ----
```

```

##          k'      edf k-index p-value
## s(grid)     8 6.330362    NA    NA
## te(temp,month) 131 6.070230 1.118394  0.975

```



```

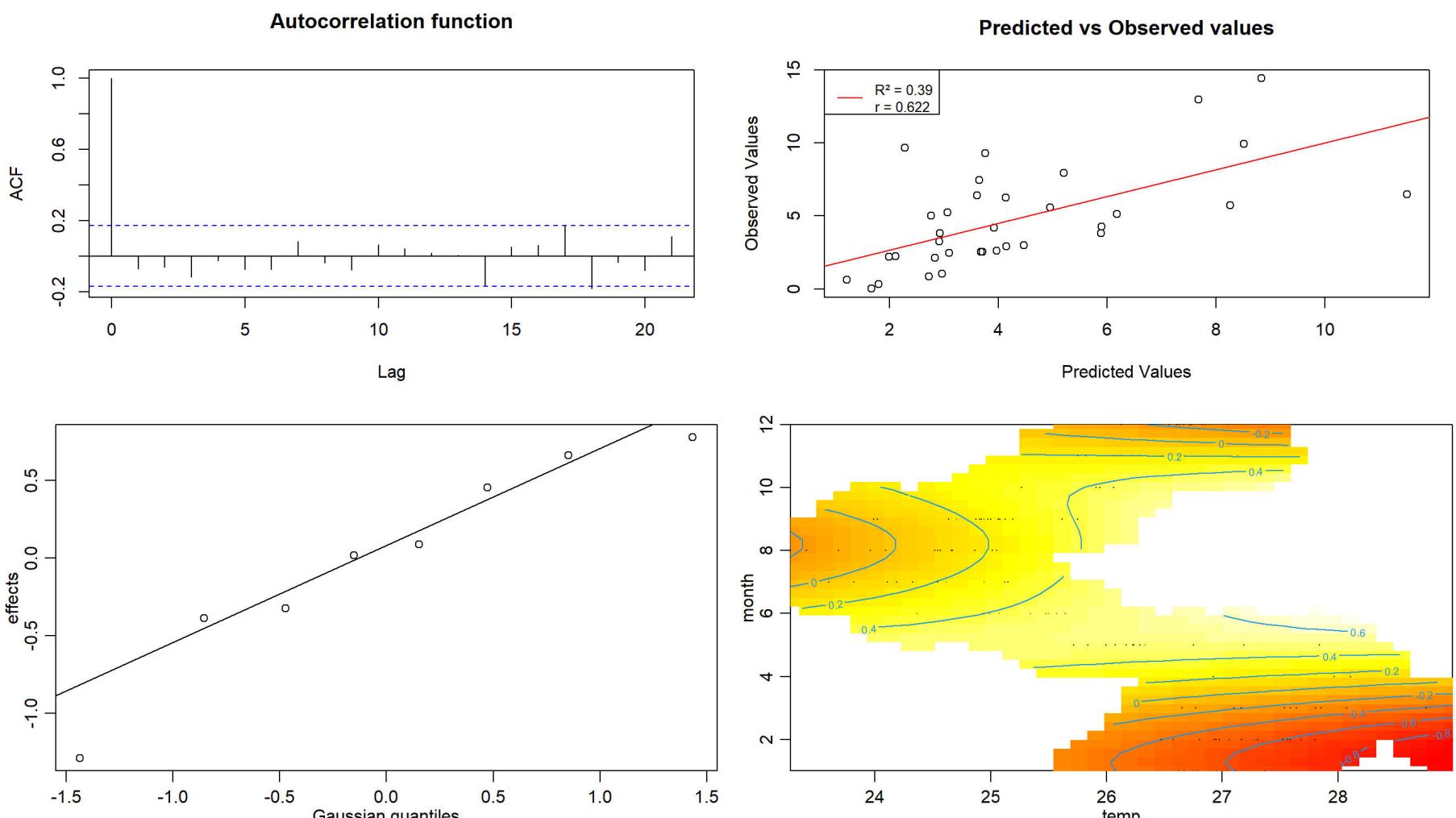
## Average percentage deviation = 1.21 %

```

```

## AIC = 544.8689

```



## PP

### CPUE model as function of isolated factor

```

## ----- Model summary -----

```

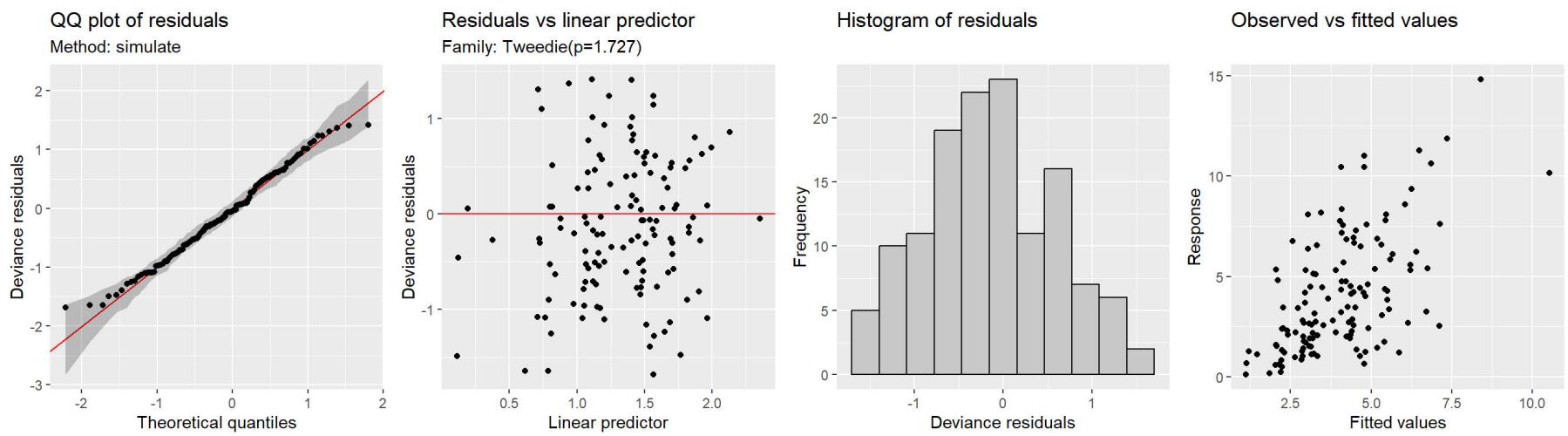
```

##
## Family: Tweedie(p=1.727)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + s(PP, k = 10, bs = "tp")
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.2410    0.2167   5.727 7.34e-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(grid) 5.886    7 6.627 < 2e-16 ***
## s(PP)   1.772    9 2.203 0.000207 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.302  Deviance explained = 33%
## -REML = 293.78  Scale est. = 0.53388 n = 132

```

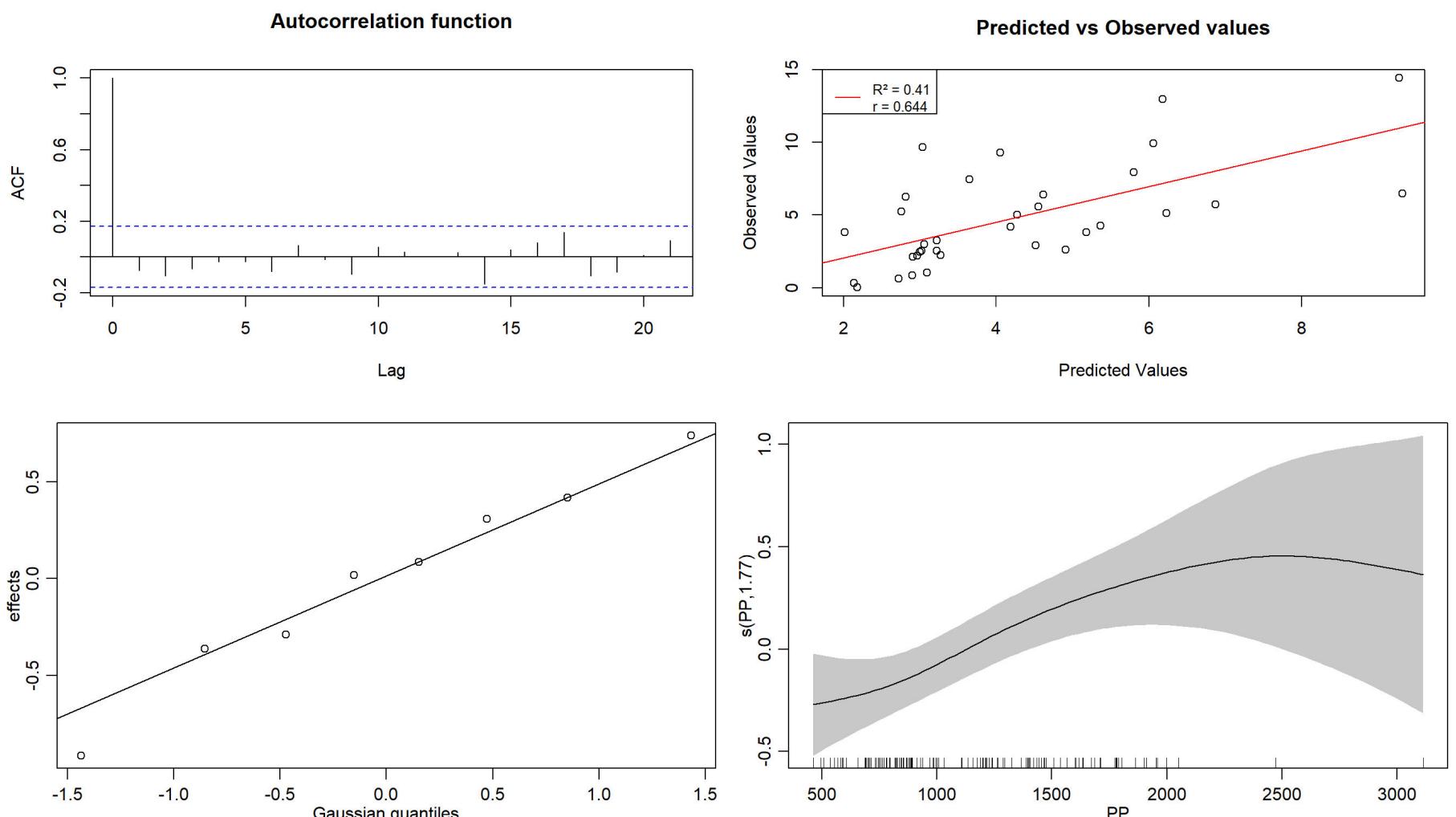
```
## ---- k check ----
```

```
##      k'    edf  k-index p-value
## s(grid) 8 5.885948      NA     NA
## s(PP)    9 1.771976 0.9722998 0.5175
```



```
## Average percentage deviation = 1.25 %
```

```
## AIC = 579.7686
```



### CPUE model as function of tensor product of variable and months

```
## Warning in smooth.construct.tensor.smooth.spec(object, dk$data, dk$knots):
## reparameterization unstable for margin: not done
```

```
## ---- Model summary ----
```

```

## 
## Family: Tweedie(p=1.592)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + te(PP, month, k = c(12, 12), bs = c("tp",
## "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.2068     0.2677   4.508 1.56e-05 ***
## ---
## Signif. codes:  0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##             edf Ref.df      F p-value
## s(grid)      6.344      7 10.467 < 2e-16 ***
## te(PP,month) 7.465     95  0.912 1.23e-05 ***
## ---
## Signif. codes:  0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.487  Deviance explained = 52.8%
## -REML = 281.95  Scale est. = 0.46725 n = 132

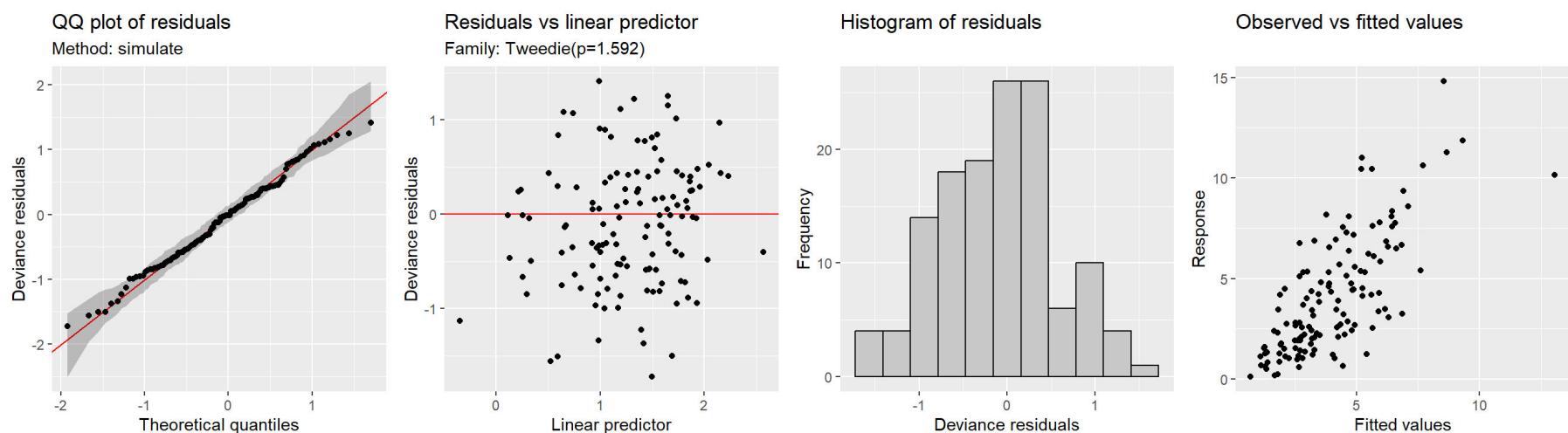
```

```
## ---- k check ----
```

```

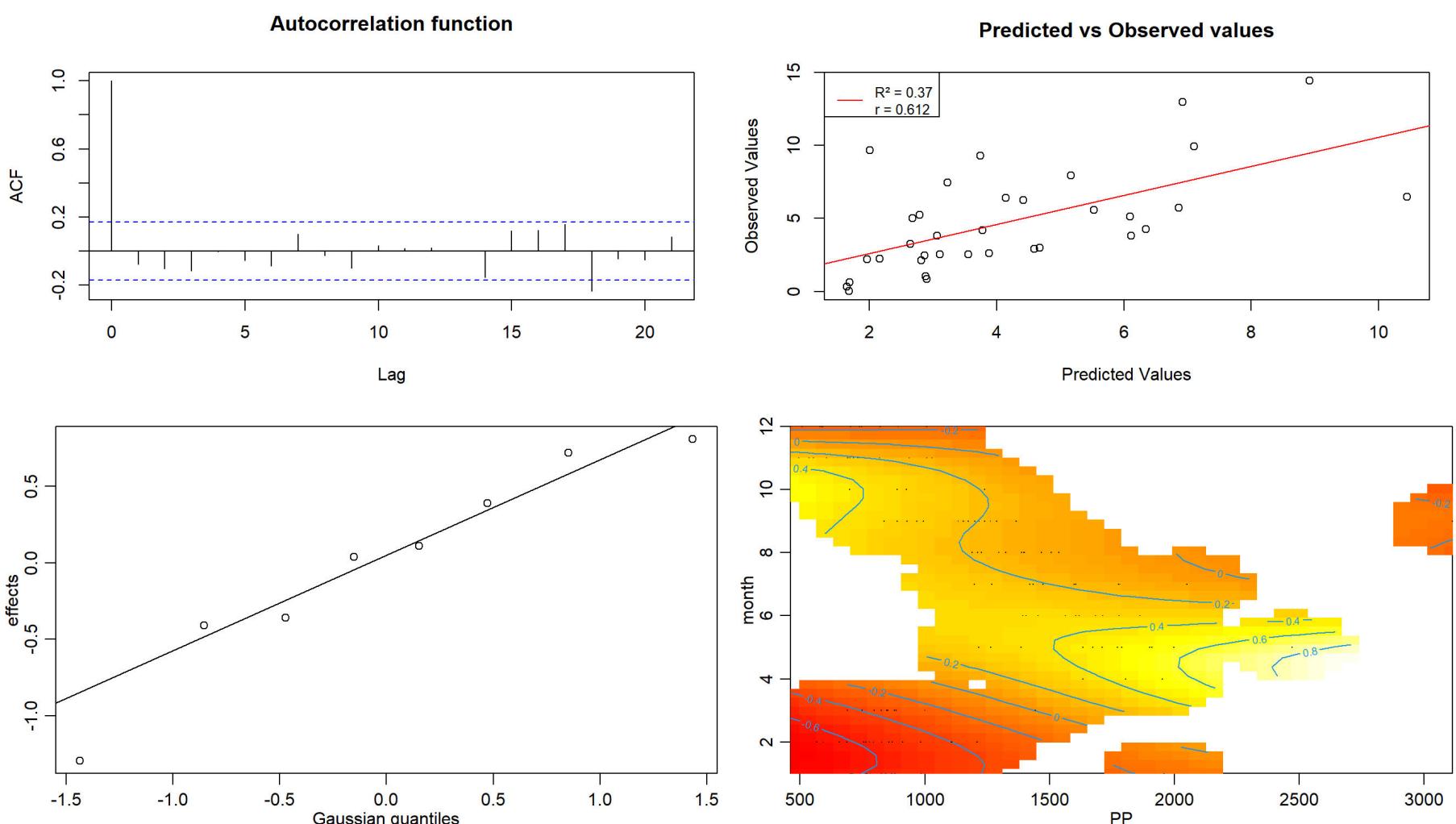
##          k'      edf k-index p-value
## s(grid)    8 6.344241      NA      NA
## te(PP,month) 131 7.464535 1.094855  0.9425

```



```
## Average percentage deviation = 1.44 %
```

```
## AIC = 548.6247
```



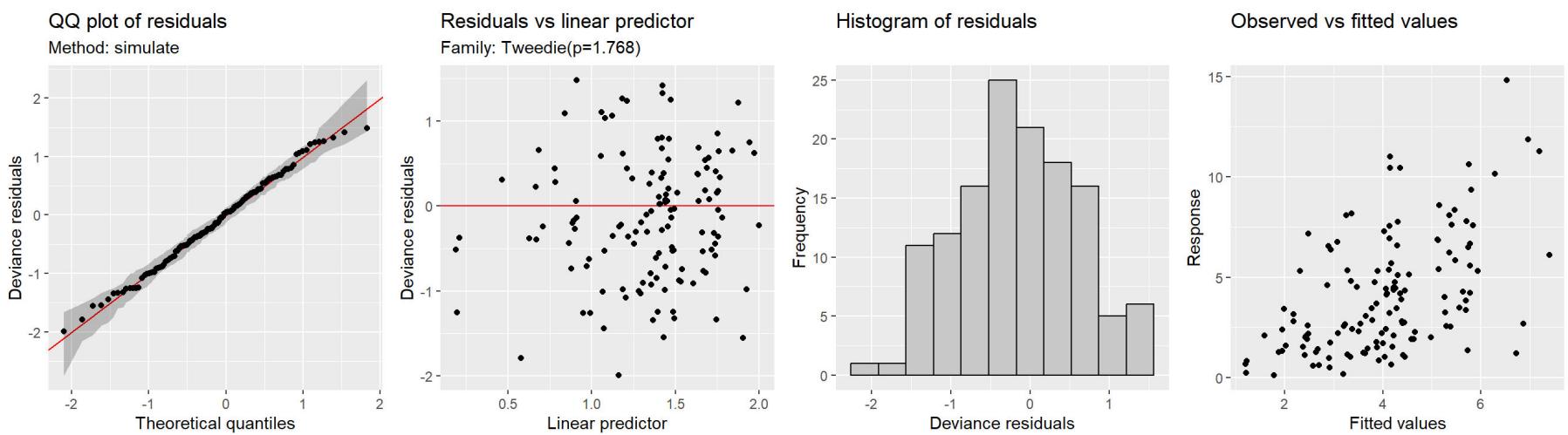
# River flow

## CPUE model as function of isolated factors

```
## ---- Model summary ----  
  
##  
## Family: Tweedie(p=1.768)  
## Link function: log  
##  
## Formula:  
## CPUE ~ s(grid, bs = "re") + s(flow, k = 12, bs = "tp")  
##  
## Parametric coefficients:  
##             Estimate Std. Error t value Pr(>|t|)  
## (Intercept) 1.3599     0.1245   10.93   <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(grid) 4.2178      7 1.41  0.0348 *  
## s(flow) 0.9424     11 6.17 5.23e-05 ***  
## ---  
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1  
##  
## R-sq.(adj) =  0.234  Deviance explained = 26.3%  
## -REML = 294.89  Scale est. = 0.54923 n = 132
```

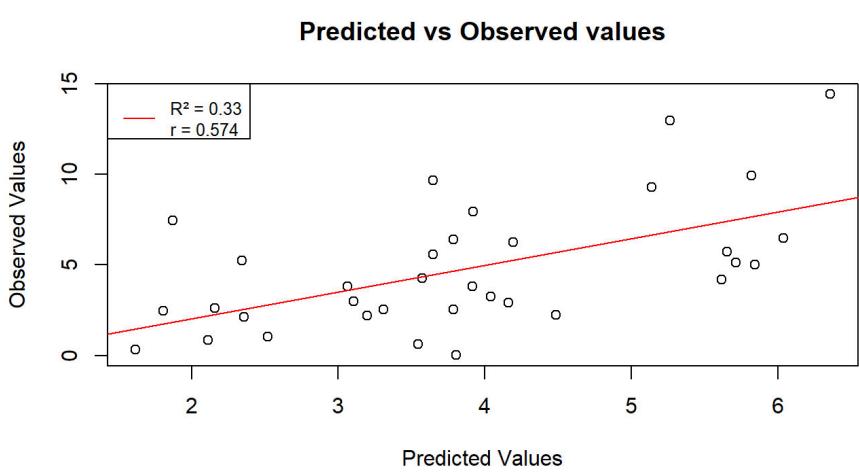
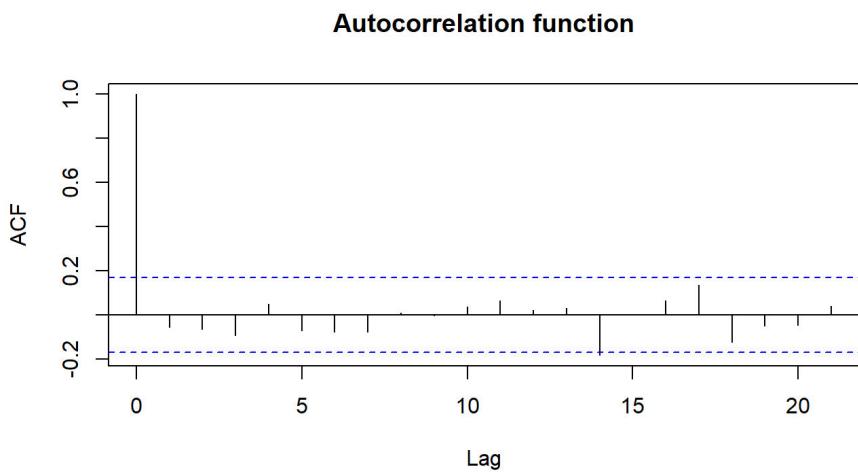
```
## ---- k check ----
```

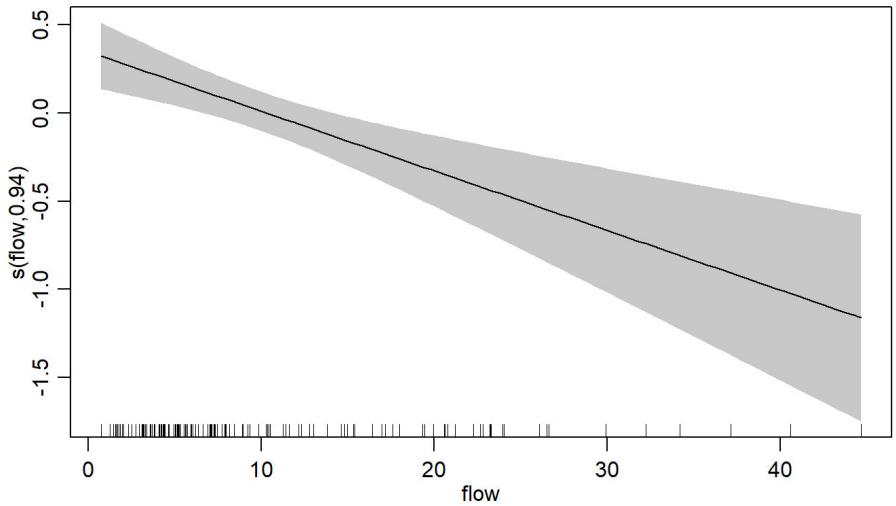
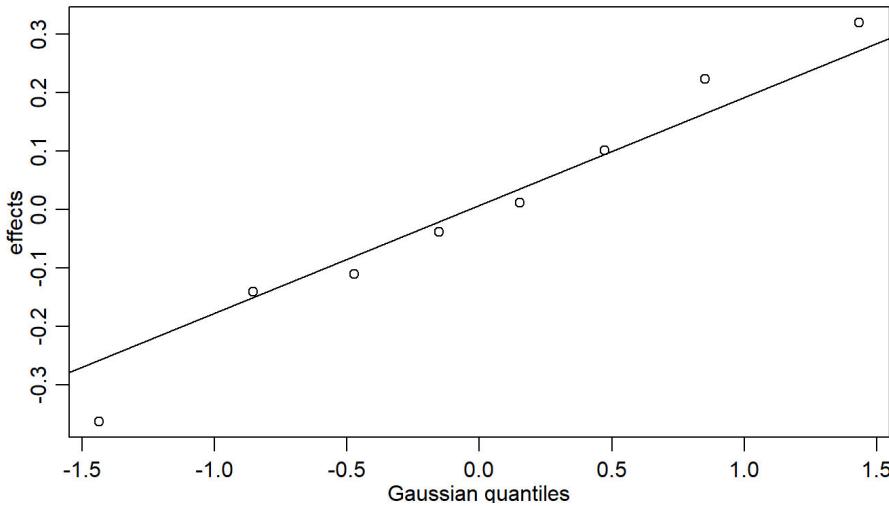
```
##          k'      edf  k-index p-value  
## s(grid) 8 4.2178048      NA      NA  
## s(flow) 11 0.9424185 0.9437942  0.4075
```



```
## Average percentage deviation = 1.03 %
```

```
## AIC = 588.4797
```





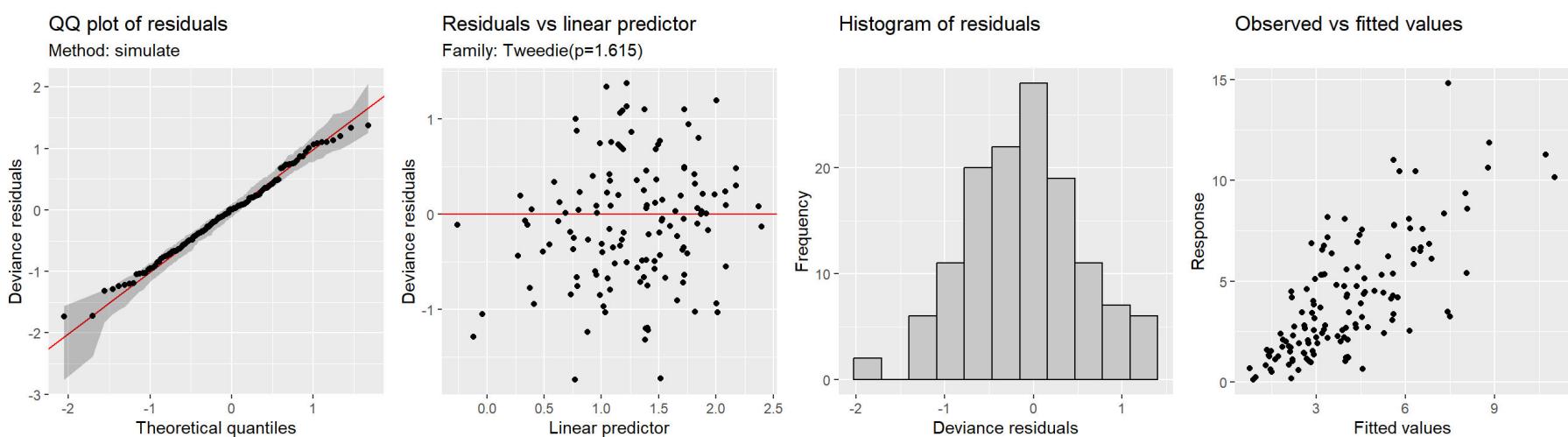
### CPUE model as function of tensor product of variables and months

```
## ---- Model summary ----
```

```
##
## Family: Tweedie(p=1.615)
## Link function: log
##
## Formula:
## CPUE ~ s(grid, bs = "re") + te(flow, month, k = c(12, 12), bs = c("tp",
##     "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.2766    0.2023   6.311  5.1e-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(grid)      5.794      7 4.388 7.21e-05 ***
## te(flow,month) 7.918     49 185.291     0.94
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) = 0.484 Deviance explained = 52.7%
## -REML = 281.52 Scale est. = 0.45578 n = 132
```

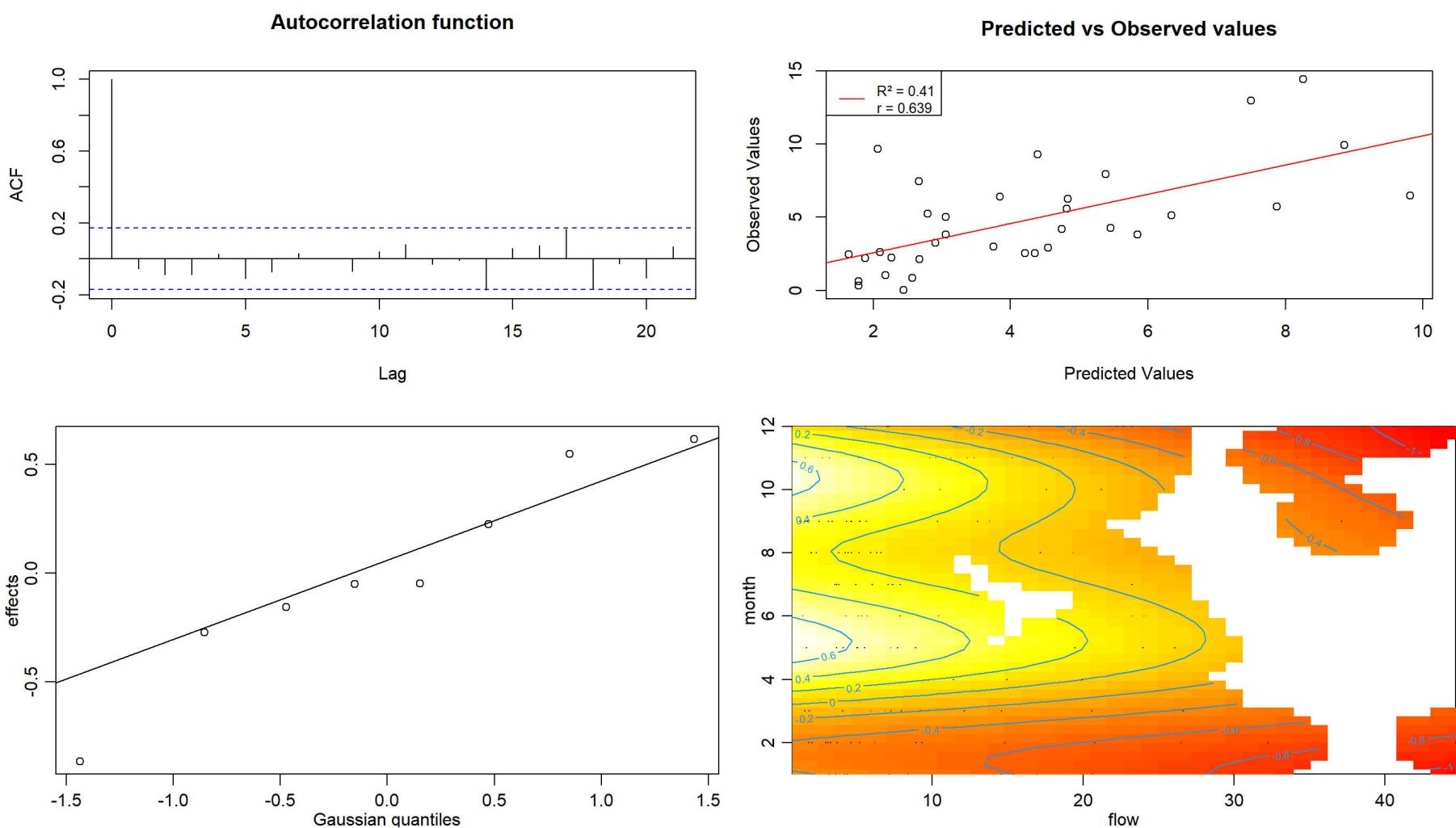
```
## ---- k check ----
```

```
##          k'      edf k-index p-value
## s(grid) 8 5.79386     NA     NA
## te(flow,month) 131 7.91793 1.07151  0.9125
```



```
## Average percentage deviation = 1.34 %
```

```
## AIC = 547.9133
```



## CPUE models as function additive factors

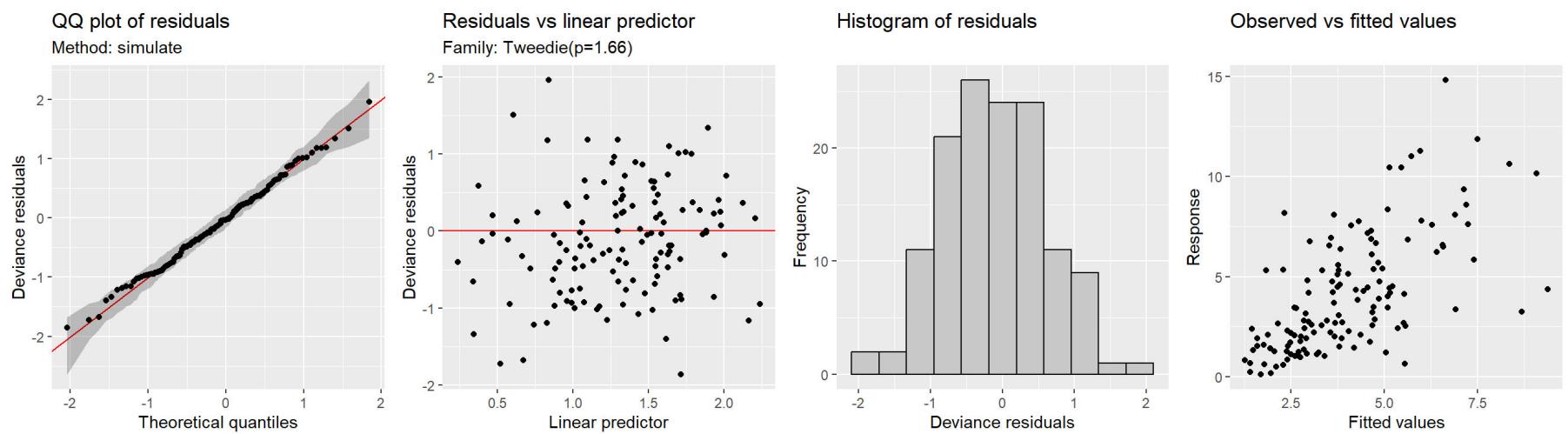
### Single index model

```
## ---- Model summary ----

## 
## Family: Tweedie(p=1.66)
## Link function: log
## 
## Formula:
## CPUE ~ s(month_count, k = 10, bs = "cr", m = 2) + s(temp, k = 10,
##     bs = "tp") + s(PP, k = 50, bs = "cr") + s(flow, k = 10, bs = "cr") +
##     s(grid, bs = "re")
## 
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.33418   0.07193 18.55   <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(month_count) 0.8759      9 2.326 0.000706 ***
## s(temp)        2.3281      9 1.840 0.000273 ***
## s(PP)          0.8750     23 0.427 0.001053 **
## s(flow)        0.8088      9 0.766 0.006089 **
## s(grid)        1.9388      7 0.617 0.054280 .
## --- 
## Signif. codes:  0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## R-sq.(adj) =  0.37  Deviance explained = 40.7%
## -REML = 205.96  Scale est. = 0.52153  n = 132
```

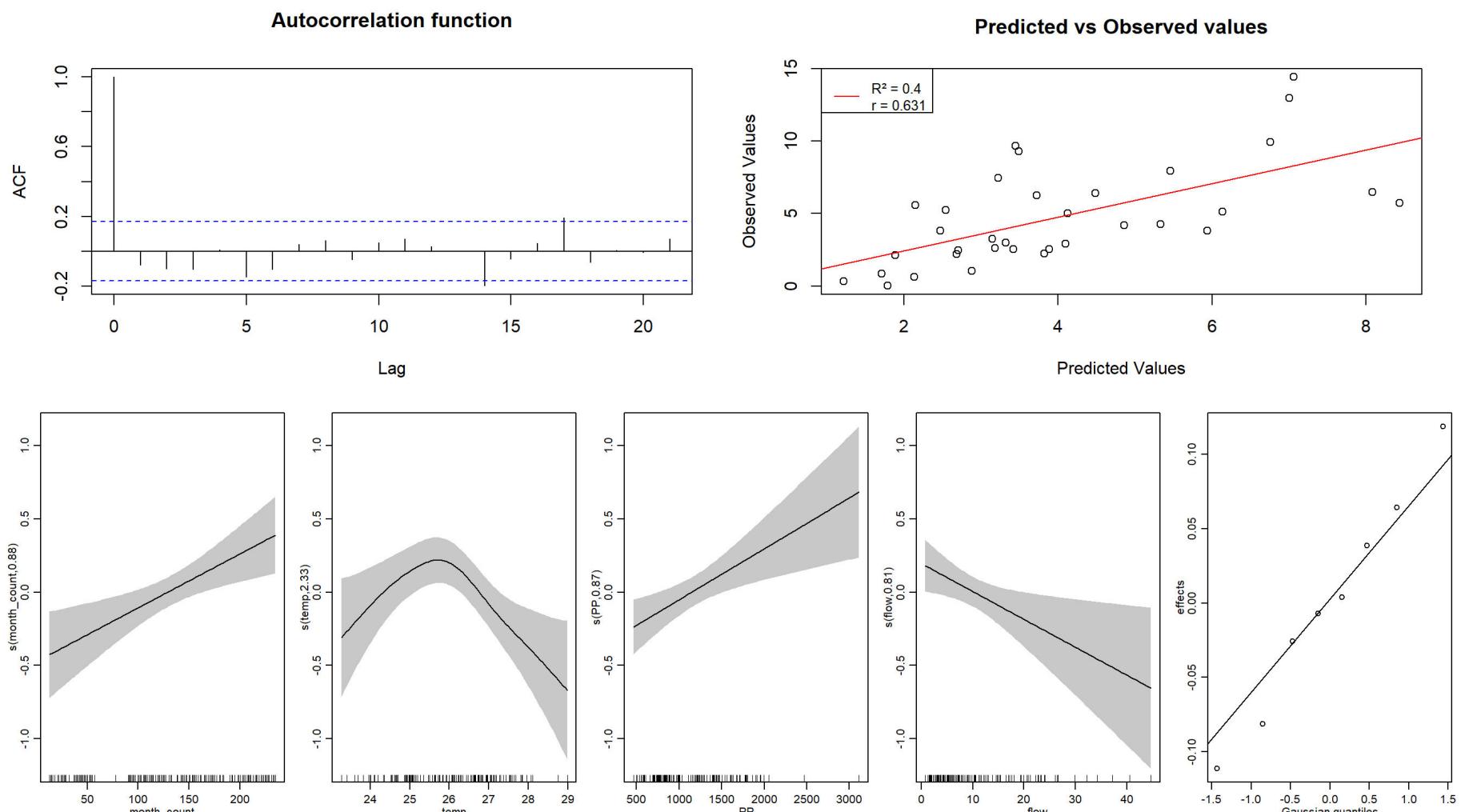
```
## ---- k check ----
```

	k'	edf	k-index	p-value
s(month_count)	9	0.8759268	0.9101811	0.2075
s(temp)	9	2.3280553	0.9378648	0.3450
s(PP)	49	0.8749673	0.9989330	0.5975
s(flow)	9	0.8087642	0.8611058	0.0775
s(grid)	8	1.9387610	NA	NA



```
## Average percentage deviation = 1.3 %
```

```
## AIC = 563.6923
```



## Seasonal Interaction Model

```
## ---- Model summary ----
```

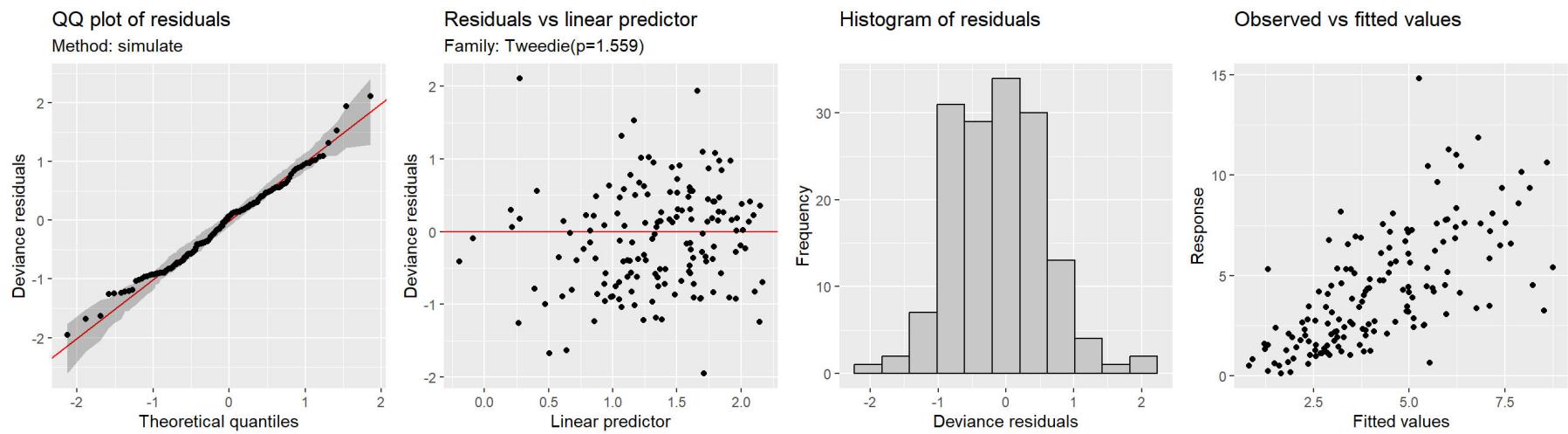
```
##
## Family: Tweedie(p=1.559)
## Link function: log
##
## Formula:
## CPUE ~ s(month_count, k = 10, bs = "cr", m = 2) + te(temp, month,
##           k = c(10, 12), bs = c("cr", "cc")) + te(PP, month, k = c(10,
##           12), bs = c("cr", "cc")) + te(flow, month, k = c(10, 12),
##           bs = c("cr", "cc"))
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.33543   0.04294   31.1   <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(month_count) 0.9208      9 2.036 2.36e-05 ***
## te(temp,month) 3.5969     65 0.329 0.000128 ***
## te(PP,month)   2.4751     56 0.159 0.001663 **
## te(flow,month) 0.8493     97 0.112 0.002041 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.422  Deviance explained = 46.9%
## -ML = 233.97  Scale est. = 0.50124  n = 154
```

```
## ---- k check ----
```

```

##          k'      edf  k-index p-value
## s(month_count) 9 0.9207566 0.7778484 0.0075
## te(temp,month) 109 3.5969393 1.1272420 0.9850
## te(PP,month)   109 2.4750904 1.0580484 0.9050
## te(flow,month) 109 0.8493326 0.9471978 0.2775

```



```

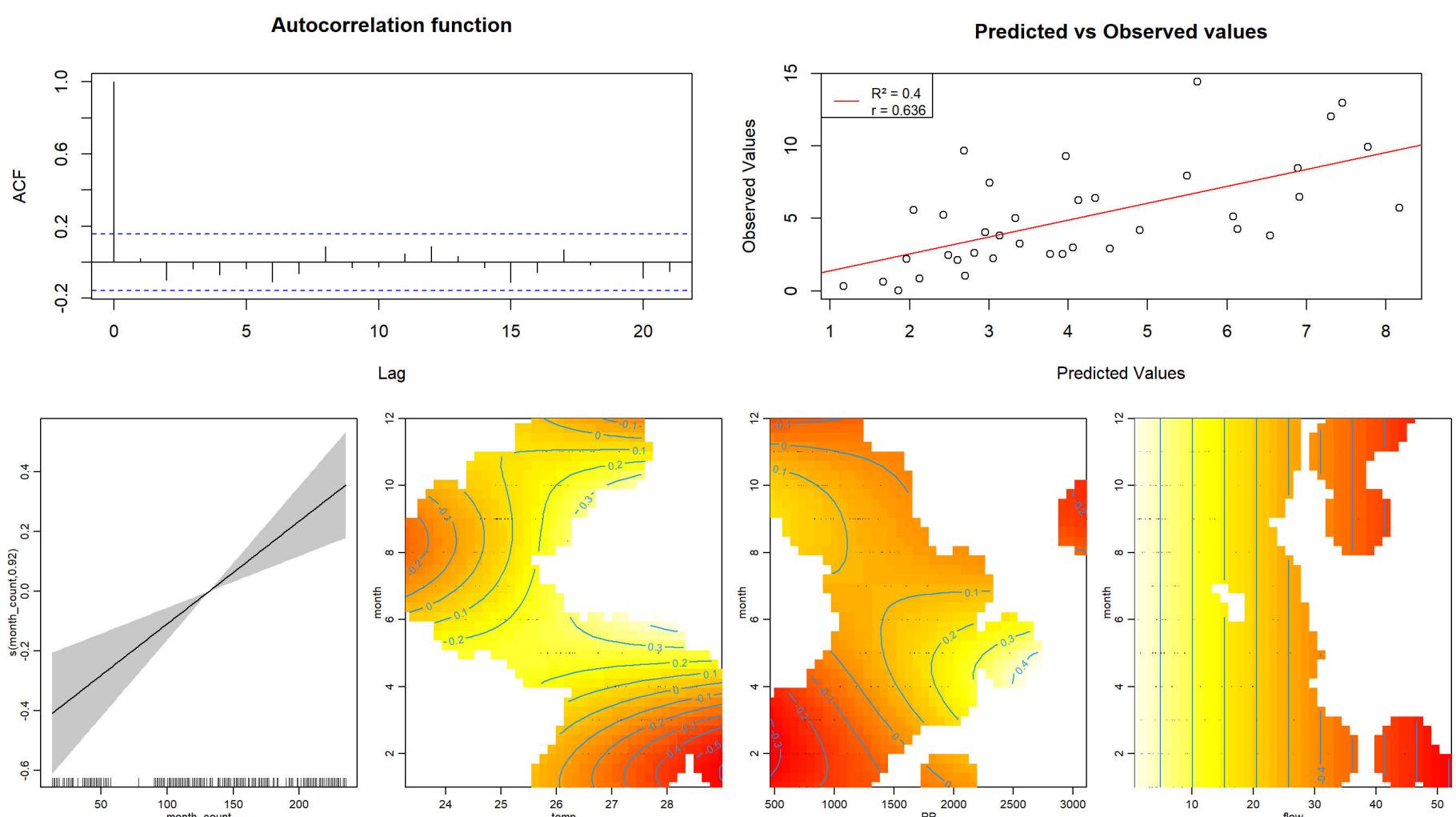
## Average percentage deviation = 0.92 %

```

```

## AIC = 645.9732

```

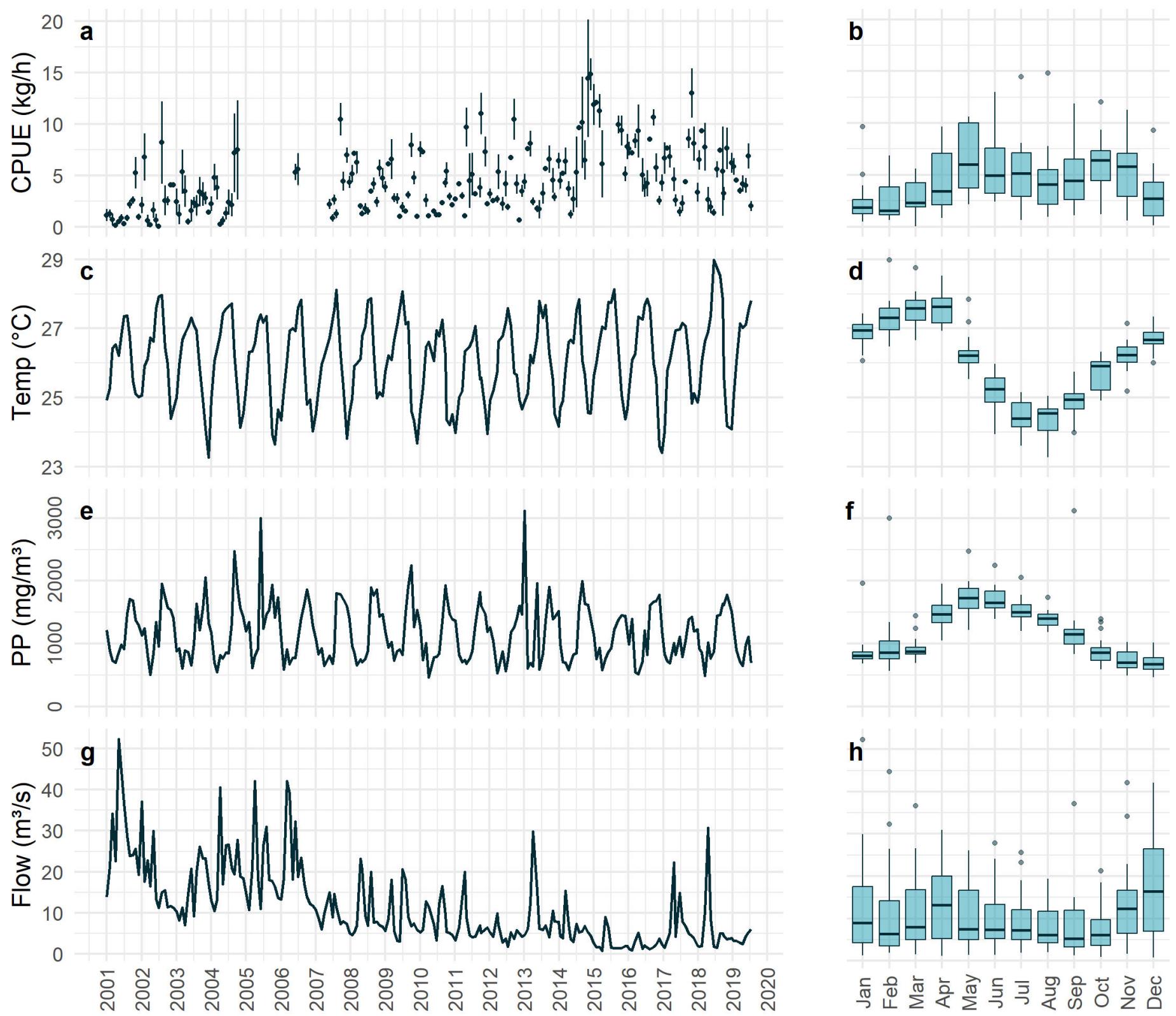


## Figures e Tables

**Table 1:** Statistical Results of the Generalized Additive Models (GAMs) Fitted to CPUE and Environmental Variables. The models are organized into three analytical blocks: (i) Univariate Temporal Models of the environmental variables (PP, Temperature, and Flow); (ii) Bivariate CPUE Models exploring the effects of each covariate in contemporaneous, seasonal, and distributed lag formats; and (iii) Multivariate Models, including a Single Index Model and a Distributed Lag Model for overall CPUE prediction.

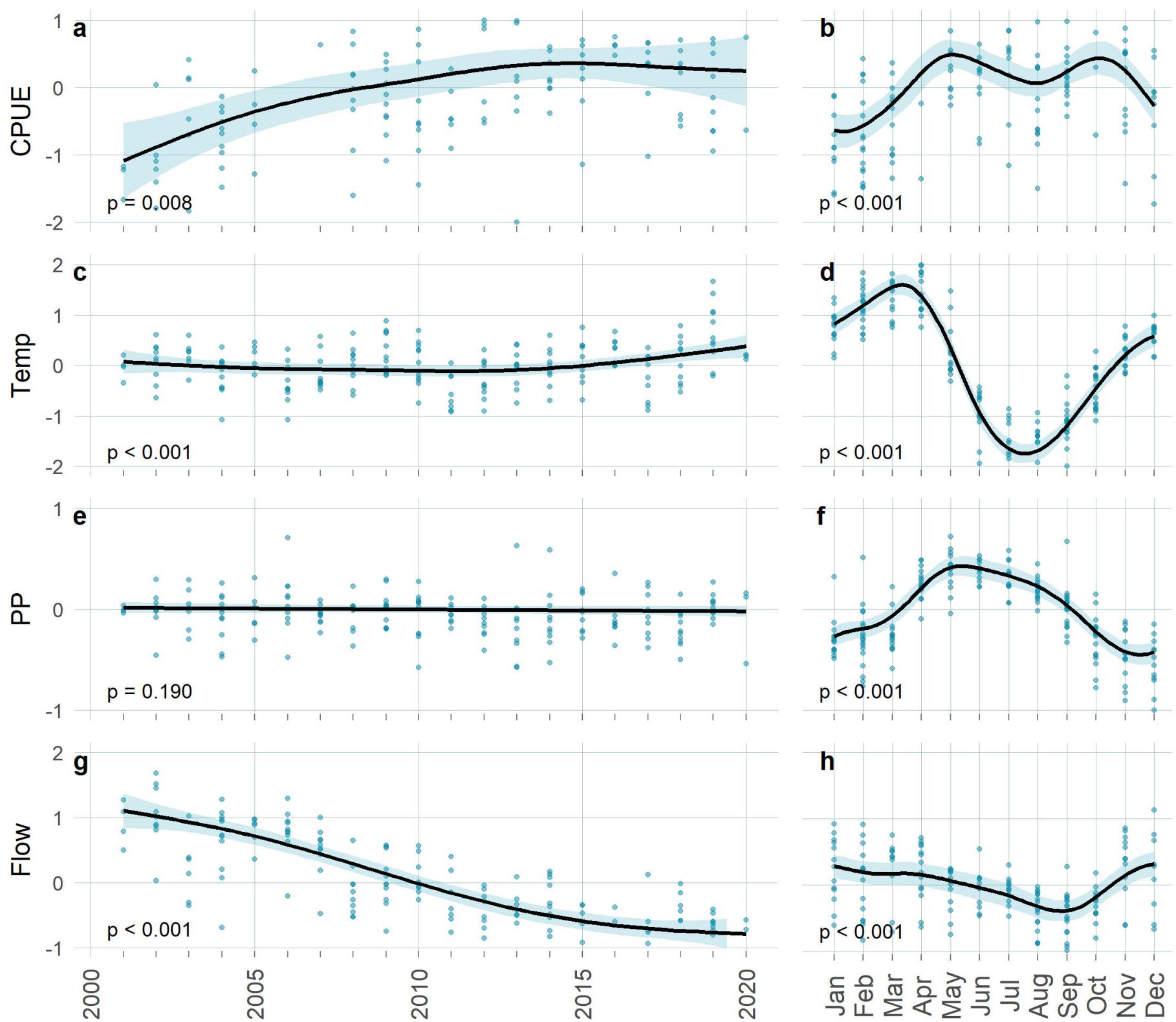
Model	Term	Family	Intercept	AIC	Deviance explained	R <sup>2</sup> adjusted	R <sup>2</sup> of prediction	Ref. edf	df	F	p-value
CPUE ~ Time	s(grid)	tw	1.36	534	55.1	0.522	0.399	4.11	7	2.17	0.001
CPUE ~ Time	s(month)							5.44	10	7.06	0.000
CPUE ~ Time	s(year)							2.60	7	54.97	0.008
CPUE ~ Time	ti(year,month)							1.51	90	0.02	0.356
Temp ~ Time	s(month)	gaussian(link = identity)	26.07	244	87.4	0.863	0.887	7.01	10	107.11	0.000
Temp ~ Time	s(year)							2.58	5	3.07	0.000
Temp ~ Time	ti(year,month)							4.23	50	0.14	0.087
PP ~ Time	s(month)	tw	7.02	2502	61.7	0.544	0.831	5.78	10	25.74	0.000
PP ~ Time	s(year)							0.41	9	0.08	0.190

Model	Term	Family	Intercept	AIC	Deviance explained	R <sup>2</sup> adjusted	R <sup>2</sup> of prediction	Ref. edf	Ref. df	F	p-value
PP ~ Time	ti(year,month)							3.92	90	0.06	0.109
Flow ~ Time	s(month)	tw	2.17	1017	64.6	0.563	0.419	4.36	10	4.27	0.000
Flow ~ Time	s(year)							2.98	5	53.79	0.000
Flow ~ Time	ti(year,month)							3.51	50	0.11	0.127
CPUE ~ Temp	s(grid)	tw	1.23	562	41.9	0.415	0.390	5.95	7	7.88	0.000
CPUE ~ Temp	s(temp)							3.90	7	8.10	0.000
CPUE ~ Temp x Month	s(grid)	tw	1.20	538	52.5	0.490	0.387	6.33	7	10.66	0.000
CPUE ~ Temp x Month	te(temp,month)							6.07	93	0.96	0.000
CPUE ~ PP	s(grid)	tw	1.24	576	33.0	0.302	0.415	5.89	7	6.63	0.000
CPUE ~ PP	s(PP)							1.77	9	2.20	0.000
CPUE ~ PP x Month	s(grid)	tw	1.21	541	52.8	0.487	0.375	6.34	7	10.47	0.000
CPUE ~ PP x Month	te(PP,month)							7.46	95	0.91	0.000
CPUE ~ Flow	s(grid)	tw	1.36	584	26.3	0.234	0.329	4.22	7	1.41	0.035
CPUE ~ Flow	s(flow)							0.94	11	6.17	0.000
CPUE ~ Flow x Month	s(grid)	tw	1.28	540	52.7	0.484	0.408	5.79	7	4.39	0.000
CPUE ~ Flow x Month	te(flow,month)							7.92	49	185.29	0.940
Single Index Model	s(month_count)	tw	1.33	558	40.7	0.370	0.398	0.88	9	2.33	0.001
Single Index Model	s(temp)							2.33	9	1.84	0.000
Single Index Model	s(PP)							0.87	23	0.43	0.001
Single Index Model	s(flow)							0.81	9	0.77	0.006
Single Index Model	s(grid)							1.94	7	0.62	0.054
Seasonal Interaction Model	s(month_count)	tw	1.34	639	46.9	0.422	0.404	0.92	9	2.04	0.000
Seasonal Interaction Model	te(temp,month)							3.60	65	0.33	0.000
Seasonal Interaction Model	te(PP,month)							2.48	56	0.16	0.002
Seasonal Interaction Model	te(flow,month)							0.85	97	0.11	0.002

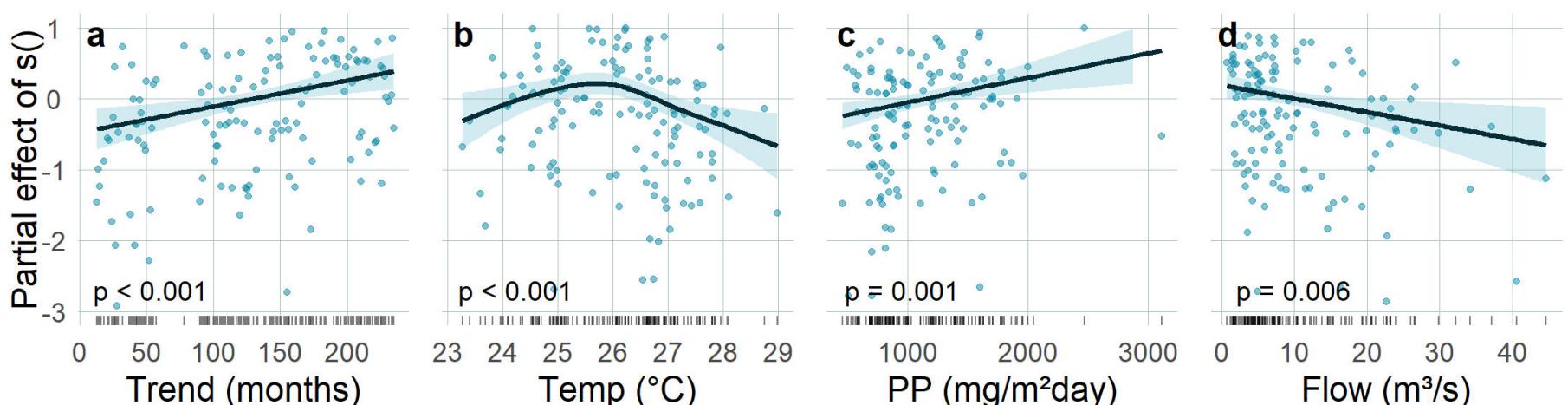


**Fig. 2.** Time series and monthly distribution of environmental variables and CPUE. The left column (a, c, e, g) displays the time series of monthly averages for CPUE (a), PP (c), Temp (e), and Flow (g) from Sep/01 to Mar/20. The right column (b, d, f, h) presents boxplots of these monthly averages, where the central line indicates the median, the box edges mark the 1st and 3rd quartiles, the whiskers extend to 1.5 times the interquartile range, and the individual points are outliers.

```
## Scale for y is already present.
## Adding another scale for y, which will replace the existing scale.
```



**Fig. 3.** Partial effects of smooth functions for temporal Generalized Additive Models (GAMs). The figure displays partial effects for models of CPUE (rows a–c), Sea Bottom Temperature (Temp) (rows d–f), Particulate Primary Production (PP) (rows g–i), and Flow (rows j–l). The left column (a, d, g, j) shows the partial effect of the monthly smooth function; the middle column (b, e, h, k) shows the partial effect of the long-term (Year) smooth function; and the right column (c, f, i, l) displays the tensor product interaction (heatmap) between Month and Year. In the heatmaps, orange to reddish colors indicate a negative partial effect, and yellow to white colors indicate a positive partial effect. P-values for each smooth term in their respective temporal models are displayed in the upper right corner of each plot.

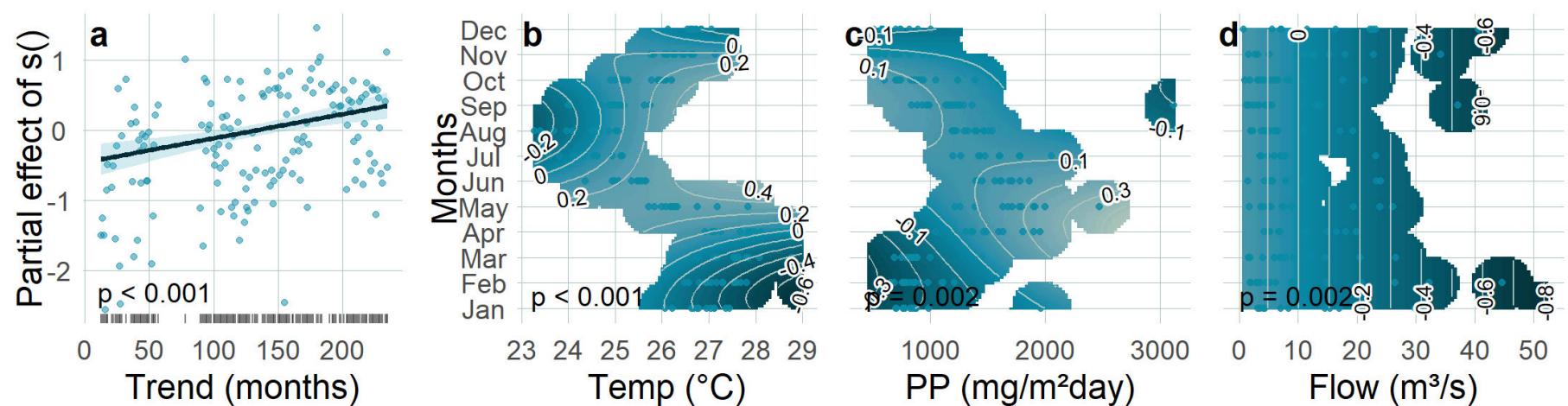


**Fig. 4.** Partial effects of smooth functions for CPUE Additive Multivariate Model (a, b, c, d) as a function of long term trend (Trend - a), sea bottom temperature (Temp - b), primary productivity (PP - c) and river flow (Flow - d). P-values for each smooth term are displayed in the bottom left corner of each plot.

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**Fig. 5.** Partial effects of smooth functions for CPUE Seasonal Interaction Multivariate Model (a, b, c, d) as a function of long term trend (Trend - a), sea bottom temperature (Temp - b), primary productivity (PP - c) and river flow (Flow - d). The partial effects of smooths of Seasonal Model displays the full tensor product interaction (color gradient and values) between Month and factor. In the heatmaps, darker colors indicate a negative partial effect, and lighter colors indicate a positive partial effect. P-values for each smooth term are displayed in the upper right corner of each plot.