

Trait-based products of EMODnet benthic biology

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Abstract

Aim of this analysis.

Through their activity, benthic animals play an important role in marine ecosystem functioning. More specifically, they mix the sediment by their movement and feeding, a process called “bioturbation”. They also create water movements, enhancing the exchange of dissolved constituents such as oxygen, and dissolved inorganic nutrients, a process called “bio-irrigation”.

Both these activities have a large impact on the biogeochemical cycles in the environment, and they are commonly parameterised as single parameters in biogeochemical models.

Biologists have tried to categorise the bioturbation or bio-irrigation activity based on the identity of the organisms. They do not derive the rate parameters as used in the biogeochemical models but rather derive a potential of the organisms to perform these tasks.

Here we use Benthic abundance data from EMODnet to estimate the bioturbation potential (Solan et al., 2004).

To derive this index we need information on:

- The weights of the species and their total biomass
- The species mobility and sediment reworking mode

Reading the data

Species taxonomic tree

The names of all species encountered in the dataset were checked against the WORMS database, and their taxonomic tree added (this was done via <http://www.marinespecies.org/>, menu item *tools/Match taxa*). These data are read first. The dimensions of the data set and the first two entries are printed.

```
Taxo      <- read.csv(file= "taxo.csv")
cat("\ndimension and first part of the data set : \n")

##
## dimension and first part of the data set :
dim(Taxo)

## [1] 7650     8
head(Taxo, n = 2)

##      id      phy      clas          ord      fam
## 1 7500 Hemichordata Enteropneusta [unassigned] Enteropneusta
## 2     1   Cnidaria    Hydrozoa          Leptothecata Sertulariidae
##           gen            tx            txa
```

```

## 1 [unassigned] [unassigned] Enteropneusta [unassigned] Enteropneusta
## 2 Abietinaria           Abietinaria           Abietinaria

```

the MWTL data

The MWTL data is the only data set that contains both species *biomass* and *densities* (the other data sets comprise only densities or just presence/absence). This data is used to estimate mean individual weights of the various species. The file *occ.csv* has been prepared by Olivier Beauchard as part of the EMODNET product on trait types. It contains average density and biomass per taxon and station. Averaging was over time. Some taxa lumping has been done in the preparation of the file, as well as taxonomic checks against WORMS.

Biomass is in *g AFDW/m²*, density in *number/m²*

```

MWTLdata <- read.csv("occ.csv", header=TRUE, stringsAsFactors = FALSE)

# calculate average weight per species and sample
MWTLdata$mw <- MWTLdata$biom/MWTLdata$ind
MWTLdata$lmw <- log(MWTLdata$mw)

# calculate arithmetic and geometric mean per species over all samples where the species occurs
spmweight <- aggregate(mw~tax, MWTLdata, FUN=mean)
spgmweight <- aggregate(lmw~tax, MWTLdata, FUN=mean)
spgmweight$gmw <- exp(spgmweight$lmw)
n <- aggregate(mw~tax, MWTLdata, FUN=function(x) length(x))
names(n) <- c("tax", "n")

mweights <- merge(spmweight, spgmweight, by="tax")
mweights <- merge(mweights, n, by="tax")
mweights <- mweights[,-3]
write.csv(mweights, file="mweights.csv")

mws.mwtl <- read.csv("mweights.csv")
cat("\ndimension and first part of the data set : \n")

## dimension and first part of the data set :
dim(mws.mwtl)

## [1] 394   5
head(mws.mwtl, n = 2)

##      X          tax        mw        gmw     n
## 1 1 Ab ludomelita obtusata 0.0003002036 0.0003002011 12
## 2 2             Abra alba 0.0028563437 0.0004744354 425
colnames(mws.mwtl)[2:3] <- c("tx", "avweight")
mws.all <- merge(mws.mwtl, Taxo, by = "tx")

```

Expanding the weight dataset

Next we estimate mean weights on species level, on genus level, on the family level, and on the level of order and bind all in one data.frame(*mws*).

```

mws.species <- data.frame(meanW = tapply(mws.all$avweight, INDEX = mws.all$tx, FUN = mean, na.rm = TRUE,
                                         sdW = tapply(mws.all$avweight, INDEX = mws.all$tx, FUN = sd, na.rm = TRUE,
                                         n = tapply(mws.all$avweight, INDEX = mws.all$tx, FUN = length),
                                         level = "species"))

mws.genus <- data.frame(meanW = tapply(mws.all$avweight, INDEX = mws.all$gen, FUN = mean, na.rm = TRUE,
                                         sdW = tapply(mws.all$avweight, INDEX = mws.all$gen, FUN = sd, na.rm = TRUE,
                                         n = tapply(mws.all$avweight, INDEX = mws.all$gen, FUN = length),
                                         level = "genus"))
mws.genus <- mws.genus[-which(rownames(mws.genus)==""),]
mws.genus <- subset(mws.genus, !is.na(meanW))

mws.family <- data.frame(meanW = tapply(mws.all$avweight, INDEX = mws.all$fam, FUN = mean, na.rm = TRUE,
                                         sdW = tapply(mws.all$avweight, INDEX = mws.all$fam, FUN = sd, na.rm = TRUE,
                                         n = tapply(mws.all$avweight, INDEX = mws.all$fam, FUN = length),
                                         level = "family"))
mws.family <- mws.family[-which(rownames(mws.family)==""),]
mws.family <- subset(mws.family, !is.na(meanW))

mws.order <- data.frame(meanW = tapply(mws.all$avweight, INDEX = mws.all$ord, FUN = mean, na.rm = TRUE,
                                         sdW = tapply(mws.all$avweight, INDEX = mws.all$ord, FUN = sd, na.rm = TRUE,
                                         n = tapply(mws.all$avweight, INDEX = mws.all$ord, FUN = length),
                                         level = "order"))
mws.order <- mws.order[-which(rownames(mws.order)==""),]
mws.order <- subset(mws.order, !is.na(meanW))

mws <- rbind(mws.species, mws.genus, mws.family, mws.order)
mws$taxon <- rownames(mws)

```

The total number of weight values thus obtained is 873, of which 394 are estimated at species level, 280 at genus level, 156 at family level, and 43 at level or order.

FeedingTypes

Feedingtypes are known from a subset of the species. The following types are distinguished:

- “CaSc” = carnivore/scavenger
- “De” = depositfeeder
- “He” = herbivore
- “Om” = omnivore
- “Pa” = parasite
- “Su” = suspension feeder
- “SuDe” = suspension/deposit feeder

```

FeedingType <- read.csv("feedingtype_matched.txt")
cat("\ndimension and first part of the data set : \n")

```

```

##
## dimension and first part of the data set :
head(FeedingType[,1:2], n = 2)

```

```

##          n.acc Trophy
## 1 Abludomelita obtusata    De

```

```

## 2           Abra alba   SuDe
table(FeedingType$Trophy)

##
## CaSc    De     He    Om    Pa    Su  SuDe
## 78    100    20    56     3    79    37

```

Feeding types on higher taxonomic levels

We now assign feeding types to the genera and families, for which we take the most commonly encountered feedingtype at the lower level.

```

ft.species <- data.frame(FeedingType[,1:2], level = "species")
colnames(ft.species)[1:2] <- c("taxon", "ft")
ft.species$n <- 1

ft.genus <- data.frame(ft      = tapply(FeedingType$Trophy, INDEX = FeedingType$Genus,
                                         FUN = function(x) names(sort(table(x), decreasing = TRUE)[1])),
                        n      = tapply(FeedingType$Trophy, INDEX = FeedingType$Genus, FUN = length))
ft.genus <- data.frame(taxon = rownames(ft.genus), ft.genus, level = "genus")

ft.family <- data.frame(ft = tapply(FeedingType$Trophy, INDEX = FeedingType$Family,
                                      FUN = function(x) names(sort(table(x), decreasing = TRUE)[1])),
                           n = tapply(FeedingType$Trophy, INDEX = FeedingType$Family, FUN = length))
ft.family <- data.frame(taxon = rownames(ft.family), ft.family, level = "family")

ft.order <- data.frame(ft = tapply(FeedingType$Trophy, INDEX = FeedingType$Order,
                                      FUN = function(x) names(sort(table(x), decreasing = TRUE)[1])),
                           n = tapply(FeedingType$Trophy, INDEX = FeedingType$Order, FUN = length))
ft.order <- data.frame(taxon = rownames(ft.order), ft.order, level = "order")

ft <- rbind(ft.species, ft.genus, ft.family, ft.order)
head(ft, n = 2)

##
##          taxon   ft   level n
## 1 Abludomelita obtusata   De species 1
## 2           Abra alba SuDe species 1

```

The total number of feeding types thus obtained is 857, of which 373 are known at species level, 270 at genus level, 167 at family level and 47 at order level.

life history traits

Life history traits are also assigned on genus and family level, where we take the most commonly encountered trait at the lower level.

```

Traits.all <- read.csv("TraitsBiotur.csv")
cat("\ndimension and first part of the data set : \n")

##
## dimension and first part of the data set :
dim(Traits.all)

```

```

## [1] 273 21
head(Traits.all, n = 2)

##      phy      cla      ord      fam      gen
## 1 Annelida Polychaeta Sabellida Serpulidae Spirobranchus
## 2 Annelida Polychaeta Sabellida Sabellariidae Sabellaria
##          taxon Motility Body.size Burrowing.depth Morphology
## 1 Spirobranchus triquetus Tubicolous    1-3cm        0cm Cylindrical
## 2 Sabellaria spinulosa Tubicolous    3-10cm        0cm Cylindrical
##   Mobility Mixing.type Mixing.rate Mi Mi2 Ri Morphology.2
## 1 Very low Surface mixing     Very low 1 1 2           1
## 2 Very low Surface mixing     Very low 1 1 1           1
##   Morphology.2.1 Body.size.2 Burrowing.depth.2 Mixing.rate.2
## 1             1         2           1           2
## 2             1         3           1           3

traits.species <- data.frame(Traits.all[, c("taxon", "Motility", "Body.size", "Burrowing.depth", "Morphology")], n = 1, level = "species")

traitfun <- function(taxon = "gen", what = "Motility"){
  X <- data.frame(what = tapply(Traits.all[,what], INDEX = Traits.all[,taxon],
                                 FUN = function(x) names(sort(table(x), decreasing = TRUE)[1])),
                   n = tapply(Traits.all[,what], INDEX = Traits.all[,taxon], FUN = length))
  colnames(X)[1] <- what
  X
}

traitfun.all <- function(taxon){
  T <- traitfun(taxon, what = "Motility")
  n <- T$n
  X <- T[,1]
  What <- c("Motility", "Body.size", "Burrowing.depth", "Morphology", "Mobility", "Mixing.type",
  "Mixing.rate", "Mi", "Mi2", "Ri", "Morphology.2", "Morphology.2.1", "Body.size.2", "Burrowing.depth.2",
  "Burrowing.depth.2.1")
  for (w in What[-1])
    X <- data.frame(X, traitfun(taxon, what = w)[,1])
  names(X) <- What
  X <- data.frame(taxon = rownames(T), X, n = n)
}

traits.genus <- traitfun.all("gen")
traits.genus$level <- "genus"
traits.family <- traitfun.all("fam")
traits.family$level <- "family"
traits.order <- traitfun.all("ord")
traits.order$level <- "order"
traits <- rbind(traits.species, traits.genus [!traits.genus$taxon %in% traits.species$taxon,])
traits <- rbind(traits, traits.family[!traits.family$taxon %in% traits$taxon,])
traits <- rbind(traits, traits.order [!traits.order$taxon %in% traits$taxon,])

```

The total number of traits thus obtained is 523, of which 273 are estimated at species level, 131 at genus level, 89 at family level and 30 at order level.

We tabulate the number of occurrences of each trait in the resulting data.frame.

```
## motility:
```

```

## Attached Crawler Crawler-Swimmer Tubicolous
##      15       288      132       88

## Body size:
## <1cm >20cm 1-3cm 10-20cm 3-10cm
##   101     36    106      55    225

## Burrowing depth:
## >30cm 0-5cm 0cm 10-15cm 15-30cm 5-10cm
##    28    216     78      61     83     57

## Morphology:
## Articulated Bivalved Cylindrical Flat Globular Stellar
##      118      108      232      1      38      26

## Mobility:
## High Intermediate Low Very low
##     40        246     153      84

## Mixing type:
## D/U conveying Diffusion Downward conveying
##           34          123          23
## Regeneration Surface mixing Upward conveying
##           10          301          32

## Mixing rate:
## High Intermediate Low Very high Very low
##     34        62      143       44      240

## Mi:
## 1 2 3 4
## 84 153 246 40

## Ri:
## 1 2 3 4 5
## 28 275 86 124 10

```

The density data

Density data are read.

```

density <- read.csv("df_ab.csv")

cat("\ndimension and first part of the data set : \n")

```

```

##  

## dimension and first part of the data set :  

dim(density)

## [1] 1128549      6

head(density, n = 2)

##   data    sta      x      y      tx      dens
## 1 HELCOM HELCOM1 8.267167 56.72267 Abra alba 139.8601
## 2 HELCOM HELCOM1 8.267167 56.72267 Abra nitida 139.8601
cat("\ntotal number of data points per provider : \n")

##  

## total number of data points per provider :
table(density$data)

##  

##   HELCOM MACROBEL  MAREANO      MWTL      NSBS      ODAM      PMP      PORT
## 10399     12701     21591     8475    14622    94544     333     6796
##  REBENT     RSMP     SHARK     SMHI
## 24516     875244    56268     3060
```

Some data providers did not record density, but just presence/absence; these data are removed.

```

density      <- density[!is.na(density$dens), ]
density$data <- droplevels(density$data)

density$ID <- paste(density$sta, density$tx, sep = "")
```

The total number of species in this data set is 5433

A look at the data

Species densities are summed per station to give the total densities

```

TotalDensity <- aggregate(density$dens, by = list(data = density$data, sta = density$sta, x = density$x
names(TotalDensity)[5] <- "TotalDens"
cat("total number of stations per provider : \n")

## total number of stations per provider :
table(TotalDensity$data)

##  

##   HELCOM MACROBEL  MAREANO      MWTL      NSBS      ODAM      PMP      REBENT
## 914       768       370       103       235      3057       23      216
##  RSMP     SHARK     SMHI
## 23915     6925      587
```

The total number of stations in this data set is 37113

The positions of the stations are plotted, colored according to the data provider

```

require(rworldmap)

## Loading required package: rworldmap
```

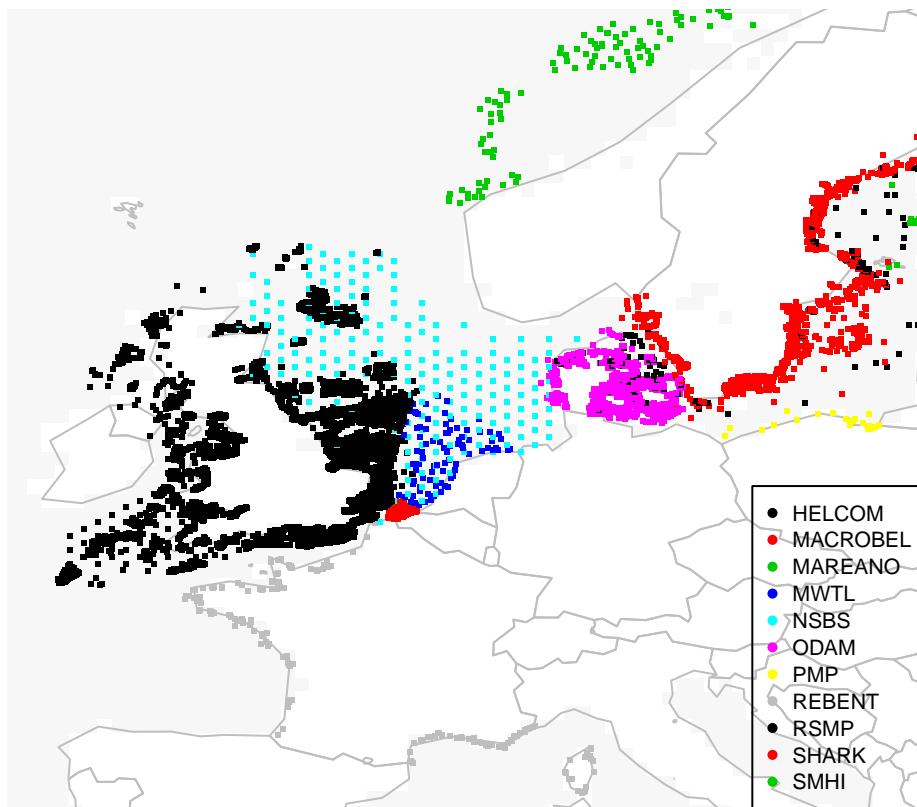
```

## Loading required package: sp
## ### Welcome to rworldmap ####
## For a short introduction type : vignette('rworldmap')
mapGriddedData(colourPalette = rep("white", 5), oceanCol = grey(0.97), addLegend = FALSE,
                xlim = c(-10,20), ylim = c(45,65))
title( "data providers")
with(TotalDensity, points(x, y, pch = ".", cex = 3, col = data))

legend("bottomright", pch = 16, cex = 0.7, col = 1:20, legend = levels(TotalDensity$data))

```

data providers

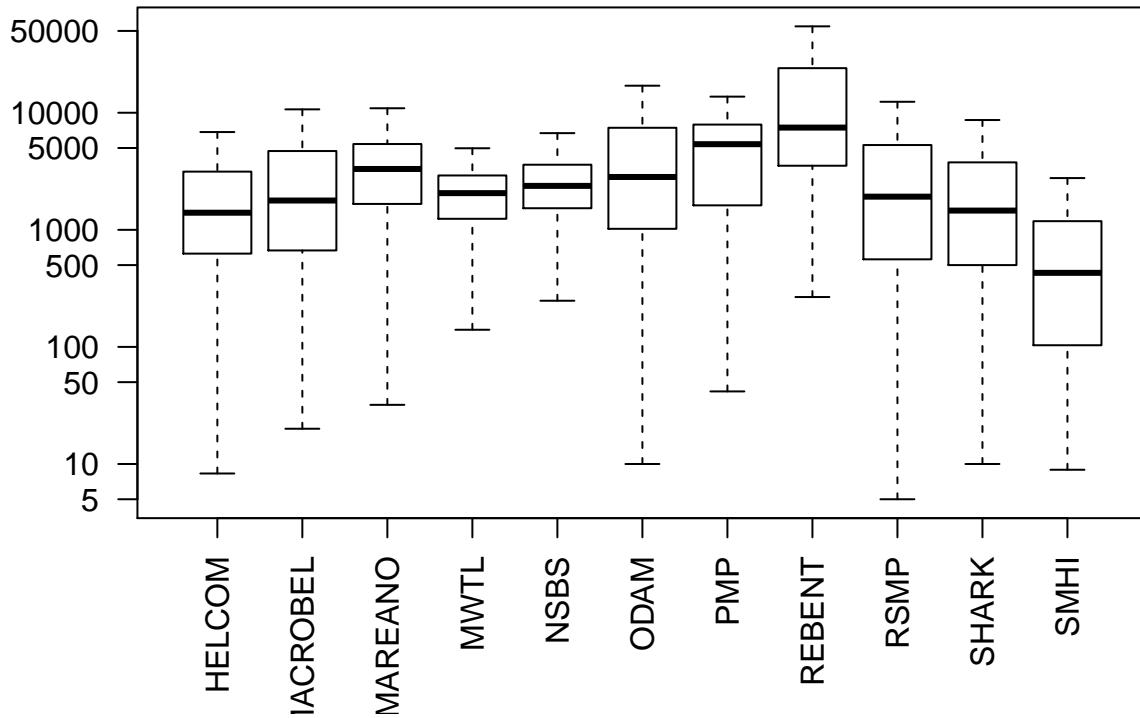


```

with (TotalDensity, boxplot((TotalDens)~data, outline = FALSE, las = 2, main = "Mean Density per data provider"))

```

Mean Density per data provider



Adding individual weights and traits to density data

Weights and trait information is not available for all species, even after determining this information on genus and family level. We create data sets that remove the species that do not have all information. We then calculate total density on this reduced data set and see what fraction of total density we obtain.

First the required taxonomic information is added to the density list:

```
which(!density$tx %in% Taxo$txa)
```

```
## integer(0)
TaxoSpec <- Taxo$txa %in% density$tx
TaxoUsed <- Taxo[Taxo$txa %in% density$tx ,]
density.full <- merge(density, TaxoUsed, by.x = "tx", by.y = "tx")
```

To merge density data with the other data sets, a function is created.

```
MergeData <- function(density = density.full, data2){
  DataWithBiomass      <-      merge(density,           data2, by.x = "tx", by.y = "taxon")  # merging
  DataWithoutBiomass   <- density[!density$ID %in% DataWithBiomass$ID, ]
  DataWithBiomass     <- rbind(DataWithoutBiomass,
                                merge(DataWithoutBiomass, data2, by.x = "gen", by.y = "taxon"))}
```

```

DataWithoutBiomass <- density[!density$ID %in% DataWithBiomass$ID, ]
DataWithBiomass     <- rbind(DataWithBiomass,
                               merge(DataWithoutBiomass, data2, by.x = "fam", by.y = "taxon"))

DataWithoutBiomass <- density[!density$ID %in% DataWithBiomass$ID, ]

DataWithBiomass     <- rbind(DataWithBiomass,
                               merge(DataWithoutBiomass, data2, by.x = "ord", by.y = "taxon"))

DataWithoutBiomass <- density[!density$ID %in% DataWithBiomass$ID, ]

totalDensity <- with (DataWithBiomass, aggregate(dens, by = list(data = data, sta = sta, x = x, y =
colnames(totalDensity)[5] <- "EstDens"
list(complete = DataWithBiomass, incomplete = DataWithoutBiomass, DENS = totalDensity)
}

```

Merging density and weights

```
DensityWeight <- MergeData(density = density.full, data2 = mws)
```

The fraction of data for which individual weight could be estimated = 0.8758442.

The type of organisms for which the information is lacking belong to the phyla:

```
TT <- table(DensityWeight$incomplete$phy)
sort(TT[TT>0], decreasing = TRUE)
```

	Cnidaria	Mollusca	Chordata	Annelida
##	34134	26415	10237	10028
##	Echinodermata	Bryozoa	Arthropoda	Sipuncula
##	9953	9538	9340	7669
##	Porifera	Nemertea	Cephalorhyncha	Platyhelminthes
##	5996	2787	2546	2437
##	Rhodophyta	Ciliophora	Entoprocta	Foraminifera
##	1568	1394	1347	483
##		Hemichordata	Chaetognatha	Brachiopoda
##	347	182	136	134
##	Gastrotricha	Phoronida	Tardigrada	Chlorophyta
##	101	95	46	38
##	Nematomorpha	Ochrophyta	Xenacoelomorpha	Tracheophyta
##	25	25	14	8
##	Nematoda	Acanthocephala	Myzozoa	
##	6	4	1	

Many of these phyla are small organisms (Tardigrada, Foraminifera,...), so the biomass that is not taken into account is probably limited.

Merging density and traits

```
DensityTrait <- MergeData(density = density.full, data2 = traits)
```

The fraction of data for which traits could be estimated = 0.8451735 The unclassified organisms belong to:

```

TT <- table(DensityTrait$incomplete$phy)
sort(TT[TT>0], decreasing = TRUE)

##          Bryozoa      Mollusca      Cnidaria      Arthropoda
##          66661       30504       25460        11490
##          Chordata     Sipuncula     Annelida     Echinodermata
##          8566        7000        6579        5512
##          Porifera    Cephalorhyncha  Ciliophora    Nemertea
##          3262         2505        1394        708
##          Foraminifera Rhodophyta   Platyhelminthes Hemichordata
##          342           341         177         123
##          Brachiopoda Chaetognatha Chlorophyta Ochrophyta
##          107            85          38          24
##          Nematoda    Tracheophyta Myzozoa
##          5              2           1

```

Merging density and feeding types

```
DensityFT <- MergeData(density = density.full, data2 = ft)
```

The fraction of data for which feeding types could be estimated = 0.8743257 The unclassified organisms belong to:

```

TT <- table(DensityFT$incomplete$phy)
sort(TT[TT>0], decreasing = TRUE)

```

```

##          Bryozoa      Cnidaria      Mollusca      Chordata
##          66661       25460       11121        8566
##          Sipuncula     Annelida     Porifera     Arthropoda
##          7000        6579        3262        3086
##          Cephalorhyncha  Ciliophora  Echinodermata Nemertea
##          2505         1394        1123        708
##          Foraminifera  Rhodophyta  Platyhelminthes Hemichordata
##          342           341         177         123
##          Brachiopoda   Chaetognatha Chlorophyta Ochrophyta
##          107            85          38          24
##          Nematoda     Tracheophyta Myzozoa
##          5              2           1

```

Data for estimating bioturbation potential

```

DataAll <- merge(DensityWeight$complete [, c("tx", "data", "sta", "x", "y", "dens", "ID", "meanW")],
                  DensityTrait$complete[, c("ID", "Motility", "Body.size", "Burrowing.depth", "Morphology",
                  "Mixing.rate", "Mi", "Mi2", "Ri", "Morphology.2", "Morphology.2",
                  "Body.size.2", "Burrowing.depth.2", "Mixing.rate.2")], by = "ID"

dim(DataAll)
## [1] 880265      23

```

```
dim(density.full)
```

```
## [1] 1103726      14
```

The fraction of data that has all information to estimate bioturbation potential = 0.7975394

Check on the representativeness of the reduced data set

For the mwltl data we now compare the measured biomass with the biomass that we estimate, based on the mean weights. Note that in the MWTLdata, the density is called "ind" (from number of individuals)

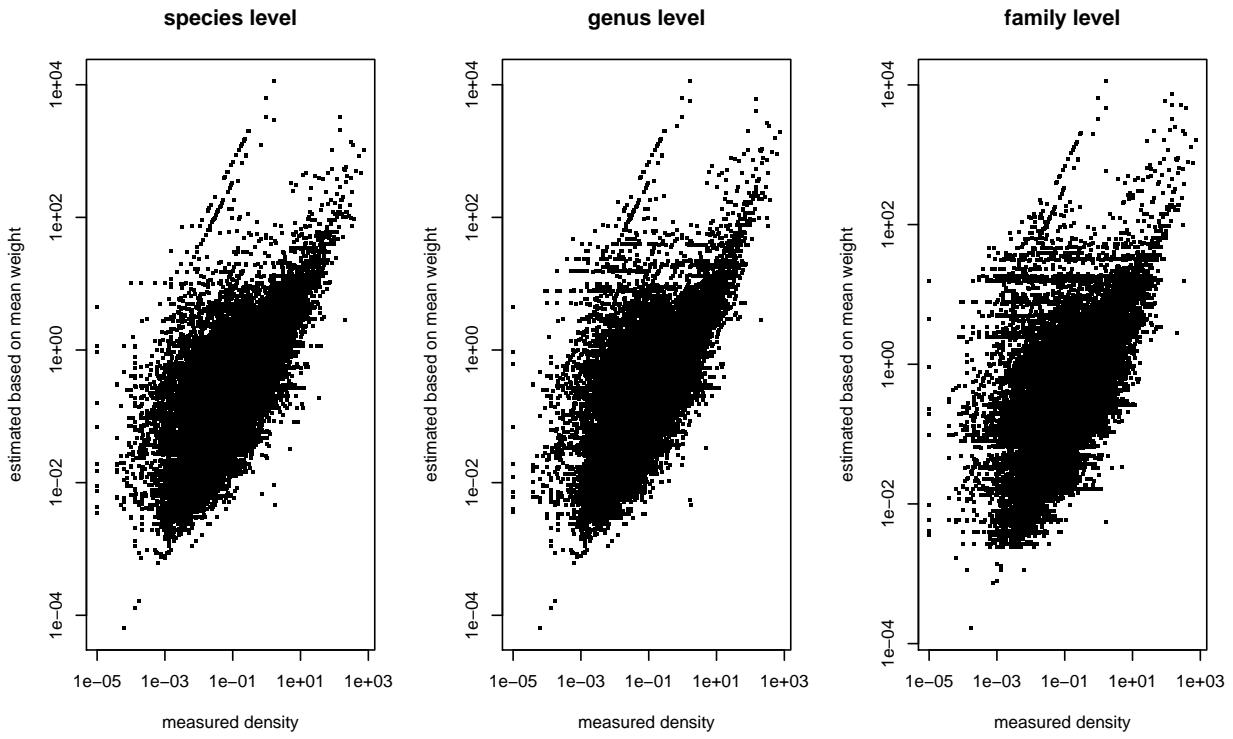
```
par(mfrow = c(1,3))
mws.species$tax <- rownames(mws.species)
MWTL.data <- subset(MWTLdata, ind > 0 & biom > 0)
#MWTL.data <- merge(MWTL.data, Taxo)
mwscompare <- merge(mws.species, MWTL.data)
with(mwscompare, plot(biom, ind*meanW, log = "xy", pch = ".", cex = 3,
                      xlab = "measured density", ylab = "estimated based on mean weight", main = "species level"))
with(mwscompare, summary(ind*meanW-biom))

##      Min.    1st Qu.     Median      Mean    3rd Qu.      Max.
## -274.205   -0.001     0.011     1.743     0.128 11264.787

mws.genus$gen <- rownames(mws.genus)
mwscompare <- merge(mws.genus, MWTL.data)
with(mwscompare, plot(biom, ind*meanW, log = "xy", pch = ".", cex = 3,
                      xlab = "measured density", ylab = "estimated based on mean weight", main = "genus level"))
with(mwscompare, summary(ind*meanW-biom))

##      Min.    1st Qu.     Median      Mean    3rd Qu.      Max.
## -264.275   -0.001     0.010     2.966     0.171 11264.787

mws.family$fam <- rownames(mws.family)
mwscompare <- merge(mws.family, MWTL.data)
with(mwscompare, plot(biom, ind*meanW, log = "xy", pch = ".", cex = 3,
                      xlab = "measured density", ylab = "estimated based on mean weight", main = "family level"))
```



```
with(mwscompare, summary(ind*meanW-biom))
```

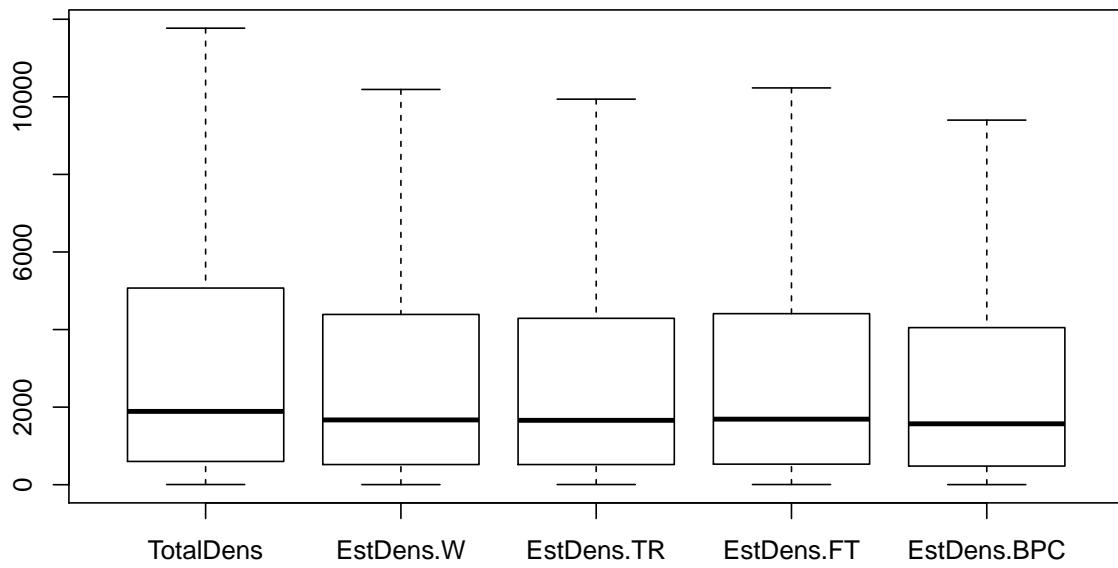
	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
##	-323.832	-0.001	0.028	4.318	0.357	11264.787

We also check the error we would make in the density data if we would estimate them on the merged data sets.

```
DENS <- merge(TotalDensity, DensityWeight$DENS); colnames(DENS)[ncol(DENS)] <- "EstDens.W"
DENS <- merge(DENS, DensityTrait$DENS); colnames(DENS)[ncol(DENS)] <- "EstDens.TR"
DENS <- merge(DENS, DensityFT$DENS); colnames(DENS)[ncol(DENS)] <- "EstDens.FT"

TotDensAll <- with(DataAll, aggregate(dens, by = list(data = data, sta = sta, x = x, y = y), FUN = sum))
colnames(TotDensAll)[5] <- "EstDens.BPC"
DENS <- merge(DENS, TotDensAll)

boxplot(DENS[,-(1:4)], log = "", outline = FALSE)
```



```

cat("fraction of density based on species for which weight is known:\n")

## fraction of density based on species for which weight is known:
with(DENS, summary(EstDens.W/TotalDens))

##      Min. 1st Qu. Median     Mean 3rd Qu.      Max.
## 0.001316 0.830189 0.929717 0.883898 0.996558 1.000000

cat("fraction of density based on species for which traits are known:\n")

## fraction of density based on species for which traits are known:
with(DENS, summary(EstDens.TR/TotalDens))

##      Min. 1st Qu. Median     Mean 3rd Qu.      Max.
## 0.001121 0.813509 0.936709 0.878555 0.999525 1.000000

cat("fraction of density based on species for which feeding type is known:\n")

## fraction of density based on species for which feeding type is known:
with(DENS, summary(EstDens.FT/TotalDens))

##      Min. 1st Qu. Median     Mean 3rd Qu.      Max.
## 0.001316 0.840909 0.957272 0.896053 1.000000 1.000000

cat("fraction of density based on species for which all is known:\n")

## fraction of density based on species for which all is known:
with(DENS, summary(EstDens.BPC/TotalDens))

##      Min. 1st Qu. Median     Mean 3rd Qu.      Max.

```

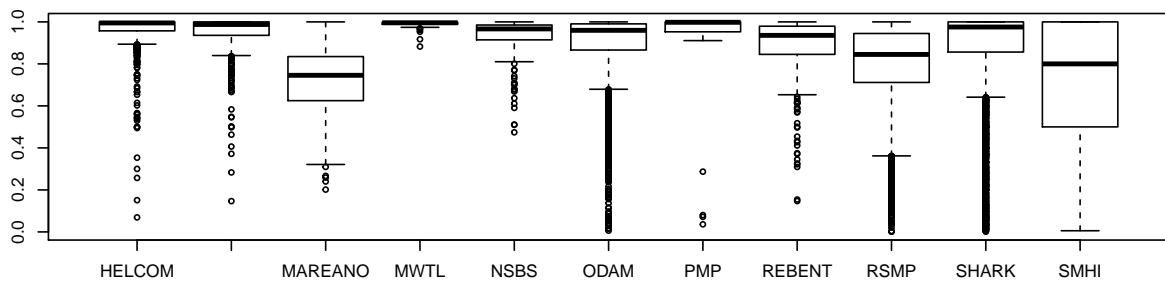
```
## 0.001121 0.741935 0.888889 0.832443 0.984615 1.000000
```

The estimated density if we only use species for which have all data required for BPc estimation is thus on average 0.8324433 of the true value.

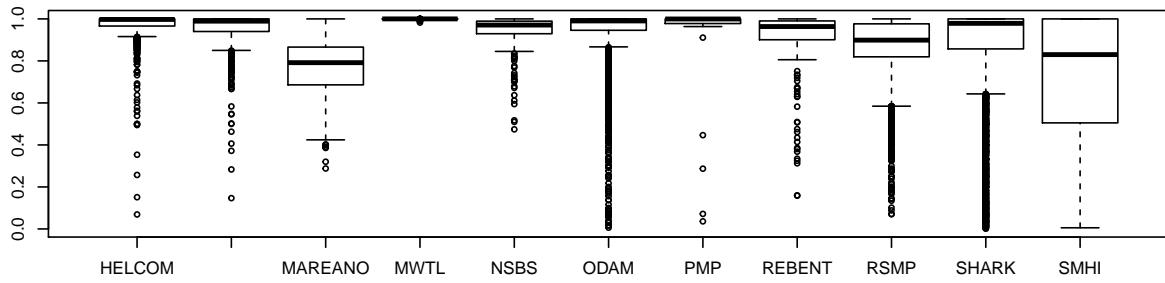
As we want to estimate bioturbation potential, we now split this number for the different data providers to see for which data sets we make the largest errors.

```
par(mfrow = c(3,1))
DENS$r.bpc <- DENS$EstDens.BPC/DENS$TotalDens
DENS$r.w   <- DENS$EstDens.W/DENS$TotalDens
DENS$r.ft  <- DENS$EstDens.FT/DENS$TotalDens
with(DENS, boxplot(r.bpc ~ data, main = "estimated fraction of density for BPc calculations"))
with(DENS, boxplot(r.w ~ data, main = "estimated fraction of density for Weights"))
with(DENS, boxplot(r.ft ~ data, main = "estimated fraction of density for Feeding types"))
```

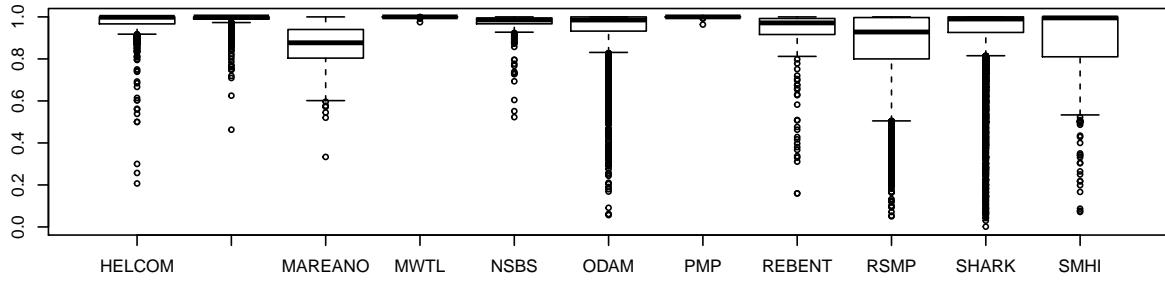
estimated fraction of density for BPc calculations



estimated fraction of density for Weights



estimated fraction of density for Feeding types



The mean recovered fraction of density for the various data providers is :

```
D <- data.frame(BPC = with(DENS, tapply(r.bpc, INDEX = data, FUN = mean)),
                 W = with(DENS, tapply(r.w, INDEX = data, FUN = mean)),
                 FT = with(DENS, tapply(r.ft, INDEX = data, FUN = mean)))
knitr:::kable(D, digits = 1)
```

	BPC	W	FT
HELCOM	0.9609198	0.9672662	0.9702654
MACROBEL	0.9500470	0.9520774	0.9826944
MAREANO	0.7202315	0.7688202	0.8585159
MWTL	0.9907961	0.9992683	0.9992434
NSBS	0.9297956	0.9352938	0.9611760
ODAM	0.8868025	0.9363271	0.9308547
PMP	0.8376353	0.8564493	0.9974889
REBENT	0.8687459	0.9011789	0.9079913
RSMP	0.8114143	0.8821951	0.8777615
SHARK	0.8589040	0.8606155	0.9233342
SMHI	0.7239096	0.7388481	0.8860511

Estimating BPc, the bioturbation potential

The bioturbation potential is now estimated on the reduced data set. First the contribution of each species to BPc is estimated, based on the individual weight, the abundance, and their mobility and reworking mode.

```
BPc <- function(weight, abundance, mobility, rework)
  sqrt(weight) * abundance * mobility * rework

DataAll$BPC <- BPc(DataAll$meanW, DataAll$dens, as.numeric(DataAll$Mi), as.numeric(DataAll$Ri))
DataAll$Biomass <- DataAll$meanW * DataAll$dens
```

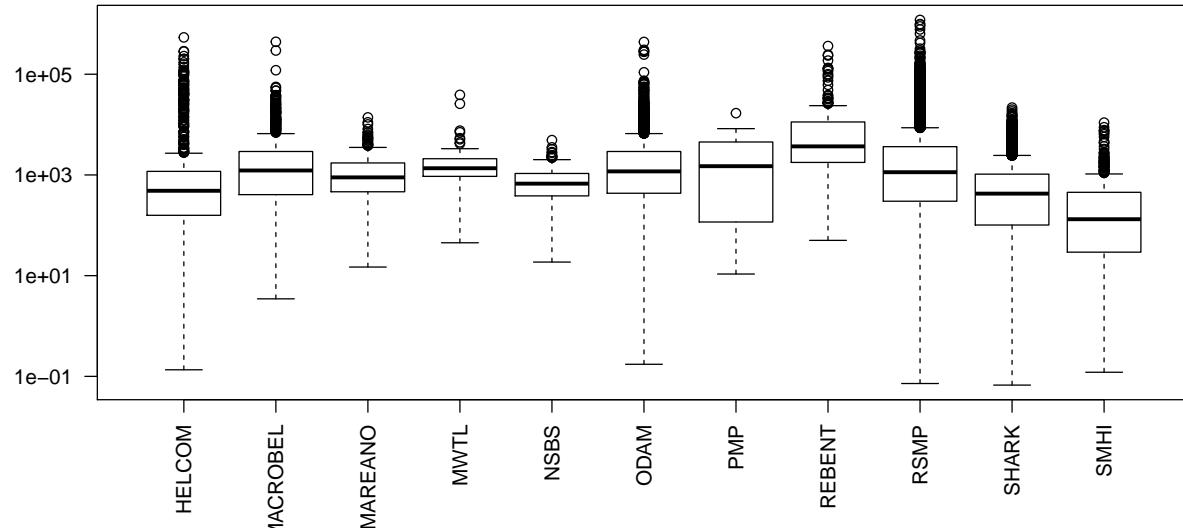
Then the BPcs of all species per station are added.

```
TotalBPC <- with (DataAll, aggregate(BPC, by=list(data = data, sta = sta, x = x, y = y), FUN=sum, na.rm = TRUE))
names(TotalBPC) [5] <- "BPc"
```

Characteristics per data provider

```
with(TotalBPC, boxplot(BPC~data, main = "BPc", log = "y", las = 2))
```

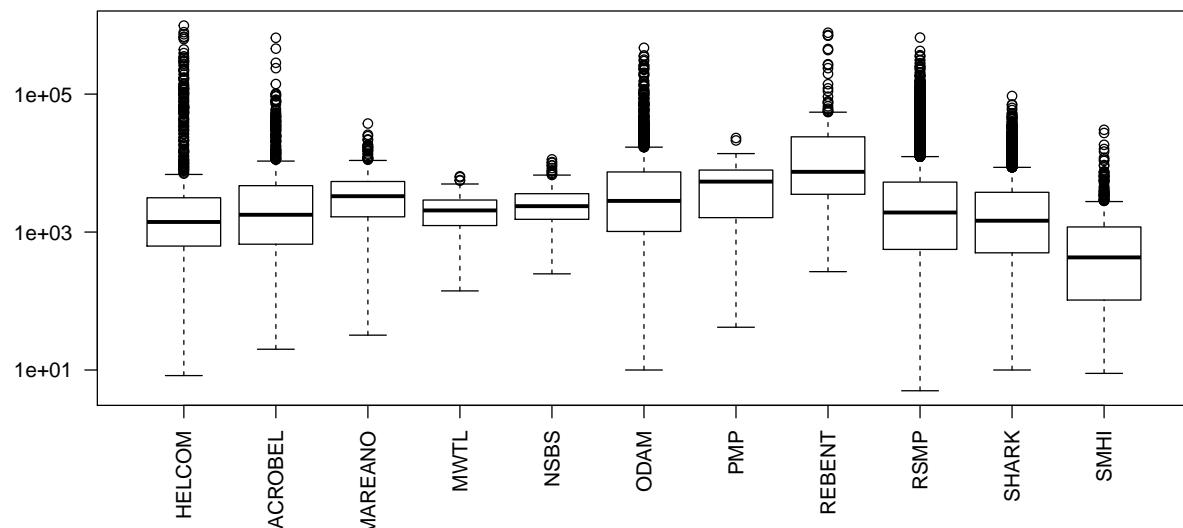
BPC



TotalDensity was already calculated

```
with(TotalDensity, boxplot(TotalDens~data, main = "Total density", log = "y", las = 2))
```

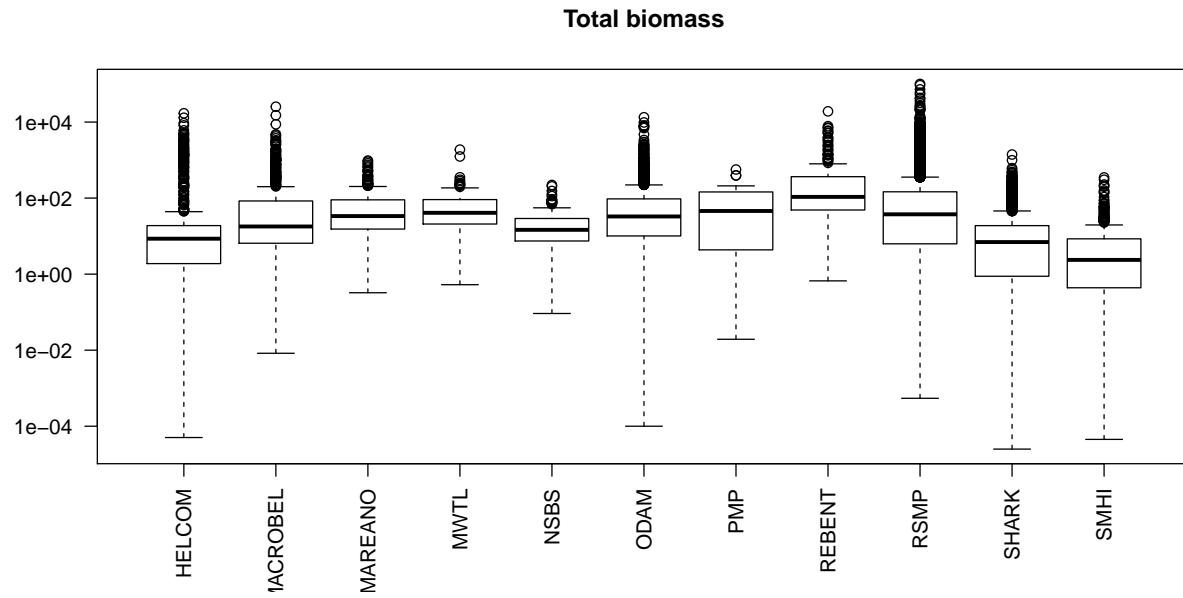
Total density



The total biomass per station:

```
TotalBiomass <- with(DensityWeight$complete, aggregate(dens*meanW, by=list(data = data, sta = sta, x = x), colnames(TotalBiomass)[5] <- "AFDW")

with(TotalBiomass, boxplot(AFDW~data, main = "Total biomass", log = "y", las = 2))
```

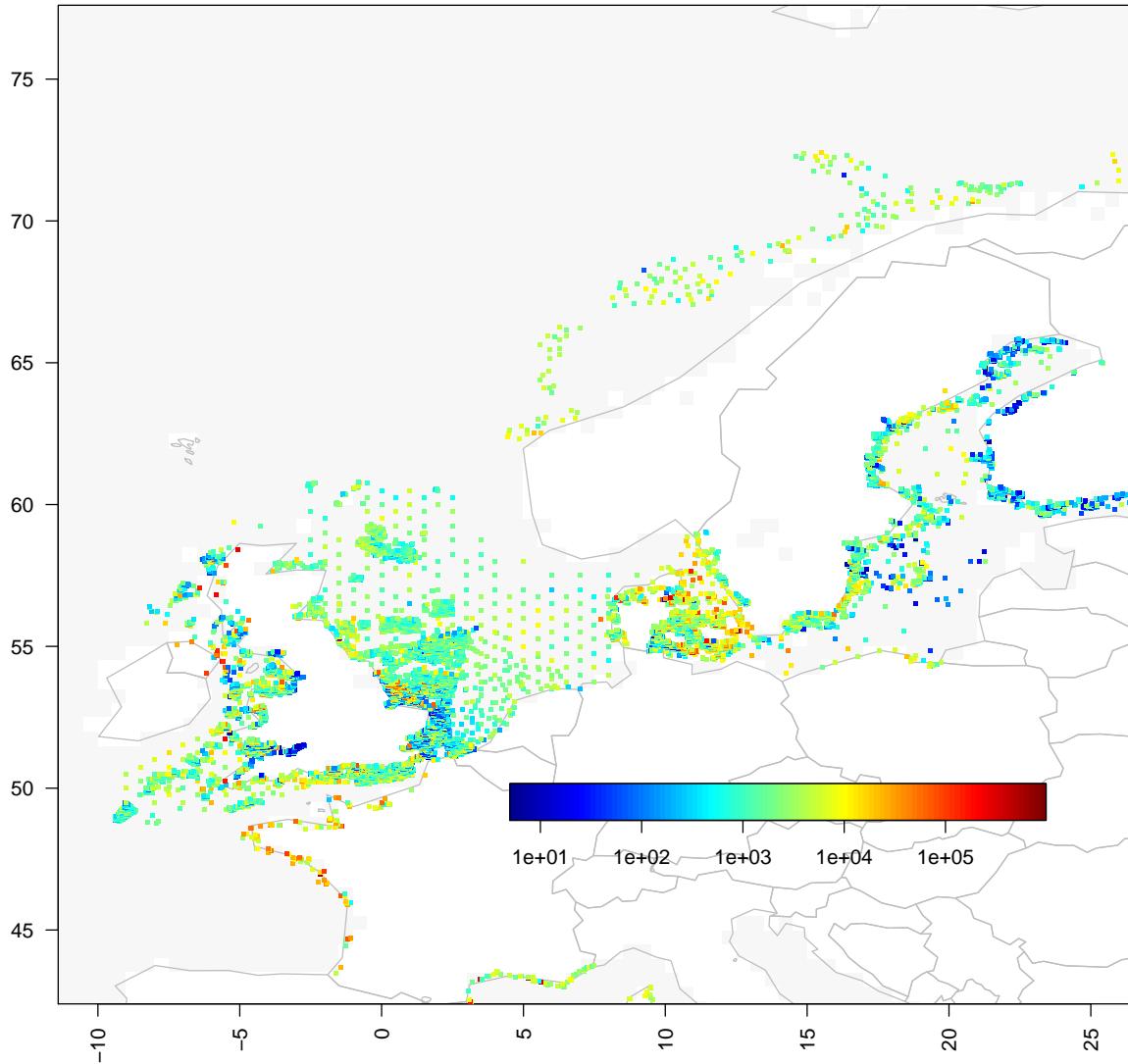


A function is created to generate image plots

```
par(mfrow = c(2,2), oma = c(0,0,0,2))
ImagePlot <- function(x, y, colvar, main = "", ...){
  par(las = 2)
  require(rworldmap)
  mapGriddedData(colourPalette = rep("white", 5), oceanCol = grey(0.97), addLegend = FALSE,
                 xlim = c(-10,25), ylim = c(45,75))
  axis(side = 1); axis(side = 2)
  box()
  title(main)
  points2D(x, y, colvar = colvar, pch = ".", cex = 4, las = 1, add = TRUE,
            colkey = list(side = 1, dist = -0.15, length = 0.5, shift = 0.15), ...)
}

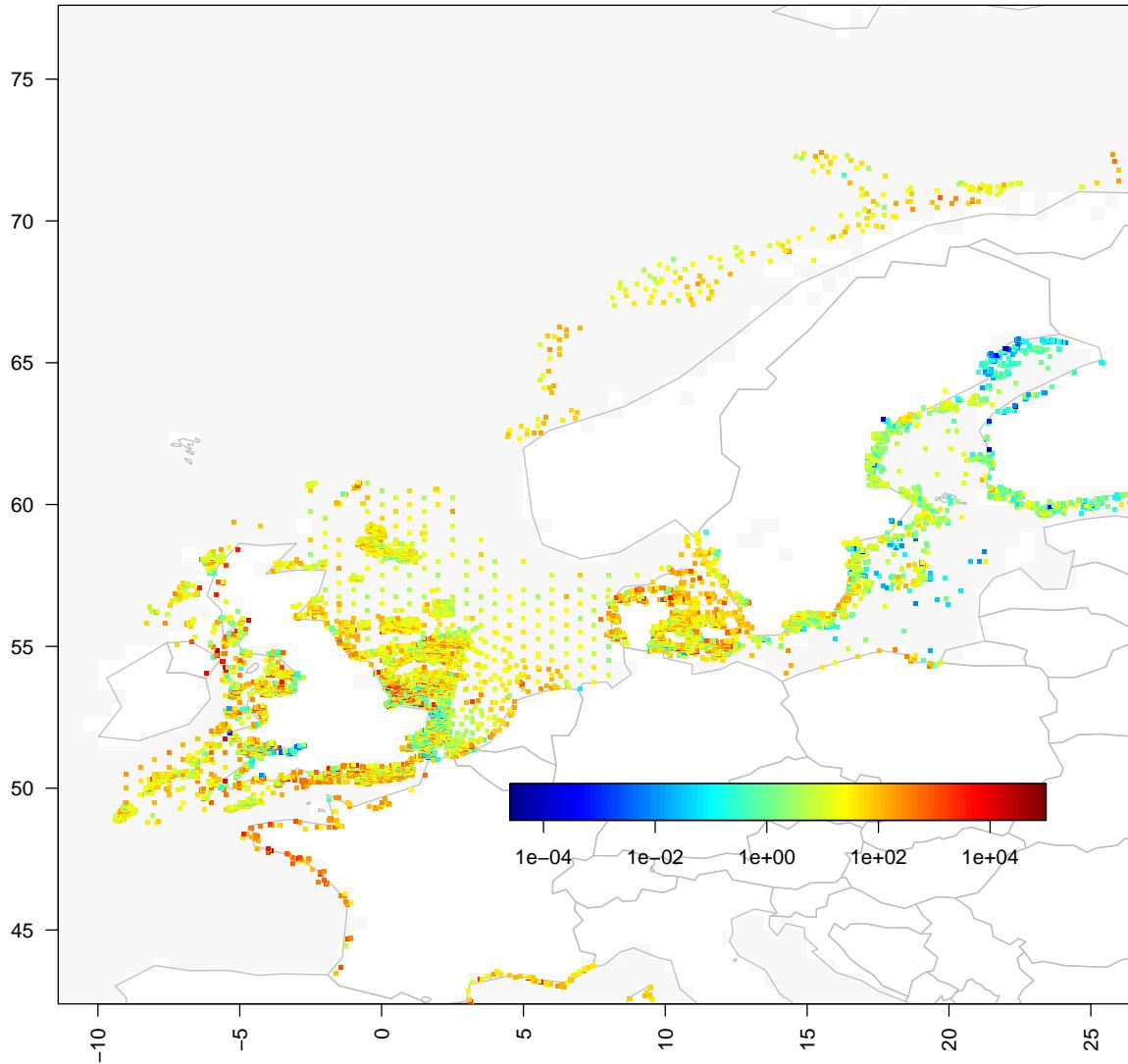
ImagePlot(x = TotalDensity$x, y = TotalDensity$y, colvar = TotalDensity$TotalDens,
          main = "Density, ind/m2", log = "c")
```

Density, ind/m²



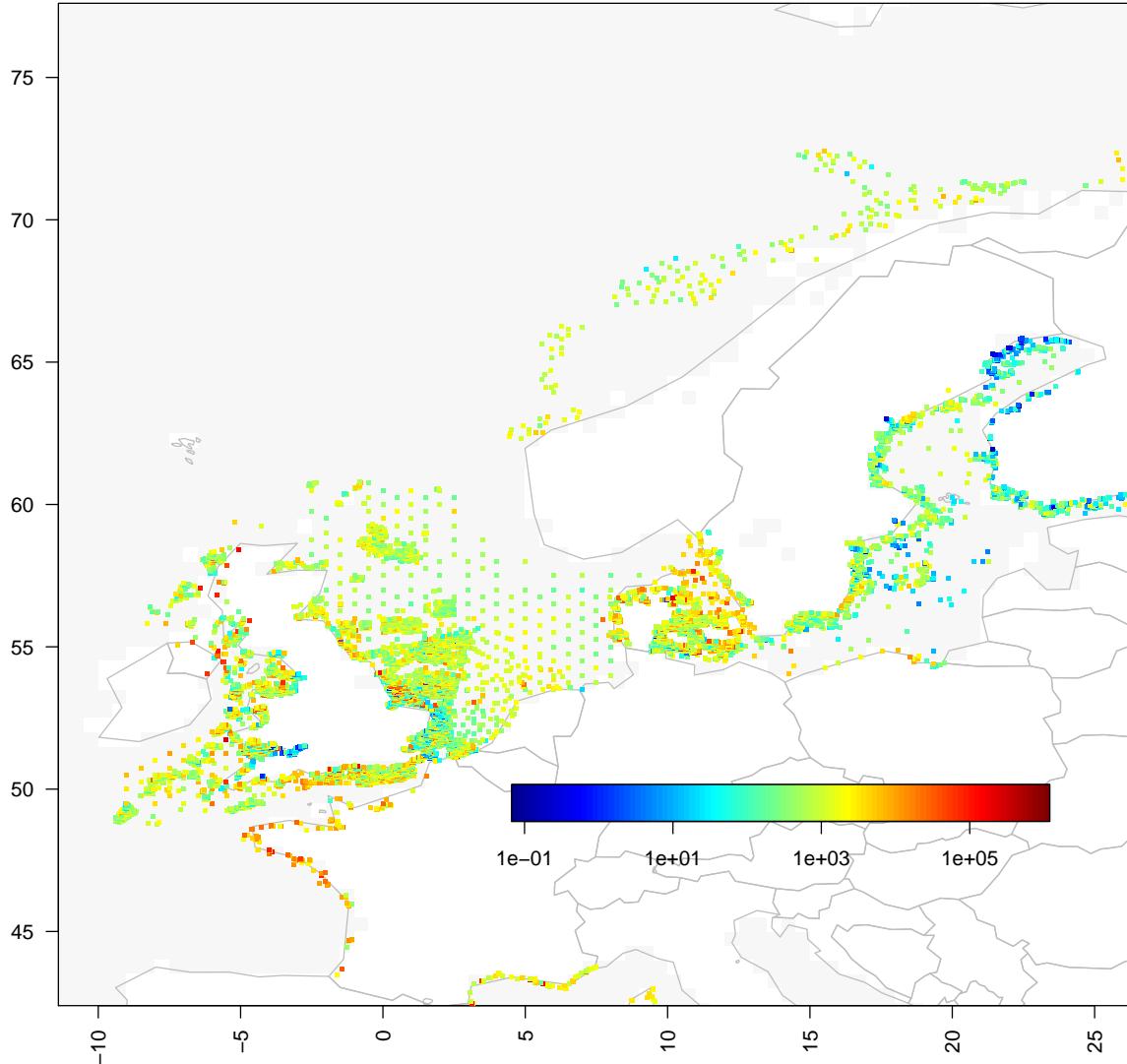
```
ImagePlot(x = TotalBiomass$x, y = TotalBiomass$y, colvar = TotalBiomass$AFDW,  
main = "AFDW, g/m2", log = "c")
```

AFDW, g/m²



```
ImagePlot(x = TotalBPC$x, y = TotalBPC$y, colvar = TotalBPC$BPC,  
main = "Bioturbation potential", log = "c")
```

Bioturbation potential



Biomass per feeding type

```

Weight_FT <- merge(DensityFT$complete[,c(1:7,15)], DensityWeight$complete[,c(7,15)], by = "ID")
Weight_FT$Biomass <- Weight_FT$dens * Weight_FT$meanW

FT_Stats <- with(Weight_FT, tapply(Biomass, INDEX = list(sta, ft), FUN = sum, na.rm = TRUE))
FT_Stats <- data.frame(sta = rownames(FT_Stats), FT_Stats,
                       AFDW_FT = rowSums(FT_Stats, na.rm = TRUE))
FT_Stats <- merge(TotalBiomass,FT_Stats, by = "sta")
head(FT_Stats)

```

```

##          sta   data      x      y     AFDW    CaSc      De
## 1  HELCOM1 HELCOM 8.267167 56.72267 1448.25300 17.149599 42.126847

```

```

## 2 HELCOM10 HELCOM 9.238333 56.65717 2397.50931 1.317834 222.075764
## 3 HELCOM100 HELCOM 11.485833 56.20500 103.42123 16.583690 19.015784
## 4 HELCOM101 HELCOM 11.500000 57.83333 16.53744 4.145739 1.867202
## 5 HELCOM102 HELCOM 11.516667 57.75000 14.20329 2.931471 2.878464
## 6 HELCOM103 HELCOM 11.525000 57.54998 149.55492 57.640406 23.736603
##          He          Om Pa          Su          SuDe        AFDW_FT
## 1 0.07849892 514.74474652 NA 788.696816 81.543487 1444.34000
## 2          NA 123.90006780 NA 2045.790024 4.425617 2397.50931
## 3 0.09126297          NA NA 24.847185 32.864295 93.40222
## 4 0.05977934 0.06218908 NA 4.780328 5.622207 16.53744
## 5 0.08151728 0.09328362 NA 4.373339 3.845220 14.20329
## 6 0.14673111 2.01267472 NA 34.686426 31.332081 149.55492

```

The stations where none of the feeding types are known are removed, and the most dominant feeding type selected.

```
ISNAS <- unlist(apply(FT_Stats[,6:12], FUN = function(x) sum(is.na(x)), MARGIN = 1))
table(ISNAS)
```

```

## ISNAS
##    0    1    2    3    4    5    6    7
## 1077 5117 13905 6480 4270 3601 2360   48

```

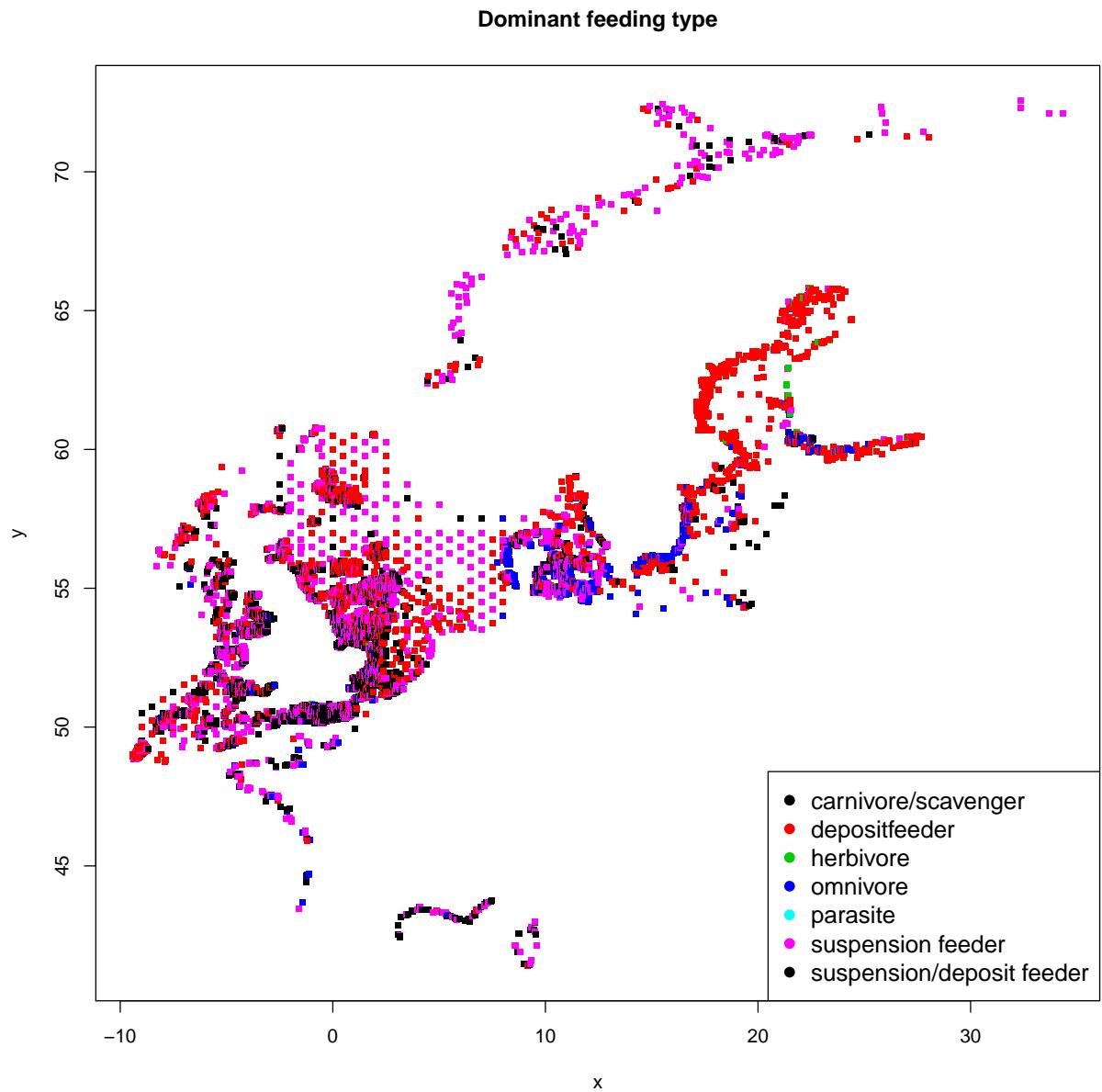
```
FT_Stats <- FT_Stats[ISNAS < 7,]
NAMES <- colnames(FT_Stats)[6:12]
```

```
FT_Stats$dominant <- unlist(apply(FT_Stats[,6:12], FUN = function(x) NAMES[which.max(x)], MARGIN = 1))
FT_Stats$dominant <- as.factor(FT_Stats$dominant)
```

```
FTnames <- as.data.frame(matrix(ncol = 2, byrow = TRUE, data = c(
  "CaSc" , "carnivore/scavenger",
  "De" , "depositfeeder",
  "He" , "herbivore",
  "Om" , "omnivore",
  "Pa" , "parasite",
  "Su" , "suspension_feeder",
  "SuDe" , "suspension/deposit_feeder"
)))

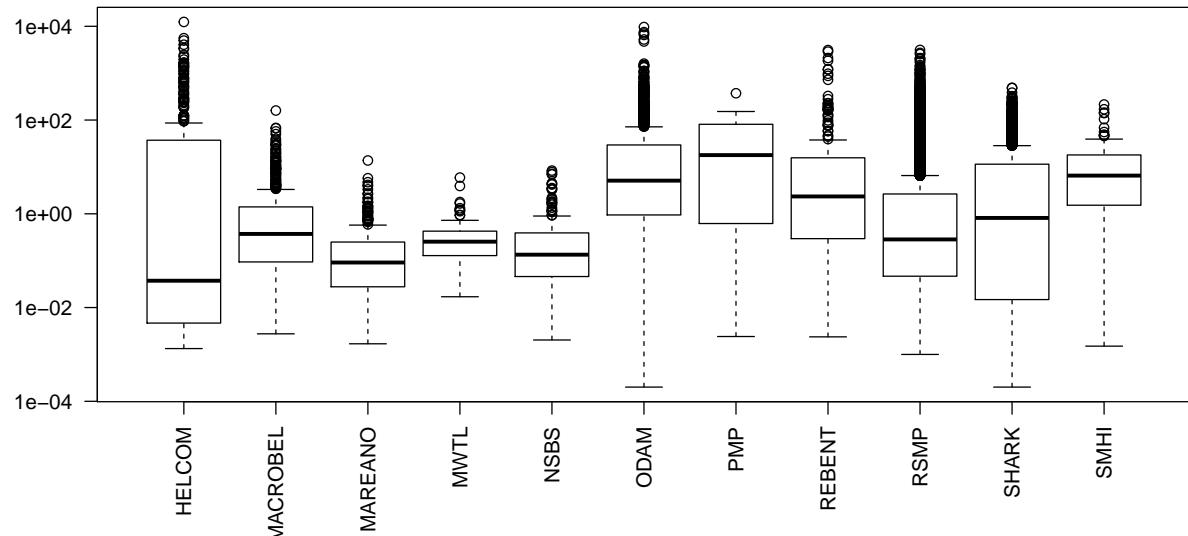
```

```
with (FT_Stats, plot(x, y, col = c(1:6)[dominant], pch = ".", cex = 5, main = "Dominant feeding type"))
legend("bottomright", col = 1:6, legend = FTnames[,2], pch = 16, cex = 1.25)
```

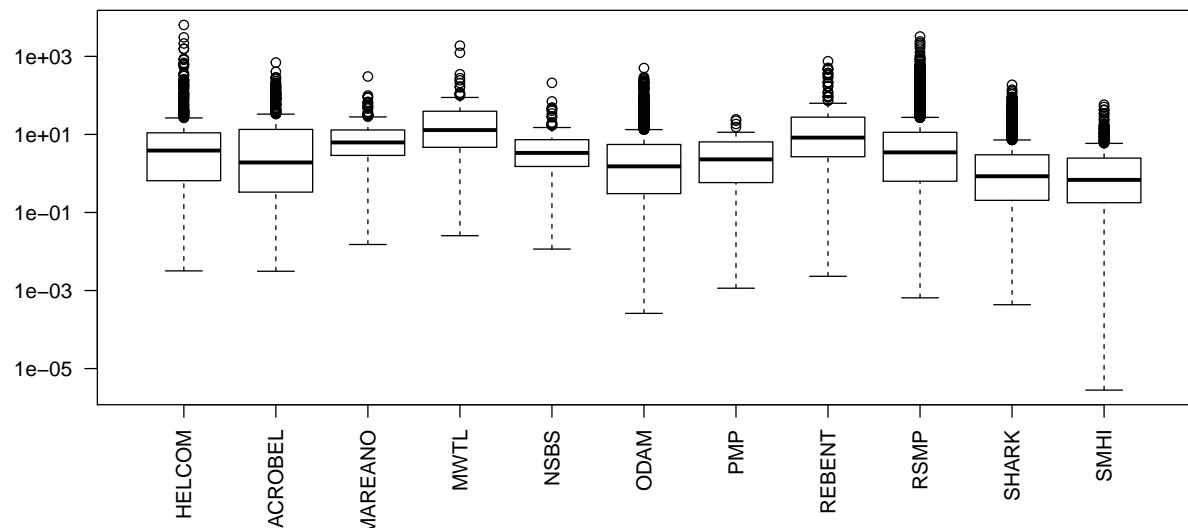


```
par(mfrow = c(2,1))
with(FT_Stats, boxplot(0m~data, main = "Total biomass Omnivores", log = "y", las = 2))
with(FT_Stats, boxplot(De~data, main = "Total biomass Deposit feeders", log = "y", las = 2))
```

Total biomass Omnivores

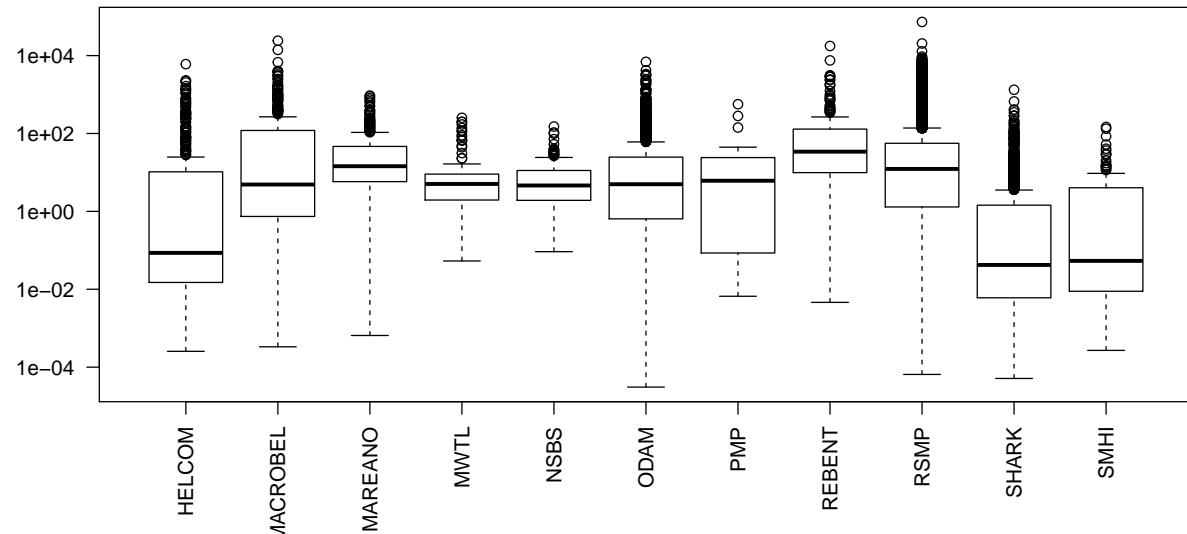


Total biomass Deposit feeders

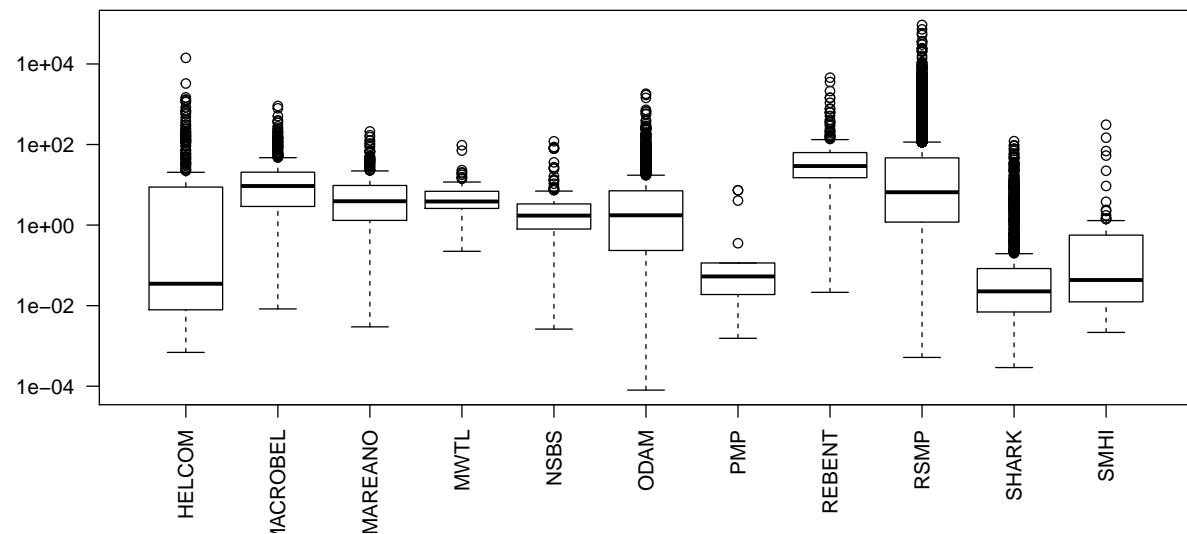


```
par(mfrow = c(2,1))
with(FT_Stats, boxplot(Su~data, main = "Total biomass Suspension feeders", log = "y", las = 2))
with(FT_Stats, boxplot(CaSc~data, main = "Total biomass Carnivore/scavengers", log = "y", las = 2))
```

Total biomass Suspension feeders

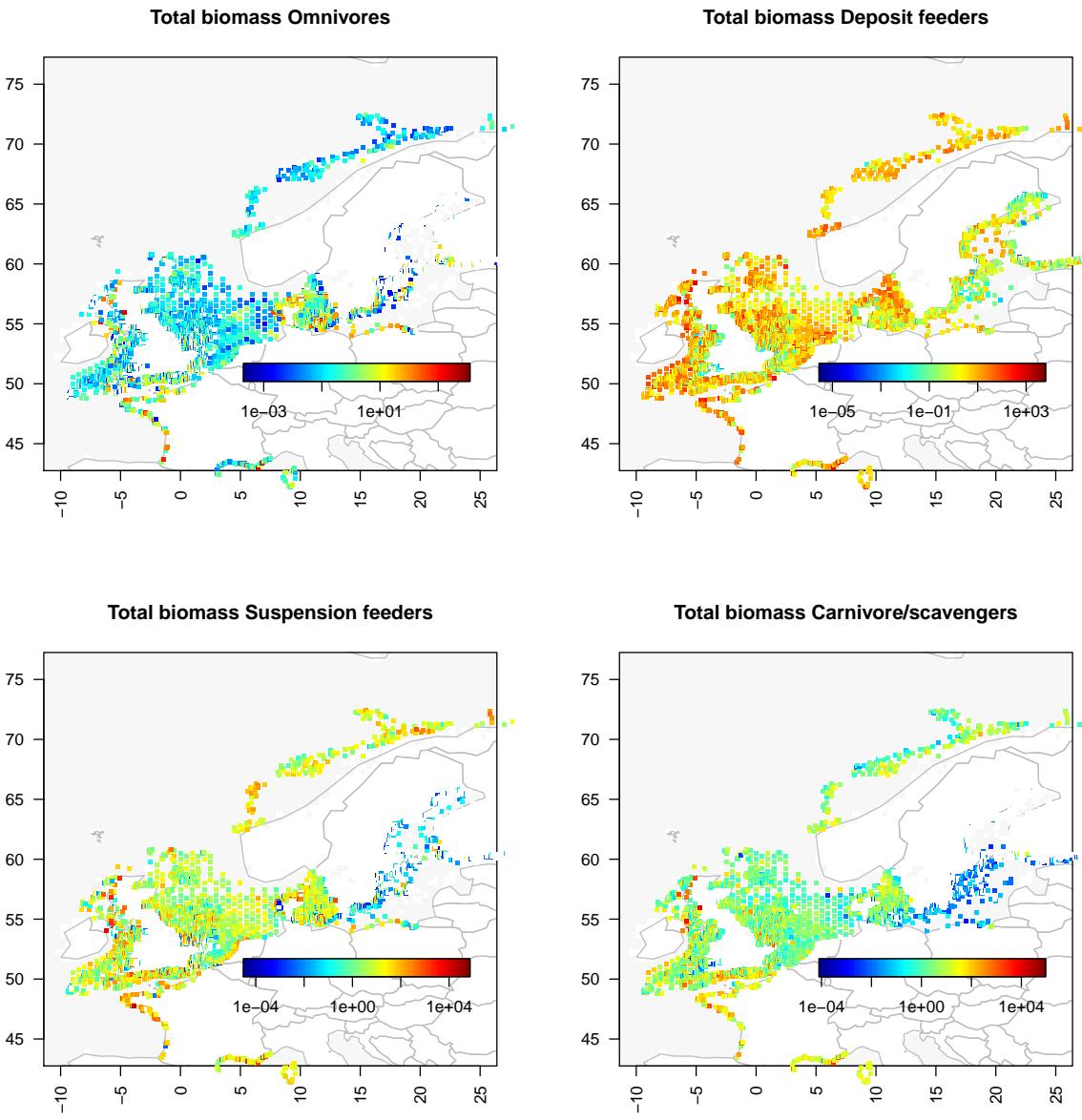


Total biomass Carnivore/scavengers



The total biomasses of feeding types

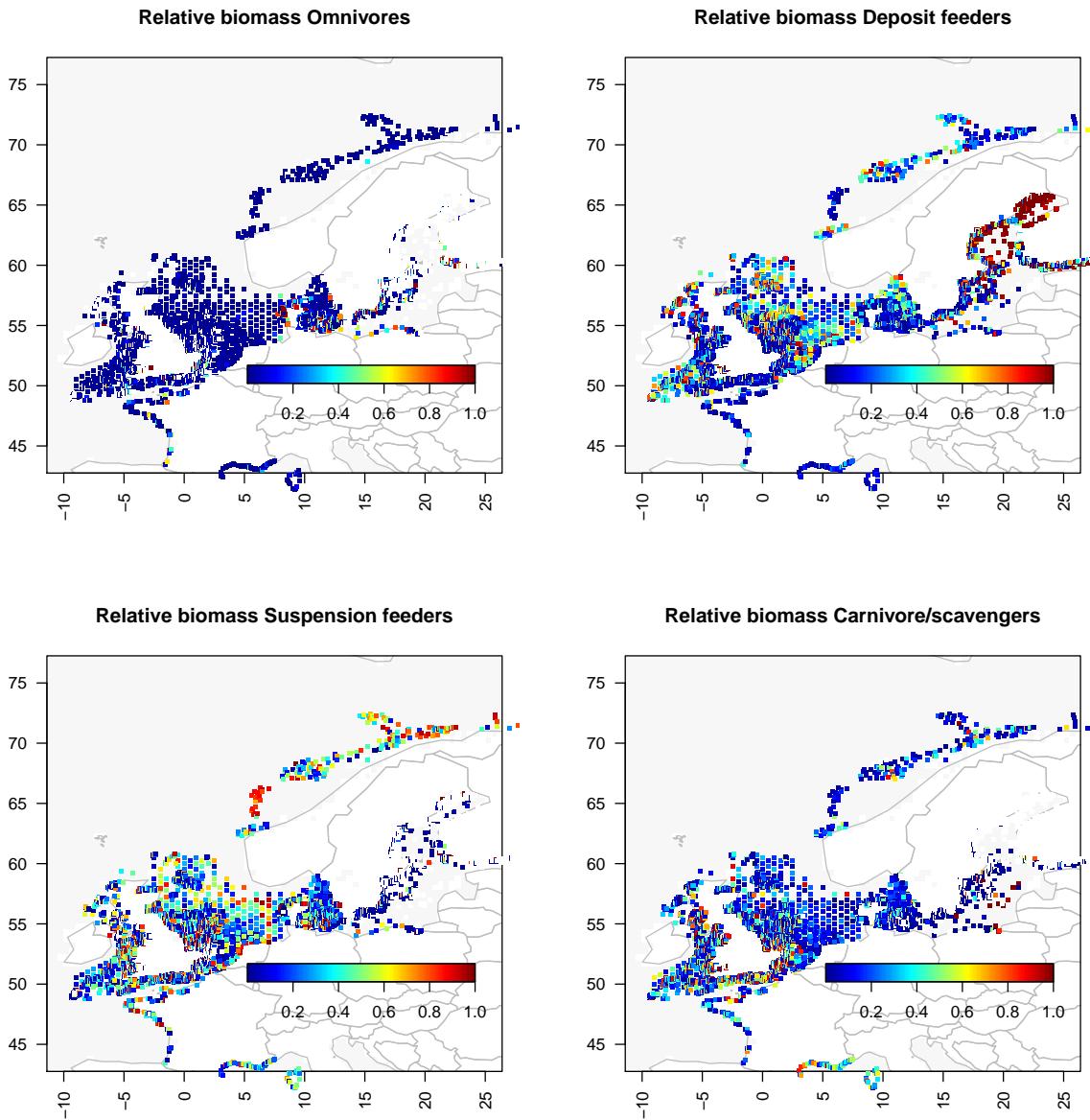
```
par(mfrow = c(2,2), oma = c(0,0,0,2))
ImagePlot(x = FT_Stats$x, y = FT_Stats$y, colvar = FT_Stats$Om,
           main = "Total biomass Omnivores", log = "c")
ImagePlot(x = FT_Stats$x, y = FT_Stats$y, colvar = FT_Stats$De,
           main = "Total biomass Deposit feeders", log = "c")
ImagePlot(x = FT_Stats$x, y = FT_Stats$y, colvar = FT_Stats$Su,
           main = "Total biomass Suspension feeders", log = "c")
ImagePlot(x = FT_Stats$x, y = FT_Stats$y, colvar = FT_Stats$CaSc,
           main = "Total biomass Carnivore/scavengers", log = "c")
```



The relative biomasses of feeding types

```
par(mfrow = c(2,2), oma = c(0,0,0,2))
FT_rel <- FT_Stats
FT_rel[,6:12] <- FT_rel[,6:12]/FT_rel$AFDW_FT

ImagePlot(x = FT_rel$x, y = FT_rel$y, colvar = FT_rel$Om,
           main = "Relative biomass Omnivores", log = "")
ImagePlot(x = FT_rel$x, y = FT_rel$y, colvar = FT_rel$De,
           main = "Relative biomass Deposit feeders", log = "")
ImagePlot(x = FT_rel$x, y = FT_rel$y, colvar = FT_rel$Su,
           main = "Relative biomass Suspension feeders", log = "")
ImagePlot(x = FT_rel$x, y = FT_rel$y, colvar = FT_rel$CaSc,
           main = "Relative biomass Carnivore/scavengers", log = "")
```



Writing the results

```

write.csv(file = "results/Density.csv", TotalDensity)
write.csv(file = "results/Biomass.csv", TotalBiomass)
write.csv(file = "results/BPC.csv", TotalBPC)
SuspensionFeeders <- FT_Stats[,c(2,1,3,4,11)]; names(SuspensionFeeders)[5] <- "AFDW_S"
DepositFeeders <- FT_Stats[,c(2,1,3,4,7)]; names(DepositFeeders)[5] <- "AFDW_D"
write.csv(file = "results/SuspensionFeeders.csv", SuspensionFeeders)
write.csv(file = "results/DepositFeeders.csv", DepositFeeders)

```

References

Solan M, Cardinale BJ, Downing AL, Engelhardt KAM, Ruesink JL, Srivastava DS. 2004. Extinction and ecosystem function in the marine benthos. *Science* 306:1177–80.