

*#Reproducible R-script for : 'Tracking the killer shrimp: *Dikerogammarus villosus* invasion dynamics ac*

```
suppressMessages({
  library(dplyr, quiet = TRUE, warn.conflicts = FALSE)
  library(reshape, quiet = TRUE, warn.conflicts = FALSE)
  library(metafor, quiet = TRUE, warn.conflicts = FALSE)
  library(ggplot2)
  library(tidyr)
  library(stringr)
  library(readxl)
  library(vegan)
  library(sjPlot)
  library(RCurl)
  library(MuMIn); eval(metafor:::MuMIn)
}) #load libraries
```

```
df <- read_excel("D.villosus6.xlsx")
head(df)
```

```
## # A tibble: 6 x 49
##   site_id year link      Diker~1 Propo~2 S_Dv Var_Dv Abund~3 S_Abun Var_A~4
##   <dbl> <dbl> <chr>      <dbl>   <dbl> <dbl>  <dbl>   <dbl>   <dbl>
## 1 100000001 2006 100000001~    12 7.32e-4    20    92   16389   -14    92
## 2 100000001 2007 100000001~    31 2.83e-3    20    92   10923   -14    92
## 3 100000001 2008 100000001~    33 4.99e-3    20    92    6574   -14    92
## 4 100000001 2009 100000001~    87 2.04e-2    20    92    4180   -14    92
## 5 100000001 2010 100000001~    73 1.16e-2    20    92    6223   -14    92
## 6 100000001 2011 100000001~     0 0          20    92    6056   -14    92
## # ... with 39 more variables: Richness <dbl>, S_Rich <dbl>, Var_Rich <dbl>,
## # Diversity <dbl>, S_Diver <dbl>, Var_Diver <dbl>, Eveness <dbl>,
## # S_Eve <dbl>, Var_Eve <dbl>, Turnover <dbl>, S_Turn <dbl>, Var_Turn <dbl>,
## # 'ID_Time Series' <dbl>, 'Years in time serie' <dbl>, 'Years Total' <dbl>,
## # Country <chr>, Biogeo <chr>, Koopen <chr>, E <dbl>, N <dbl>,
## # Elevation <dbl>, Precipitation <dbl>, Slope_preci <dbl>, Temperature <dbl>,
## # Slope_temp <dbl>, Mean_precipita <dbl>, Mean_temp <dbl>, ...
```

```
str(df)
```

```
## tibble [744 x 49] (S3: tbl_df/tbl/data.frame)
## $ site_id      : num [1:744] 1e+08 1e+08 1e+08 1e+08 1e+08 ...
## $ year        : num [1:744] 2006 2007 2008 2009 2010 ...
## $ link        : chr [1:744] "100000001_2006" "100000001_2007" "100000001_2008" "100000001_2009" ...
## $ Dikerogammarus villosus: num [1:744] 12 31 33 87 73 0 56 90 483 4 ...
## $ Proportion   : num [1:744] 0.000732 0.00283 0.004995 0.020389 0.011595 ...
## $ S_Dv        : num [1:744] 20 20 20 20 20 20 20 20 20 9 ...
## $ Var_Dv      : num [1:744] 92 92 92 92 92 92 92 92 92 125 ...
## $ Abundance    : num [1:744] 16389 10923 6574 4180 6223 ...
## $ S_Abun      : num [1:744] -14 -14 -14 -14 -14 -14 -14 -14 -14 9 ...
## $ Var_Abun    : num [1:744] 92 92 92 92 92 92 92 92 92 125 ...
## $ Richness     : num [1:744] 35 44 35 37 51 45 57 42 37 21 ...
## $ S_Rich      : num [1:744] 10 10 10 10 10 10 10 10 10 23 ...
## $ Var_Rich    : num [1:744] 90 90 90 90 90 90 90 90 90 125 ...
```

```

## $ Diversity : num [1:744] 0.284 0.656 1.933 1.991 2.124 ...
## $ S_Diver : num [1:744] 14 14 14 14 14 14 14 14 14 23 ...
## $ Var_Diver : num [1:744] 92 92 92 92 92 92 92 92 92 125 ...
## $ Eveness : num [1:744] 0.0799 0.1734 0.5438 0.5513 0.5403 ...
## $ S_Eve : num [1:744] 12 12 12 12 12 12 12 12 12 19 ...
## $ Var_Eve : num [1:744] 92 92 92 92 92 92 92 92 92 125 ...
## $ Turnover : num [1:744] NA 0.519 0.429 0.372 0.436 ...
## $ S_Turn : num [1:744] -12 -12 -12 -12 -12 -12 -12 -12 -12 0 ...
## $ Var_Turn : num [1:744] 65.3 65.3 65.3 65.3 65.3 ...
## $ ID_Time Series : num [1:744] 1 1 1 1 1 1 1 1 1 2 ...
## $ Years in time serie : num [1:744] 9 9 9 9 9 9 9 9 9 10 ...
## $ Years Total : num [1:744] 9 9 9 9 9 9 9 9 9 10 ...
## $ Country : chr [1:744] "France" "France" "France" "France" ...
## $ Biogeo : chr [1:744] "Alpino" "Alpino" "Alpino" "Alpino" ...
## $ Koopen : chr [1:744] "Cfb" "Cfb" "Cfb" "Cfb" ...
## $ E : num [1:744] 5.29 5.29 5.29 5.29 5.29 5.29 5.29 5.29 5.29 5.29 ...
## $ N : num [1:744] 45.8 45.8 45.8 45.8 45.8 ...
## $ Elevation : num [1:744] 195 195 195 195 195 195 195 195 195 195 ...
## $ Precipitation : num [1:744] 2.26 3.08 2.08 3.47 2.62 ...
## $ Slope_preci : num [1:744] 6 6 6 6 6 6 6 6 6 7 ...
## $ Temperature : num [1:744] 10.08 9.71 10.99 10.64 11.45 ...
## $ Slope_temp : num [1:744] 12 12 12 12 12 12 12 12 12 0 ...
## $ Mean_precipita : num [1:744] 2.76 2.76 2.76 2.76 2.76 2.76 2.76 2.76 2.76 2.73 ...
## $ Mean_temp : num [1:744] 10.7 10.7 10.7 10.7 10.7 ...
## $ DistanceKm : num [1:744] 366 366 366 366 366 ...
## $ slope : num [1:744] 0.00432 0.00432 0.00432 0.00432 0.00432 ...
## $ Tmin : num [1:744] 7.29 7.08 6.83 7.08 6.22 ...
## $ Avg_Tmin : num [1:744] 7.1 7.1 7.1 7.1 7.1 ...
## $ Slope_Tmin : num [1:744] 0 0 0 0 0 0 0 0 0 7 ...
## $ Tmax : num [1:744] 17.1 16.9 46.4 17.2 15.8 ...
## $ Avg_Tmax : num [1:744] 20.2 20.2 20.2 20.2 20.2 ...
## $ Slope_Tmax : num [1:744] -2 -2 -2 -2 -2 -2 -2 -2 -2 7 ...
## $ Start_year : num [1:744] 2006 2006 2006 2006 2006 ...
## $ Middle_point : num [1:744] 2010 2010 2010 2010 2010 ...
## $ River : chr [1:744] "Rhône" "Rhône" "Rhône" "Rhône" ...
## $ Ecosystem : chr [1:744] "large" "large" "large" "large" ...

```

```

df$Country<- as.factor(df$Country)
df$Biogeo <- as.factor(df$Biogeo)
df$Koopen <- as.factor(df$Koopen)
df$Ecosystem <- as.factor(df$Ecosystem)
glimpse(df)

```

```

## Rows: 744
## Columns: 49
## $ site_id <dbl> 1000000001, 1000000001, 1000000001, 1000000001, ~
## $ year <dbl> 2006, 2007, 2008, 2009, 2010, 2011, 2012, 20~
## $ link <chr> "1000000001_2006", "1000000001_2007", "1000000~
## $ 'Dikerogammarus villosus' <dbl> 12, 31, 33, 87, 73, 0, 56, 90, 483, 4, 434, ~
## $ Proportion <dbl> 0.0007316627, 0.0028300164, 0.0049947026, 0.~
## $ S_Dv <dbl> 20, 20, 20, 20, 20, 20, 20, 20, 20, 9, 9, 9,~
## $ Var_Dv <dbl> 92.00, 92.00, 92.00, 92.00, 92.00, 92.00, 92~
## $ Abundance <dbl> 16389, 10923, 6574, 4180, 6223, 6056, 7402, ~
## $ S_Abun <dbl> -14, -14, -14, -14, -14, -14, -14, -14, -14,~

```

```
## $ Var_Abun <dbl> 92.0000, 92.0000, 92.0000, 92.0000, 92.0000,~
## $ Richness <dbl> 35, 44, 35, 37, 51, 45, 57, 42, 37, 21, 22, ~
## $ S_Rich <dbl> 10, 10, 10, 10, 10, 10, 10, 10, 10, 23, 23, ~
## $ Var_Rich <dbl> 90.00, 90.00, 90.00, 90.00, 90.00, 90.00, 90.00, 90~
## $ Diversity <dbl> 0.2842428, 0.6562465, 1.9334419, 1.9908388, ~
## $ S_Diver <dbl> 14, 14, 14, 14, 14, 14, 14, 14, 14, 23, 23, ~
## $ Var_Diver <dbl> 92.0000, 92.0000, 92.0000, 92.0000, 92.0000,~
## $ Eveness <dbl> 0.07994796, 0.17341797, 0.54381226, 0.551338~
## $ S_Eve <dbl> 12, 12, 12, 12, 12, 12, 12, 12, 12, 19, 19, ~
## $ Var_Eve <dbl> 92.0000, 92.0000, 92.0000, 92.0000, 92.0000,~
## $ Turnover <dbl> NA, 0.5192308, 0.4285714, 0.3720930, 0.43636~
## $ S_Turn <dbl> -12, -12, -12, -12, -12, -12, -12, -12, -12, -12,~
## $ Var_Turn <dbl> 65.33333, 65.33333, 65.33333, 65.33333, 65.3~
## $ 'ID_Time Series' <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 2, 2,~
## $ 'Years in time serie' <dbl> 9, 9, 9, 9, 9, 9, 9, 9, 9, 10, 10, 10, 10, 1~
## $ 'Years Total' <dbl> 9, 9, 9, 9, 9, 9, 9, 9, 9, 10, 10, 10, 10, 1~
## $ Country <fct> France, France, France, France, France, Fran~
## $ Biogeo <fct> Alpino, Alpino, Alpino, Alpino, Alpino, Alpi~
## $ Koopen <fct> Cfb, Cfb, Cfb, Cfb, Cfb, Cfb, Cfb, Cfb, Cfb,~
## $ E <dbl> 5.29, 5.29, 5.29, 5.29, 5.29, 5.29, 5.29, 5.~
## $ N <dbl> 45.82, 45.82, 45.82, 45.82, 45.82, 45.82, 45.82, 45~
## $ Elevation <dbl> 195, 195, 195, 195, 195, 195, 195, 195, 195,~
## $ Precipitation <dbl> 2.255906, 3.082219, 2.076989, 3.473626, 2.62~
## $ Slope_preci <dbl> 6, 6, 6, 6, 6, 6, 6, 6, 6, 7, 7, 7, 7, 7, 7,~
## $ Temperature <dbl> 10.08, 9.71, 10.99, 10.64, 11.45, 11.23, 10.~
## $ Slope_temp <dbl> 12, 12, 12, 12, 12, 12, 12, 12, 12, 0, 0, 0,~
## $ Mean_precipita <dbl> 2.76, 2.76, 2.76, 2.76, 2.76, 2.76, 2.76, 2.~
## $ Mean_temp <dbl> 10.680, 10.680, 10.680, 10.680, 10.680, 10.6~
## $ DistanceKm <dbl> 366.42, 366.42, 366.42, 366.42, 366.42, 366.~
## $ slope <dbl> 0.004316876, 0.004316876, 0.004316876, 0.004~
## $ Tmin <dbl> 7.291667, 7.083333, 6.825000, 7.083333, 6.21~
## $ Avg_Tmin <dbl> 7.096296, 7.096296, 7.096296, 7.096296, 7.09~
## $ Slope_Tmin <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 7, 7, 7, 7, 7, 7,~
## $ Tmax <dbl> 17.08, 16.89, 46.42, 17.23, 15.84, 17.67, 16~
## $ Avg_Tmax <dbl> 20.20889, 20.20889, 20.20889, 20.20889, 20.2~
## $ Slope_Tmax <dbl> -2, -2, -2, -2, -2, -2, -2, -2, -2, 7, 7, 7,~
## $ Start_year <dbl> 2006, 2006, 2006, 2006, 2006, 2006, 2006, 20~
## $ Middle_point <dbl> 2010.0, 2010.0, 2010.0, 2010.0, 2010.0, 2010~
## $ River <chr> "Rhône", "Rhône", "Rhône", "Rhône", "Rhône",~
## $ Ecosystem <fct> large, large, large, large, large, large, la~
```

```
#Not run
```

```
# In case of **missing sampling years** in time series; we filled the missing years with NAs
#new.row <- head(Time_series1[NA,], 5) #Create new row
#new.row["year"] <- c(2007,2013,2014,2015,2016)
#new.row["year"] <- 2006
# assign the year without data
```

```
#We calculated a modified slope time series following Hamed & Rao 1998; Pilotto et al. 2020
```

```
My.mmkh=function(x, ci = 0.95)
{
  x = x
```

```

z = NULL
z0 = NULL
pval = NULL
pval0 = NULL
S = 0
Tau = NULL
essf = NULL
ci = ci
if (is.vector(x) == FALSE) {
  stop("Input data must be a vector")
}
if (any(is.finite(x) == FALSE)) {
  x <- x[-c(which(is.finite(x) == FALSE))]
  warning("The input vector contains non-finite numbers. An attempt was made to remove them")
}
n <- length(x)
V <- rep(NA, n * (n - 1)/2)
k = 0
for (i in 1:(n - 1)) {
  for (j in (i + 1):n) {
    k = k + 1
    V[k] = (x[j] - x[i])/(j - i)
  }
}
slp <- median(V, na.rm = TRUE)
t = 1:length(x)
xn <- (x[1:n]) - ((slp) * (t))
for (i in 1:(n - 1)) {
  for (j in (i + 1):n) {
    S = S + sign(x[j] - x[i])
  }
}
ro <- acf(rank(xn), lag.max = (n - 1), plot = FALSE)$acf[-1]
sig <- qnorm((1 + ci)/2)/sqrt(n)
rof <- rep(NA, length(ro))
for (i in 1:(length(ro))) {
  if (ro[i] > sig || ro[i] < -sig) {
    rof[i] <- ro[i]
  }
  else {
    rof[i] = 0
  }
}
cte <- 2/(n * (n - 1) * (n - 2))
ess = 0
for (i in 1:(n - 1)) {
  ess = ess + (n - i) * (n - i - 1) * (n - i - 2) * rof[i]
}
essf = 1 + ess * cte
var.S = n * (n - 1) * (2 * n + 5) * (1/18)
if (length(unique(x)) < n) {
  aux <- unique(x)
  for (i in 1:length(aux)) {

```

```

    tie <- length(which(x == aux[i]))
    if (tie > 1) {
      var.S = var.S - tie * (tie - 1) * (2 * tie +
                                         5) * (1/18)
    }
  }
}
VS = var.S * essf
if (S == 0) {
  z = 0
  z0 = 0
}
if (S > 0) {
  z = (S - 1)/sqrt(VS)
  z0 = (S - 1)/sqrt(var.S)
}
else {
  z = (S + 1)/sqrt(VS)
  z0 = (S + 1)/sqrt(var.S)
}
pval = 2 * pnorm(-abs(z))
pval0 = 2 * pnorm(-abs(z0))
Tau = S/(0.5 * n * (n - 1))
return(c("Corrected Zc" = z, "new P-value" = pval, "N/N*" = essf,
        "Original Z" = z0, "old P.value" = pval0, "Tau" = Tau,
        "Sen s slope" = slp, "old.variance" = var.S, "new.variance" = VS, "S statistic" = S, "n" = n))
}

MK <- as.data.frame(do.call(rbind, lapply(xy.list[1:96], function(x) unlist(My.mmh(x)))))
head(MK)

```

Meta-regression modelling

##Meta-regression

```

df1<- df[!duplicated(df$site_id), ] #Remove duplicated
df1<- df1 %>% mutate(const=1) #Create a new column with "1"

```

In the next code E and N refers to coordinates of time series

#Dikerogammarus villosus trend

```

res <- rma.mv(S_Dv, Var_Dv, random = ~ E+N | const, struct="SPGAU", data= df1)
res

```

##

Multivariate Meta-Analysis Model (k = 96; method: REML)

##

Variance Components:

##

outer factor: const (nlvls = 1)

inner term: ~E + N (nlvls = 92)

##

estim sqrt fixed

```
## tau^2      160.8138  12.6812      no
## rho        6.1105      no
##
## Test for Heterogeneity:
## Q(df = 95) = 132.4769, p-val = 0.0067
##
## Model Results:
##
## estimate      se      zval      pval      ci.lb      ci.ub
##  4.7476  7.1808  0.6612  0.5085  -9.3265  18.8217
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

#Total abundance

```
res1 <- rma.mv(S_Abun, Var_Abun, random = ~ E+N | const, struct="SPGAU",
              mods=~ S_Dv +Middle_point , data= df1, control=list(maxiter=1000))
res1
```

```
##
## Multivariate Meta-Analysis Model (k = 96; method: REML)
##
## Variance Components:
##
## outer factor: const (nlvls = 1)
## inner term: ~E + N (nlvls = 92)
##
##      estim      sqrt  fixed
## tau^2      6.2111  2.4922      no
## rho        5.5337      no
##
## Test for Residual Heterogeneity:
## QE(df = 93) = 124.0067, p-val = 0.0175
##
## Test of Moderators (coefficients 2:3):
## QM(df = 2) = 3.4372, p-val = 0.1793
##
## Model Results:
##
##      estimate      se      zval      pval      ci.lb      ci.ub
## intrcpt      -265.6340  271.4396  -0.9786  0.3278  -797.6458  266.3777
## S_Dv           0.1312   0.0912   1.4390  0.1501   -0.0475   0.3100
## Middle_point    0.1321   0.1352   0.9767  0.3287   -0.1330   0.3971
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

#Taxa richness

```
res2 <- rma.mv(S_Rich,Var_Rich, random = ~ E+N | const ,
              mods=~ S_Dv +Middle_point, struct="SPGAU",
              data= df1, control=list(maxiter=1000))
res2
```

```
##
```

```
## Multivariate Meta-Analysis Model (k = 96; method: REML)
##
## Variance Components:
##
## outer factor: const (nlvls = 1)
## inner term: ~E + N (nlvls = 92)
##
##          estim      sqrt  fixed
## tau^2      39.1752  6.2590    no
## rho         0.4714           no
##
## Test for Residual Heterogeneity:
## QE(df = 93) = 196.3242, p-val < .0001
##
## Test of Moderators (coefficients 2:3):
## QM(df = 2) = 6.6325, p-val = 0.0363
##
## Model Results:
##
##          estimate      se      zval      pval      ci.lb      ci.ub
## intrcpt      -236.2580  416.0980  -0.5678  0.5702  -1051.7952  579.2791
## S_Dv          -0.2589   0.1043  -2.4819  0.0131   -0.4634  -0.0544 *
## Middle_point    0.1175   0.2074   0.5663  0.5712   -0.2891   0.5240
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#Shannon diversity
res3 <- rma.mv(S_Diver, Var_Diver, random = ~ E+N | const,
              mods=~ S_Dv +Middle_point, struct="SPGAU",
              data= df1, control=list(maxiter=1000))
res3
```

```
##
## Multivariate Meta-Analysis Model (k = 96; method: REML)
##
## Variance Components:
##
## outer factor: const (nlvls = 1)
## inner term: ~E + N (nlvls = 92)
##
##          estim      sqrt  fixed
## tau^2      14.8776  3.8571    no
## rho         0.5535           no
##
## Test for Residual Heterogeneity:
## QE(df = 93) = 155.6233, p-val < .0001
##
## Test of Moderators (coefficients 2:3):
## QM(df = 2) = 4.9651, p-val = 0.0835
##
## Model Results:
##
##          estimate      se      zval      pval      ci.lb      ci.ub
```

```
## intrcpt      -17.9526  320.6955  -0.0560  0.9554  -646.5042  610.5989
## S_Dv         -0.2187   0.0982  -2.2271  0.0259   -0.4112  -0.0262  *
## Middle_point  0.0084   0.1599   0.0523  0.9583   -0.3051   0.3218
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

#Temporal turnover
res4 <- rma.mv(S_Turn, Var_Turn, random = ~ E+N | const, struct="SPGAU", mods=~ S_Dv +
              Middle_point, data= df1, control=list(maxiter=1000))
```

```
## Warning: Rows with NAs omitted from model fitting.
```

```
res4
```

```
##
## Multivariate Meta-Analysis Model (k = 84; method: REML)
##
## Variance Components:
##
## outer factor: const (nlvls = 1)
## inner term: ~E + N (nlvls = 92)
##
##      estim      sqrt  fixed
## tau^2      3.1708  1.7807    no
## rho         0.1649          no
##
## Test for Residual Heterogeneity:
## QE(df = 81) = 122.8135, p-val = 0.0019
##
## Test of Moderators (coefficients 2:3):
## QM(df = 2) = 4.2444, p-val = 0.1198
##
## Model Results:
##
##      estimate      se      zval      pval      ci.lb      ci.ub
## intrcpt      61.5749 192.4691  0.3199  0.7490 -315.6577  438.8074
## S_Dv        -0.1631  0.0798 -2.0436  0.0410  -0.3195  -0.0067  *
## Middle_point -0.0305  0.0960 -0.3177  0.7507  -0.2187   0.1577
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

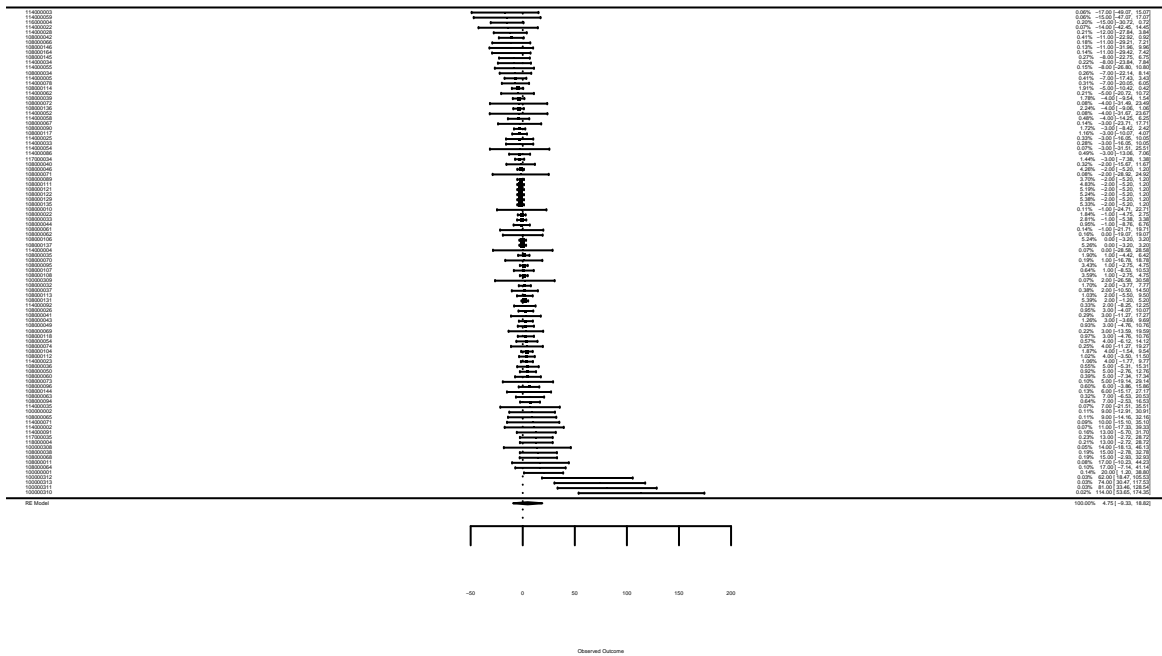
```
#Temporal Evenness
res5 <- rma.mv(S_Eve, Var_Eve, random = ~ E+N | const, struct="SPGAU", mods=~ S_Dv +
              Middle_point, data= df1, control=list(maxiter=1000))
res5
```

```
##
## Multivariate Meta-Analysis Model (k = 96; method: REML)
##
## Variance Components:
```

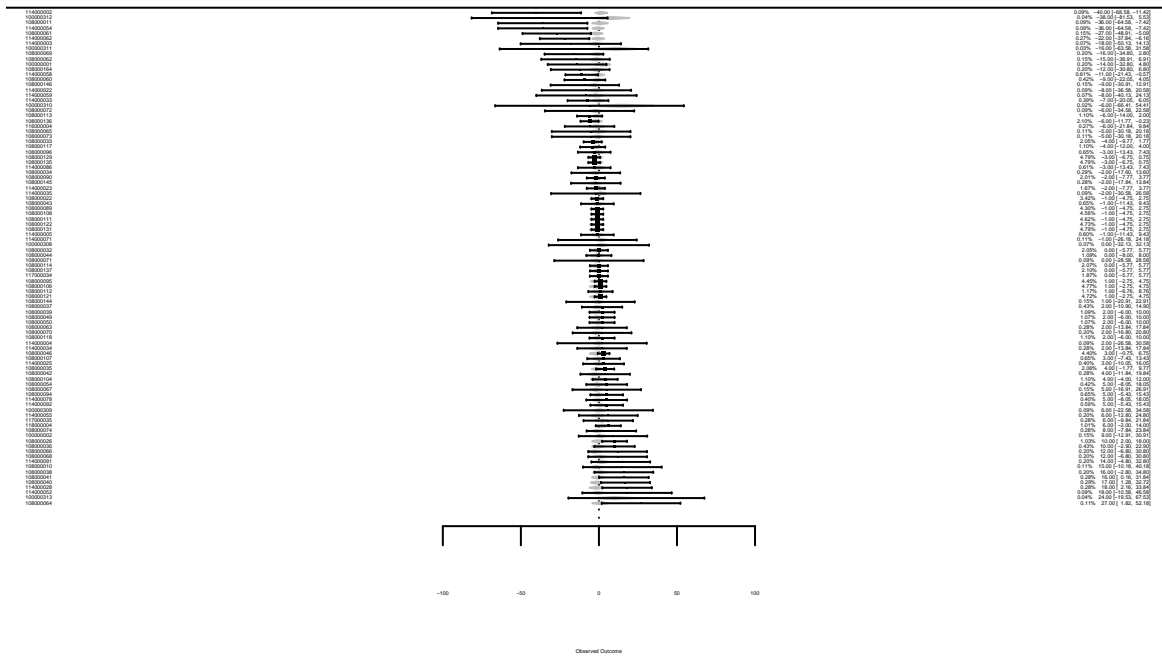


```
##
## outer factor: const (nlvls = 1)
## inner term: ~E + N (nlvls = 92)
##
##          estim      sqrt  fixed
## tau^2      3.6182  1.9022    no
## rho        0.9510          no
##
## Test for Residual Heterogeneity:
## QE(df = 93) = 123.3304, p-val = 0.0193
##
## Test of Moderators (coefficients 2:3):
## QM(df = 2) = 2.8616, p-val = 0.2391
##
## Model Results:
##
##          estimate      se      zval      pval      ci.lb      ci.ub
## intrcpt      67.2929  245.2473   0.2744  0.7838  -413.3830  547.9688
## S_Dv        -0.1512   0.0914  -1.6535  0.0982   -0.3303   0.0280 .
## Middle_point -0.0342   0.1224  -0.2791  0.7801   -0.2740   0.2057
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

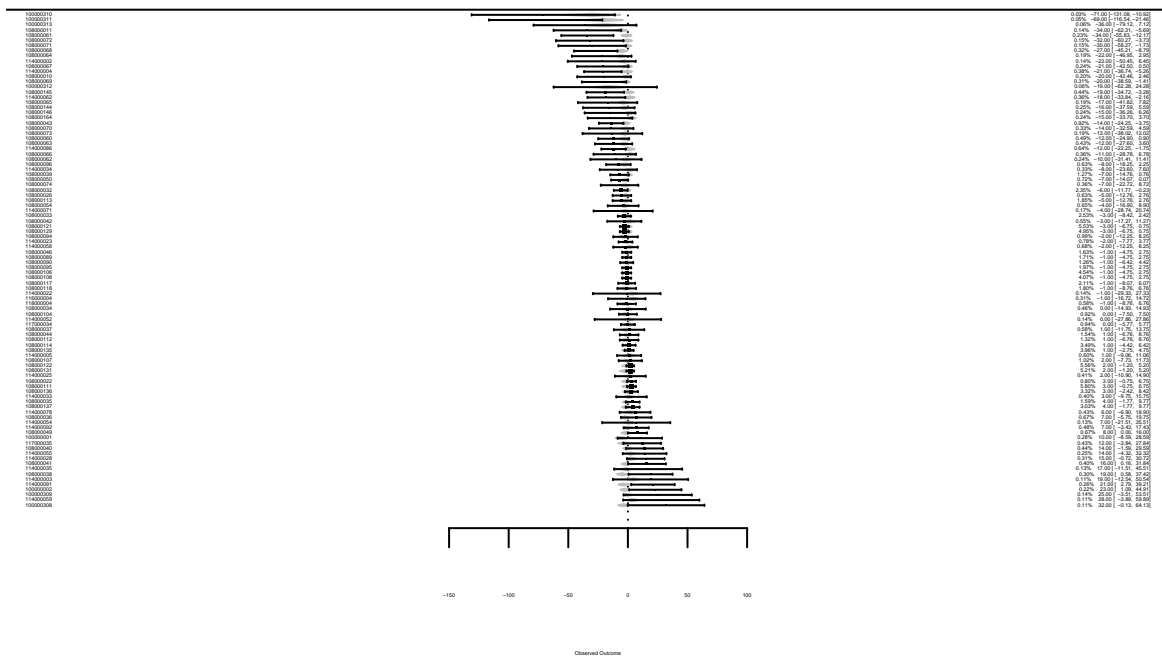
###Funnel plot
#D. villosus
forest(res, showweights = T, order="obs", slab= df1$site_id)
```



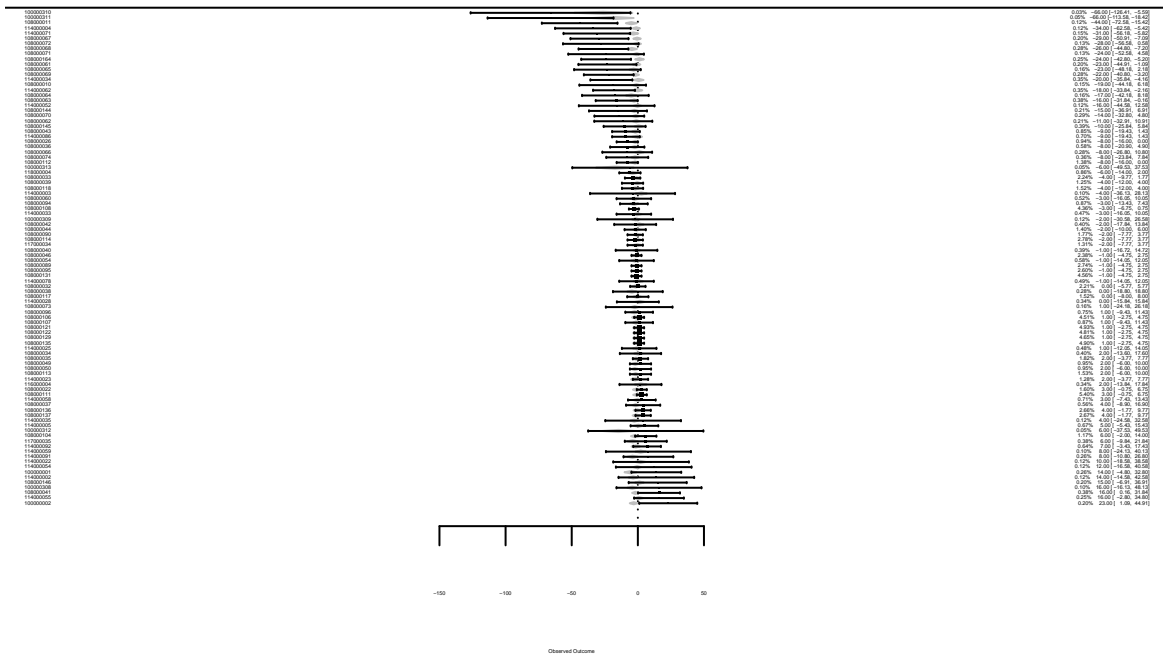
```
#Total abundance
forest(res1, showweights = T, order="obs", slab= df1$site_id)
```



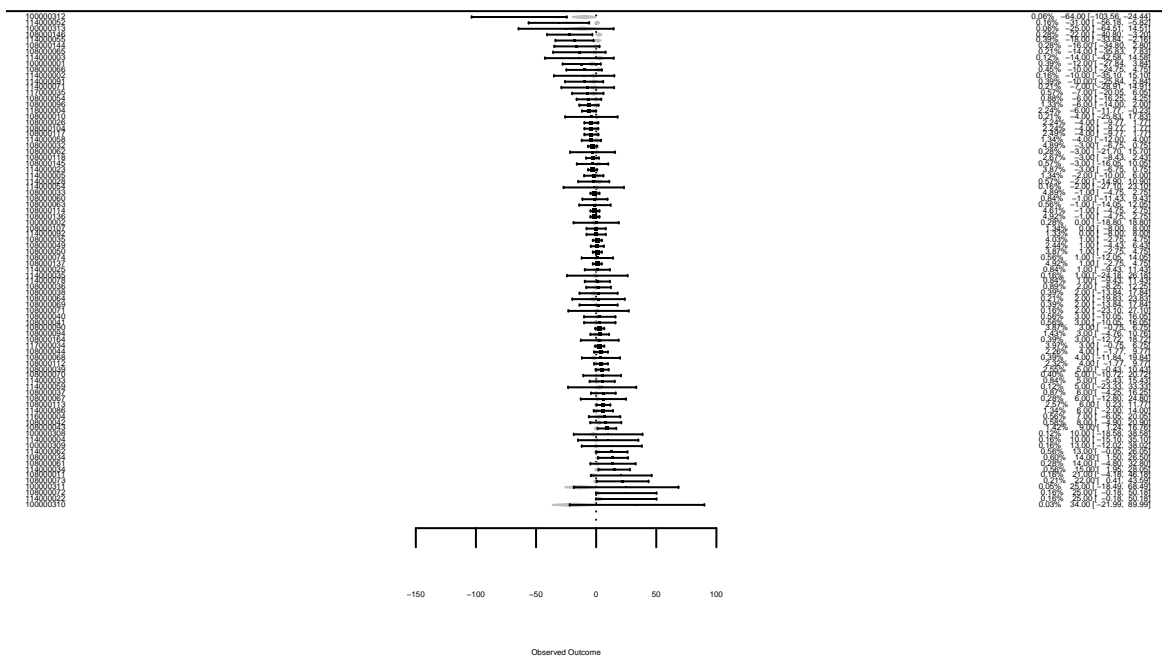
```
#Taxa Richness
forest(res2, showweights = T, order="obs", slab= df1$site_id)
```



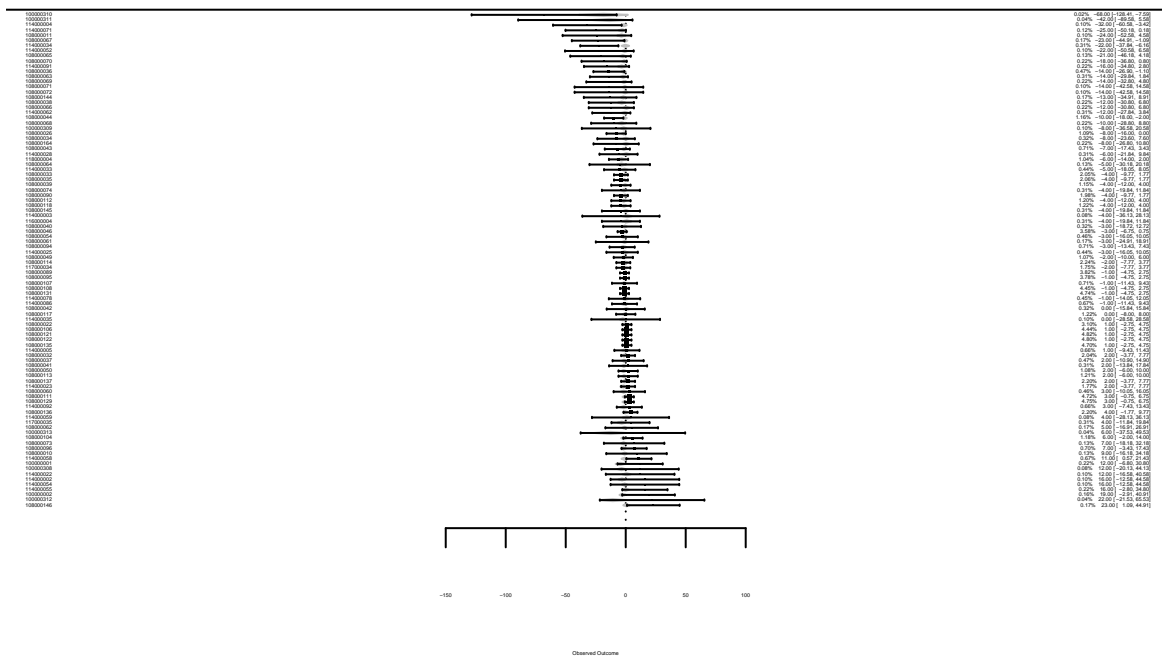
```
#Shannon diversity
forest(res3, showweights = T, order="obs", slab= df1$site_id)
```



```
#Temporal turnover
forest(res4, showweights = T, order="obs", slab= df1$site_id)
```



```
#Temporal Evenness
forest(res5, showweights = T, order="obs", slab= df1$site_id)
```



Egger Test

```
resid = rstandard(res)
eggers <- regtest(x = resid$resid, sei = sqrt(df1$Var_Dv), model = "lm")
eggers
```

```
##
## Regression Test for Funnel Plot Asymmetry
##
## Model:      weighted regression with multiplicative dispersion
## Predictor: standard error
##
## Test for Funnel Plot Asymmetry: t = 3.1424, df = 94, p = 0.0022
## Limit Estimate (as sei -> 0):  b = -6.8256 (CI: -8.1298, -5.5215)
```

```
resid = rstandard(res1)
eggers <- regtest(x = resid$resid, sei = sqrt(df1$Var_Abun), model = "lm")
eggers
```

```
##
## Regression Test for Funnel Plot Asymmetry
##
## Model:      weighted regression with multiplicative dispersion
## Predictor: standard error
##
```

```
## Test for Funnel Plot Asymmetry: t = -0.9547, df = 94, p = 0.3422
## Limit Estimate (as sei -> 0): b = 1.6932 (CI: 0.1133, 3.2731)
```

```
resid = rstandard(res2)
eggers <- regtest(x = resid$resid, sei = sqrt(df1$Var_Rich), model = "lm")
eggers
```

```
##
## Regression Test for Funnel Plot Asymmetry
##
## Model:      weighted regression with multiplicative dispersion
## Predictor: standard error
##
## Test for Funnel Plot Asymmetry: t = -2.6753, df = 94, p = 0.0088
## Limit Estimate (as sei -> 0): b = 2.4668 (CI: 0.6173, 4.3163)
```

```
resid = rstandard(res3)
eggers <- regtest(x = resid$resid, sei = sqrt(df1$Var_Diver), model = "lm")
eggers
```

```
##
## Regression Test for Funnel Plot Asymmetry
##
## Model:      weighted regression with multiplicative dispersion
## Predictor: standard error
##
## Test for Funnel Plot Asymmetry: t = -3.3503, df = 94, p = 0.0012
## Limit Estimate (as sei -> 0): b = 2.8965 (CI: 1.2260, 4.5669)
```

```
###
resid = rstandard(res5)
eggers <- regtest(x = resid$resid, sei = sqrt(df1$Var_Eve), model = "lm")
eggers
```

```
##
## Regression Test for Funnel Plot Asymmetry
##
## Model:      weighted regression with multiplicative dispersion
## Predictor: standard error
##
## Test for Funnel Plot Asymmetry: t = -2.5005, df = 94, p = 0.0141
## Limit Estimate (as sei -> 0): b = 1.9234 (CI: 0.3999, 3.4469)
```

Generalised Lineal Model

```
#Before run this model, first we checked the collinearity using the corvif function
# Functions from Zuur et al., 2009
myvif <- function(mod) {
  v <- vcov(mod)
  assign <- attributes(model.matrix(mod))$assign
```



```

if (names(coefficients(mod)[1]) == "(Intercept)") {
  v <- v[-1, -1]
  assign <- assign[-1]
} else warning("No intercept: vifs may not be sensible.")
terms <- labels(terms(mod))
n.terms <- length(terms)
if (n.terms < 2) stop("The model contains fewer than 2 terms")
if (length(assign) > dim(v)[1] ) {
  diag(tmp_cor)<-0
  if (any(tmp_cor==1.0)){
    return("Sample size is too small, 100% collinearity is present")
  } else {
    return("Sample size is too small")
  }
}
}
R <- cov2cor(v)
detR <- det(R)
result <- matrix(0, n.terms, 3)
rownames(result) <- terms
colnames(result) <- c("GVIF", "Df", "GVIF^(1/2Df)")
for (term in 1:n.terms) {
  subs <- which(assign == term)
  result[term, 1] <- det(as.matrix(R[subs, subs])) * det(as.matrix(R[-subs, -subs])) / detR
  result[term, 2] <- length(subs)
}
if (all(result[, 2] == 1)) {
  result <- data.frame(GVIF=result[, 1])
} else {
  result[, 3] <- result[, 1]^(1/(2 * result[, 2]))
}
invisible(result)
}

corvif <- function(dataz) {
  dataz <- as.data.frame(dataz)
  #correlation part
  cat("Correlations of the variables\n\n")
  tmp_cor <- cor(dataz,use="complete.obs")
  print(tmp_cor)

  #vif part
  form <- formula(paste("fooy ~ ",paste(strsplit(names(dataz)," "),collapse=" + "))
  dataz <- data.frame(fooy=1,dataz)
  lm_mod <- lm(form,dataz)

  cat("\n\nVariance inflation factors\n\n")
  print(myvif(lm_mod))}

#VIF threshold = 5
df1 <- df[!duplicated(df$site_id),]
#VIF for Dikerragammarus villosus trend (GLM)
moderators <- c("S_Dv", "E", "N", "Elevation", "Slope_preci", "Slope_temp", "Mean_precipita",
               "Mean_temp", "DistanceKm", "slope", "Avg_Tmin", "Slope_Tmin", "Slope_Tmax", "Avg_Tmax", "Middl

```

```
corvif(mutate_if(df1[, moderators], is.factor, as.numeric))
```

```
## Correlations of the variables
```

```
##
##           S_Dv           E           N      Elevation Slope_preci
## S_Dv          1.000000000 -0.29498281 -0.351797217  0.15779035  0.14928080
## E            -0.294982812  1.000000000 -0.509808913  0.10971656 -0.31387298
## N            -0.351797217 -0.50980891  1.000000000 -0.58055294  0.25742546
## Elevation     0.157790351  0.10971656 -0.580552937  1.000000000 -0.16321570
## Slope_preci   0.149280802 -0.31387298  0.257425459 -0.16321570  1.000000000
## Slope_temp    -0.176766023  0.09972639  0.135946452 -0.03922977  0.04496056
## Mean_precipita 0.298390969 -0.79633102  0.278502472  0.11345394  0.25228742
## Mean_temp     -0.003013052 -0.04015251 -0.003959704  0.01862232 -0.03544936
## DistanceKm    -0.041428717 -0.71546194  0.627811104 -0.15855460  0.35163388
## slope         -0.084355395 -0.14827363  0.253301241 -0.15305841 -0.01553525
## Avg_Tmin       0.485955006 -0.20680600 -0.270498368 -0.14832896  0.09242185
## Slope_Tmin     0.693021874 -0.01561980 -0.483938608  0.16111401 -0.11848532
## Slope_Tmax     0.590978218  0.03641882 -0.453067046  0.03735041 -0.03169006
## Avg_Tmax       0.049125350 -0.06433243  0.049799087 -0.09281866  0.02712434
## Middle_point   0.149434563  0.66537721 -0.734498506  0.38435663 -0.36950036
##
##           Slope_temp Mean_precipita Mean_temp DistanceKm slope
## S_Dv          -0.176766023  0.298390969 -0.003013052 -0.04142872 -0.08435539
## E             0.099726391 -0.796331024 -0.040152514 -0.71546194 -0.14827363
## N             0.135946452  0.278502472 -0.003959704  0.62781110  0.25330124
## Elevation     -0.039229769  0.113453943  0.018622320 -0.15855460 -0.15305841
## Slope_preci   0.044960563  0.252287415 -0.035449362  0.35163388 -0.01553525
## Slope_temp    1.000000000 -0.085450335  0.002311115  0.01443316  0.03836502
## Mean_precipita -0.085450335  1.000000000 -0.073249397  0.47207321  0.16067729
## Mean_temp     0.002311115 -0.073249397  1.000000000  0.04169471 -0.06960749
## DistanceKm    0.014433162  0.472073214  0.041694706  1.000000000  0.13214946
## slope         0.038365023  0.160677291 -0.069607495  0.13214946  1.000000000
## Avg_Tmin      -0.233667316  0.290416759 -0.106685807  0.03322479  0.02036989
## Slope_Tmin    -0.201452407  0.057561053  0.006972887 -0.30794912 -0.10458632
## Slope_Tmax    -0.134045510 -0.003790154 -0.018320256 -0.25094452 -0.07649401
## Avg_Tmax      -0.015277968  0.097924450 -0.016744689  0.05111826  0.20573252
## Middle_point   0.005417120 -0.345651098 -0.079491787 -0.68769070 -0.18344594
##
##           Avg_Tmin Slope_Tmin Slope_Tmax Avg_Tmax Middle_point
## S_Dv          0.48595501 0.693021874 0.590978218 0.04912535 0.14943456
## E            -0.20680600 -0.015619797 0.036418818 -0.06433243 0.66537721
## N            -0.27049837 -0.483938608 -0.453067046 0.04979909 -0.73449851
## Elevation     -0.14832896 0.161114014 0.037350413 -0.09281866 0.38435663
## Slope_preci   0.09242185 -0.118485323 -0.031690062 0.02712434 -0.36950036
## Slope_temp    -0.23366732 -0.201452407 -0.134045510 -0.01527797 0.00541712
## Mean_precipita 0.29041676 0.057561053 -0.003790154 0.09792445 -0.34565110
## Mean_temp     -0.10668581 0.006972887 -0.018320256 -0.01674469 -0.07949179
## DistanceKm    0.03322479 -0.307949116 -0.250944519 0.05111826 -0.68769070
## slope         0.02036989 -0.104586317 -0.076494009 0.20573252 -0.18344594
## Avg_Tmin      1.00000000 0.387700973 0.401550422 0.06856120 0.18040436
## Slope_Tmin    0.38770097 1.000000000 0.841810142 -0.01953010 0.35880710
## Slope_Tmax    0.40155042 0.841810142 1.000000000 -0.07777827 0.28159836
## Avg_Tmax      0.06856120 -0.019530096 -0.077778269 1.000000000 -0.08413697
## Middle_point   0.18040436 0.358807104 0.281598356 -0.08413697 1.000000000
##
```

```
##
## Variance inflation factors
##
##          GVIF
## S_Dv      2.930936
## E         8.885482
## N         7.404985
## Elevation  3.885924
## Slope_preci 1.361869
## Slope_temp  1.129546
## Mean_precipita 4.266825
## Mean_temp   1.064678
## DistanceKm  3.574575
## slope       1.168368
## Avg_Tmin    2.733108
## Slope_Tmin  5.566225
## Slope_Tmax  4.377839
## Avg_Tmax    1.120344
## Middle_point 4.310337
```

```
#GLM model of D. villosus trend
m1 <- glm(S_Dv ~
  Elevation+ #Elevation
  Slope_preci+ #Trend precipitation
  Slope_temp+ # Trend of temperature
  Mean_precipita + #Average precipitation
  Mean_temp+ # Average temperature
  DistanceKm+ #Distance to the next barrier
  slope+ #Slope of stream
  Avg_Tmax+ # Avg maximum temperature
  Avg_Tmin+ # Aveg minimum temperature
  Slope_Tmax+ # Trend of maximum temperature
  Middle_point+ #Middle point of time series
  Biogeo+ #Biogeographical regions
  Ecosystem, #Ecosystem type (stream/canal)
  data = df1, na.action="na.fail")

summary(m1)
```

```
##
## Call:
## glm(formula = S_Dv ~ Elevation + Slope_preci + Slope_temp + Mean_precipita +
##   Mean_temp + DistanceKm + slope + Avg_Tmax + Avg_Tmin + Slope_Tmax +
##   Middle_point + Biogeo + Ecosystem, data = df1, na.action = "na.fail")
##
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -34.289  -5.946   0.234   4.610  57.075
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -1.251e+03  9.146e+02  -1.368   0.1751
## Elevation      6.460e-02  4.323e-02   1.494   0.1391
## Slope_preci    3.625e-01  2.019e-01   1.795   0.0764 .
```

```
## Slope_temp          -2.839e-02  1.972e-01  -0.144  0.8859
## Mean_precipita      4.819e+00  6.854e+00   0.703  0.4841
## Mean_temp           5.715e-02  1.190e-01   0.480  0.6322
## DistanceKm          -1.705e-02  8.027e-03  -2.124  0.0368 *
## slope              -2.910e+01  5.395e+01  -0.539  0.5911
## Avg_Tmax            8.386e-02  5.204e-02   1.611  0.1111
## Avg_Tmin            5.593e+00  2.762e+00   2.025  0.0463 *
## Slope_Tmax          8.463e-01  1.587e-01   5.334  8.92e-07 ***
## Middle_point        5.936e-01  4.569e-01   1.299  0.1976
## BiogeoAtlantic      1.382e+01  1.244e+01   1.111  0.2699
## BiogeoContinental   1.758e+01  1.092e+01   1.610  0.1114
## BiogeoMediterranean 3.155e+01  1.417e+01   2.226  0.0289 *
## BiogeoPannonian     -6.068e+00  1.248e+01  -0.486  0.6281
## Ecosystemminor      5.059e+00  3.530e+00   1.433  0.1558
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 145.8679)
##
## Null deviance: 32545 on 95 degrees of freedom
## Residual deviance: 11524 on 79 degrees of freedom
## AIC: 768.07
##
## Number of Fisher Scoring iterations: 2
```

```
# VIF for realtive abundance of D. villosus over time (threshold =5)
moderators <- c("Proportion", "E", "N", "Elevation", "Precipitation", "Temperature",
               "DistanceKm", "slope", "Middle_point", "Tmax", "Tmin", "year", "Avg_Tmax", "Avg_Tmin", "Mean_precipita", "Mean_temp")
corvif(mutate_if(df[, moderators], is.factor, as.numeric))
```

```
## Correlations of the variables
##
##          Proportion          E          N  Elevation Precipitation
## Proportion    1.0000000000 -0.13771421 -0.08933161  0.04772116  -0.02575671
## E             -0.1377142066  1.00000000 -0.37871524  0.11495884  -0.63538152
## N             -0.0893316100 -0.37871524  1.00000000 -0.63008742   0.13473235
## Elevation      0.0477211574  0.11495884 -0.63008742  1.00000000   0.06423241
## Precipitation  -0.0257567082 -0.63538152  0.13473235  0.06423241   1.00000000
## Temperature    0.0227585144 -0.01084357 -0.10461510  0.01740506  -0.02646033
## DistanceKm      0.0649135474 -0.71496572  0.67036889 -0.28847010   0.37476891
## slope         -0.0420845137 -0.12623753  0.30788133 -0.20134744   0.08586506
## Middle_point   -0.0314412131  0.59524009 -0.78820626  0.50144197  -0.24895233
## Tmax           0.0004026618 -0.02758705  0.02080298 -0.02992577   0.03180707
## Tmin           0.0747607842 -0.28548342 -0.30581310 -0.04284096   0.26605626
## year           0.0155292051  0.50860439 -0.66934395  0.41649051  -0.25044199
## Avg_Tmax       -0.0054822228 -0.08156937  0.06151025 -0.08848448   0.05915762
## Avg_Tmin        0.1221882346 -0.35777588 -0.38325360 -0.05368950   0.30583845
## Mean_precipita  0.0351239648 -0.85389563  0.18182249  0.11447899   0.74554944
## Mean_temp       0.0214439705 -0.04139097 -0.03098955  0.02179044  -0.03658465
##          Temperature DistanceKm      slope Middle_point          Tmax
## Proportion    2.275851e-02  0.06491355 -0.04208451 -0.03144121  0.0004026618
## E             -1.084357e-02 -0.71496572 -0.12623753  0.59524009 -0.0275870527
## N             -1.046151e-01  0.67036889  0.30788133 -0.78820626  0.0208029849
```

```

## Elevation      1.740506e-02 -0.28847010 -0.20134744  0.50144197 -0.0299257670
## Precipitation -2.646033e-02  0.37476891  0.08586506 -0.24895233  0.0318070691
## Temperature   1.000000e+00 -0.02951438 -0.01198523  0.03069880 -0.0043279443
## DistanceKm    -2.951438e-02  1.00000000  0.16953588 -0.76693620  0.0252418673
## slope         -1.198523e-02  0.16953588  1.00000000 -0.23176037  0.0763297380
## Middle_point  3.069880e-02 -0.76693620 -0.23176037  1.00000000 -0.0390550776
## Tmax         -4.327944e-03  0.02524187  0.07632974 -0.03905508  1.0000000000
## Tmin          8.403918e-02  0.03128626 -0.03114691  0.13939180  0.0303460163
## year          5.264916e-02 -0.66321528 -0.18757368  0.84510087 -0.0579431434
## Avg_Tmax      -3.058632e-03  0.07463513  0.22569171 -0.11547803  0.3382035588
## Avg_Tmin      1.111711e-01  0.03920882 -0.03903418  0.17468997  0.0159486509
## Mean_precipita 4.249386e-05  0.51963356  0.12021276 -0.34753921  0.0341113361
## Mean_temp     9.496474e-02  0.02947892 -0.03453937 -0.05452362 -0.0042694408
##              Tmin          year      Avg_Tmax      Avg_Tmin Mean_precipita
## Proportion    0.07476078  0.01552921 -0.005482223  0.12218823  3.512396e-02
## E             -0.28548342  0.50860439 -0.081569374 -0.35777588 -8.538956e-01
## N             -0.30581310 -0.66934395  0.061510248 -0.38325360  1.818225e-01
## Elevation     -0.04284096  0.41649051 -0.088484483 -0.05368950  1.144790e-01
## Precipitation 0.26605626 -0.25044199  0.059157623  0.30583845  7.455494e-01
## Temperature   0.08403918  0.05264916 -0.003058632  0.11117114  4.249386e-05
## DistanceKm    0.03128626 -0.66321528  0.074635132  0.03920882  5.196336e-01
## slope         -0.03114691 -0.18757368  0.225691706 -0.03903418  1.202128e-01
## Middle_point  0.13939180  0.84510087 -0.115478027  0.17468997 -3.475392e-01
## Tmax          0.03034602 -0.05794314  0.338203559  0.01594865  3.411134e-02
## Tmin          1.00000000  0.21945107  0.037628389  0.79793928  3.121934e-01
## year          0.21945107  1.00000000 -0.097225051  0.15529389 -2.954997e-01
## Avg_Tmax      0.03762839 -0.09722505  1.000000000  0.04715696  1.008604e-01
## Avg_Tmin      0.79793928  0.15529389  0.047156958  1.00000000  3.912496e-01
## Mean_precipita 0.31219343 -0.29549965  0.100860370  0.39124960  1.000000e+00
## Mean_temp     -0.01180118 -0.04595187 -0.012623879 -0.01478957 -3.240469e-02
##              Mean_temp
## Proportion    0.021443971
## E             -0.041390968
## N             -0.030989554
## Elevation     0.021790436
## Precipitation -0.036584647
## Temperature   0.094964735
## DistanceKm    0.029478919
## slope         -0.034539366
## Middle_point  -0.054523621
## Tmax          -0.004269441
## Tmin          -0.011801180
## year          -0.045951873
## Avg_Tmax      -0.012623879
## Avg_Tmin      -0.014789571
## Mean_precipita -0.032404686
## Mean_temp     1.000000000
##
##
## Variance inflation factors
##
##              GVIF
## Proportion    1.118597
## E             8.011324

```

```
## N            8.710754
## Elevation    4.286684
## Precipitation 2.320554
## Temperature  1.036741
## DistanceKm   4.336794
## slope        1.201090
## Middle_point 7.356723
## Tmax         1.134826
## Tmin         3.065245
## year         3.979254
## Avg_Tmax     1.215896
## Avg_Tmin     5.920547
## Mean_precipita 6.753363
## Mean_temp    1.048184
```

```
#Relative abundance of D. villosus model (GLM)
## Relative abundance model (i.e. Dominance).
m3 <- glm(Proportion ~ #Relative abundance
          Elevation+ #Elevation
          Precipitation + #Precipitation (per year)
          Temperature + #Temperature (per year)
          Mean_temp+ #Avg temperature
          DistanceKm+ #Distance to the next barrier
          slope+ #Slope of stream
          Tmin + #Minimum temperature (per year)
          Avg_Tmax + #Avg Maximum temperature
          Tmax + #Maximum temperature (per year)
          year + #Sampling years
          Biogeo+ #Biogeographical region
          Ecosystem, #Ecosystem type
          data = df,family = "quasibinomial", na.action="na.fail")

summary(m3)
```

```
##
## Call:
## glm(formula = Proportion ~ Elevation + Precipitation + Temperature +
##     Mean_temp + DistanceKm + slope + Tmin + Avg_Tmax + Tmax +
##     year + Biogeo + Ecosystem, family = "quasibinomial", data = df,
##     na.action = "na.fail")
##
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -0.6756  -0.3069  -0.1310   0.1126   1.7835
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -5.073e+01  2.277e+01  -2.228  0.026171 *
## Elevation      4.168e-03  1.601e-03   2.603  0.009437 **
## Precipitation  -1.851e-01  1.165e-01  -1.589  0.112488
## Temperature    -4.201e-03  1.014e-02  -0.414  0.678810
## Mean_temp       1.130e-03  6.713e-03   0.168  0.866338
## DistanceKm      1.074e-03  3.615e-04   2.970  0.003079 **
## slope          1.342e+00  2.102e+00   0.638  0.523527
```

```

## Tmin                -1.184e-01  6.547e-02  -1.808  0.070975 .
## Avg_Tmax            -5.165e-04  2.062e-03  -0.250  0.802283
## Tmax                1.558e-04  6.562e-04   0.237  0.812437
## year                2.389e-02  1.138e-02   2.100  0.036110 *
## BiogeoAtlantic      1.195e+00  4.227e-01   2.827  0.004834 **
## BiogeoContinental    1.645e+00  3.438e-01   4.786  2.07e-06 ***
## BiogeoMediterranean  2.450e+00  4.259e-01   5.751  1.30e-08 ***
## BiogeoPannonian      1.090e+00  3.979e-01   2.739  0.006319 **
## Ecosystemminor      -4.295e-01  1.213e-01  -3.541  0.000424 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for quasibinomial family taken to be 0.1617545)
##
## Null deviance: 118.32 on 743 degrees of freedom
## Residual deviance: 101.08 on 728 degrees of freedom
## AIC: NA
##
## Number of Fisher Scoring iterations: 5

```