



# Rmapping



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**PhD Toolbox**  
**R introductory course - stream II**

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# What does “mapping” means

**Georeferencing** of biological data (or mapping for the friends) is part of **topography**

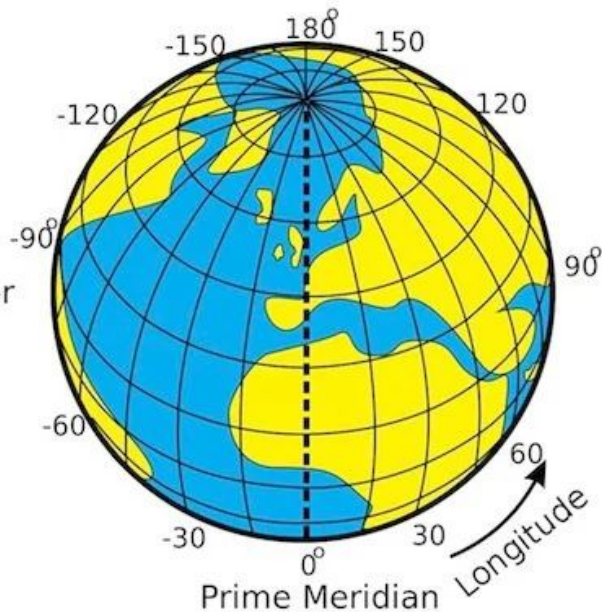
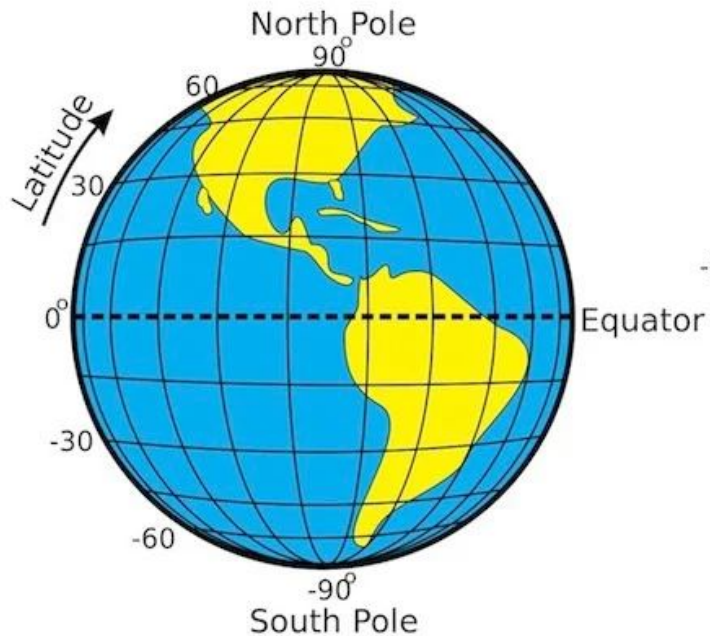
## Definition 1:

Topography is the study of the forms and **features** of land surfaces. The topography of an area may refer to the land forms and features themselves, or a description or depiction in maps.

## Definition 2:

Topography is a field of geoscience and planetary science and is concerned with local detail in general, **including** not only relief, but also **natural**, artificial, and cultural **features** such as roads, land boundaries, and buildings.

# Georeferencing



Each site on our sub-spheric planet can be individuated using an X and an Y value called coordinates.

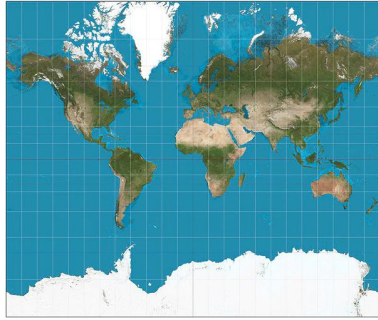
X = longitude

Y = latitude

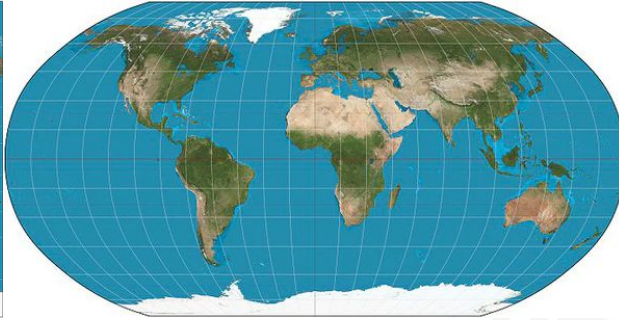
Coordinate systems are many and are based on several different models, each of them has its pros and its cons

Basically it is difficult to PROJECT on a plane something spheric without distortions

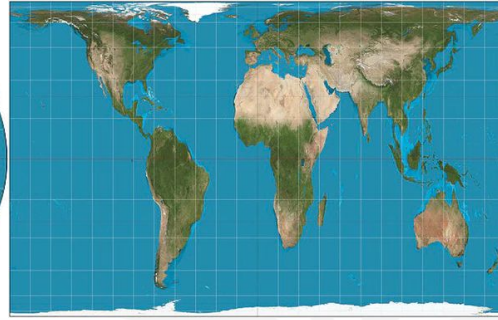
# Georeferencing



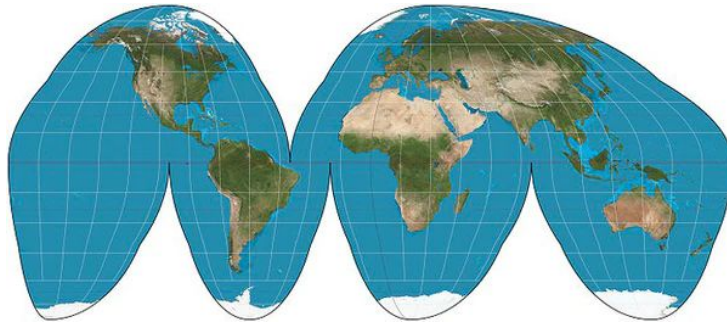
Mercator



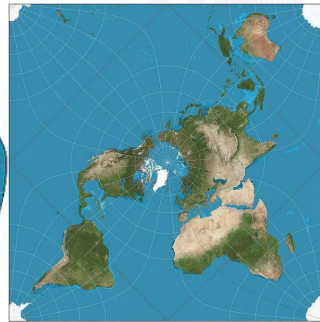
Robinson



Gall-Peters



Goode's Homolosine



Quincuncial



Dymaxion Map

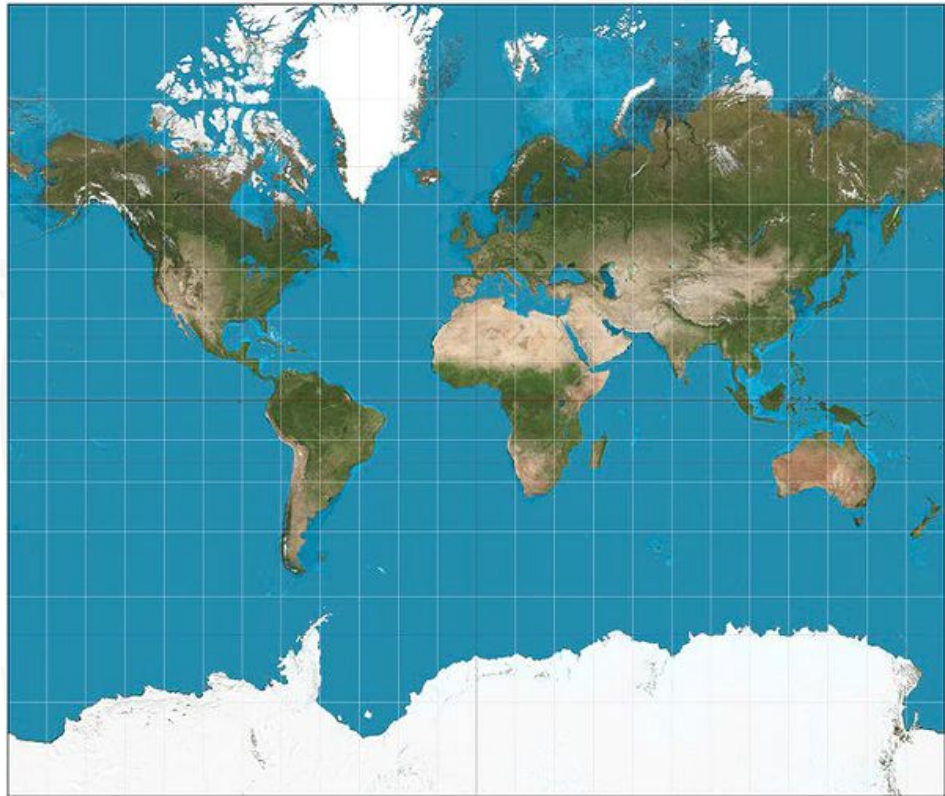
Projection  
are all  
wrong!  
choose the  
best for  
your aim

# WGS84

The World Geodetic System 1984 (or EPSG:4326) is a global geographic coordinates system based on a reference ellipsoid (or geoid).

Geoids are mathematically defined surface that approximates the Earth shape. Using ellipsoid distortions are partially corrected.

Usually maps based on the **WGS84** system are plotted using the **UTM (Mercator's) projection**.





# WGS84

The Global Position Systems (GPS) and its rivals (GLONASS, Galileo and BeiDou) are all based on WGS84

This is a very good argument to use WGS84

**!! careful !!**

Italian national and regional data are often in other reference systems:

UTM ED50 33N (EPSG:23033)

Gauss-Boaga Roma 40 (ESRI:102094)

# WGS84

lon	lat	coordinate system
7.549530	44.388654	WGS84
1384466.033970	4916154.933469	Gauss-Boaga Roma 40
-93387.969562	4942302.394422	UTM ED50 33N

moreover coordinates can be shown as:

- decimals
- degree minutes seconds
- degree minutes



# WGS84

## suggestions

- transform all your data in WGS84
- visualize all maps in UTM
- use decimals and not degree
- always ask the reference systems of the data from other people/institutions

data transformation is boring and complex, but necessary



# R vs QGIS



- Output is valuable, but!
- Code recreates output
- Code is reusable instructions
- All analysis are possible

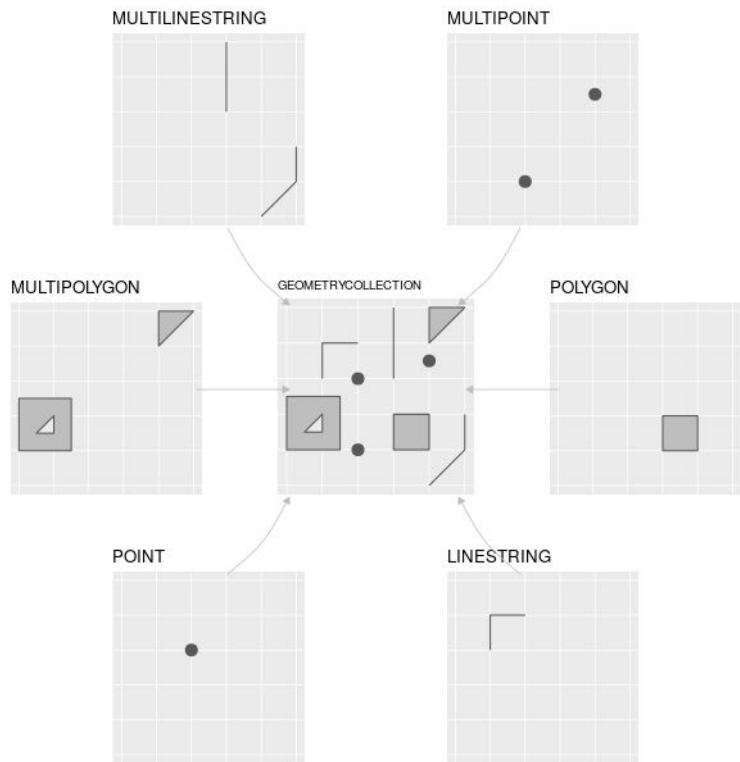
Best to analyze data



- Output is valuable
- Workspace preserves settings
- Hard to explain how
- Several analysis are not as you want

Best to interactively visualize

# What you can plot on a map



Examples:

points = a species observations

polygon = an habitat extension

linestring = a transect

# raster vs vectors

## What is a raster file?

Raster files are **images built from pixels** — tiny color squares that, in great quantity, can form highly detailed images such as photographs. The more pixels an image has, the higher quality it will be, and vice versa. The number of pixels in an image depends on the file type (for example, JPEG, GIF, or PNG).

## What is a vector file?

Vector files use **mathematical equations**, lines, and curves with fixed points on a grid to produce an image. There are no pixels in a vector file. A vector file's mathematical formulas capture shape, border, and fill color to build an image. Because the mathematical formula recalibrates to any size, you can scale a vector image up or down without impacting its quality.

## Resolution.

One of the main differences between raster and vector files is their resolution. The resolution of a raster file is referred to in **DPI** (dots per inch). If you zoom in or expand the size of a raster image, you start to see the individual pixels.

## File sizes.

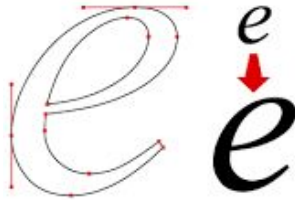
**Raster files are generally larger** than vector files. They can contain millions of pixels and incredibly high levels of detail. Their large size can impact device storage space and slow down page loading speeds on the web. However, you can compress raster files for storage and web optimization to make sharing faster and easier.

# raster vs vectors

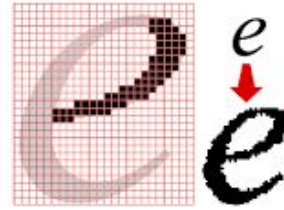
mathematical equations

lines, and curves with fixed points on  
a grid to produce an image

VECTOR GRAPHICS



BITMAPMED (RASTER) GRAPHICS



images built from pixels

higher resolution to smaller pixels

exactly the same concepts are applied to maps

vectorial maps == shapefiles (.shp)

raster maps == geotiff images (\*.tiff)

# Maps on R

Several different ways: I'll show you two options ... but they are plenty

## Basic maps (with ggplot2)

- import map from CRAN
- plot countries and regions
- fill them by variables/factors
- plot points on a country map

## Hardcore maps

- deal with rasters and shapefiles
- work with “terra”
  - crop
  - mask
  - extract
- plot them with or without ggplot2

# mapping countries on ggplot2

We are going to use several specific packages:

- terra
- geodata
- tidyterra





# Retrieving maps

## Species distribution

[GBIF](#)

## Spatial data

library(geodata)

- [CMIP6](#) projected future climate data
- Elevation 30s (~1km) and 3s (~90m)
- [GADM](#)
- Global Landcover ([ESA WorldCover](#) 10 m 2020 - Copernicus)
- [WorldClim](#) 30s (~1km)
- [SoilGrid](#) (~250m)
- ... and many others



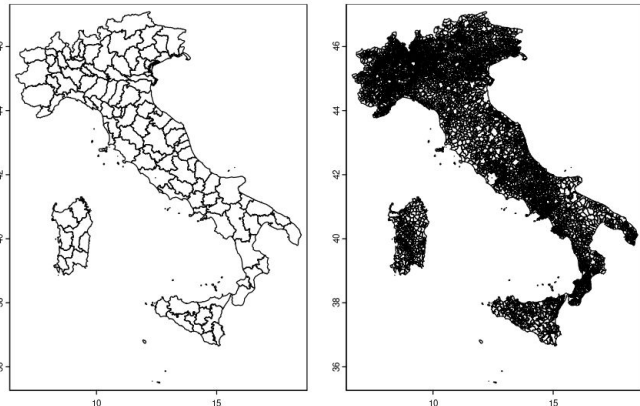
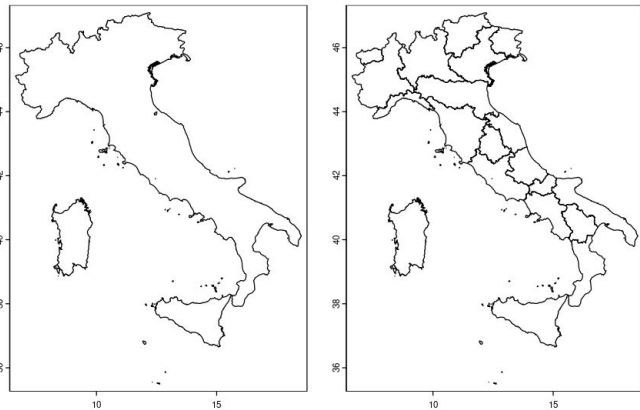
# mapping countries on ggplot2

The gadm() function:

```
library(tidyverse)
library(geodata)
library(terra)
```

```
IT0 <- gadm(country = "ITA", level=0, path = tempdir())
IT1 <- gadm(country = "ITA", level=1, path = tempdir())
IT2 <- gadm(country = "ITA", level=2, path = tempdir())
IT3 <- gadm(country = "ITA", level=3, path = tempdir())
```

```
par(mfrow = c(2,2))
plot(IT0) # country
plot(IT1) # region
plot(IT2) # province
plot(IT3) # city
```



# mapping countries on ggplot2

## inspecting spatial objects

```
print(IT2)
```

```
class       : SpatVector
geometry    : polygons
dimensions  : 110, 13  (geometries, attributes)
extent      : 6.630879, 18.52069, 35.49292, 47.09265  (xmin, xmax, ymin, ymax)
coord. ref. : lon/lat WGS 84 (EPSG:4326)
```

**OBJECT CLASS**  
**SHAPE CLASS**  
**DIM()**  
**MAP EXTENT (OR LIMITS)**  
**COORDINATES REF. SYSTEM**

**WHAT YOU CAN FIND INSIDE:**

names	:	GID_2	GID_0	COUNTRY	GID_1	NAME_1	NL_NAME_1	NAME_2	VARNAME_2	NL_NAME_2	TYPE_2	(and 3 more)
type	:	<chr>	<chr>	<chr>	<chr>	<chr>	<chr>	<chr>	<chr>	<chr>	<chr>	
values	:	ITA.1.1_1	ITA	Italy	ITA.1_1	Abruzzo	NA	Chieti	NA	NA	Provincia	
		ITA.1.2_1	ITA	Italy	ITA.1_1	Abruzzo	NA	L'Aquila	Aquila	NA	Provincia	
		ITA.1.3_1	ITA	Italy	ITA.1_1	Abruzzo	NA	Pescara	NA	NA	Provincia	

# mapping countries on ggplot2

## inspecting spatial objects

```
> unique(IT2[["NAME_1"]])
      NAME_1
1      Abruzzo
5      Apulia
11     Basilicata
13     Calabria
18     Campania
23     Emilia-Romagna
32 Friuli-Venezia Giulia
36     Lazio
41     Liguria
45     Lombardia
57     Marche
62     Molise
64     Piemonte
72     Sardegna
80     Sicily
89     Toscana
99 Trentino-Alto Adige
101    Umbria
103    Valle d'Aosta
104    Veneto
```

We can subset our spatial object basing on the features table. The function is subset:

```
subset(SpatVect, Condition, Vector of columns to keep)
```

Let's do it creating an object called NW including the three regions Piemonte, Liguria, Valle d'Aosta.

# mapping countries on ggplot2

inspecting spatial objects

```
> unique(IT2[["NAME_1"]])
      NAME_1
1      Abruzzo
5      Apulia
11     Basilicata
13     Calabria
18     Campania
23     Emilia-Romagna
32 Friuli-Venezia Giulia
36     Lazio
41     Liguria
45     Lombardia
57     Marche
62     Molise
64     Piemonte
72     Sardegna
80     Sicily
89     Toscana
99     Trentino-Alto Adige
101    Umbria
103    Valle d'Aosta
104    Veneto
```

We can subset our spatial object basing on the features table. The function is subset:

```
subset(SpatVect, Condition, Vector of columns to keep)
```

```
NW <- subset(IT2, IT2$NAME_1 == "Piemonte" | IT2$NAME_1
== "Liguria" | IT2$NAME_1 == "Valle d'Aosta",
c("NAME_1", "NAME_2"))
```

# mapping countries on ggplot2

plot the map with ggplot! we need a new package called tidyterra

```
library(tidyterra)
```

```
ggplot() +  
  geom_spatvector(data = NW, fill = NA, col = "black") +  
  theme_void()
```





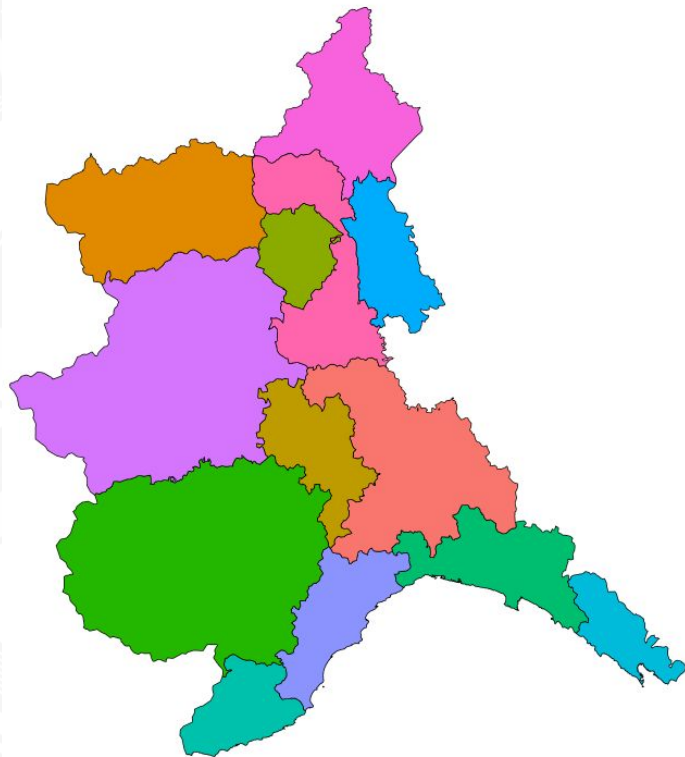
# mapping countries on ggplot2

plot the map with ggplot! we need a new package called tidyterra

```
library(tidyterra)
```

we can fill the provinces by colour

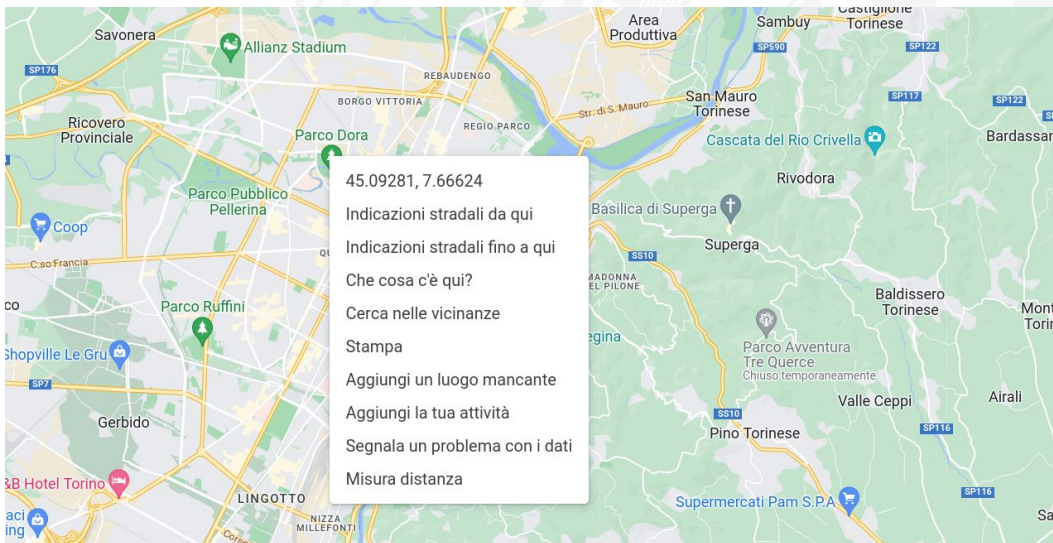
```
ggplot() +  
  geom_spatvector(data = NW, aes(fill = NAME_2),  
                 col = "black") +  
  scale_color_brewer(palette = "Dark2") +  
  theme_void() + theme(legend.position = "none")
```



# mapping countries on ggplot2

```
cities <- data.frame(cities = c("Aosta", "Novara", "Torino", "Alessandria", "Cuneo", "Genova"),  
  lat = c(45.73796224152826, 45.457835274700855, 45.0659968909342, 44.90219559193821, 44.379342903855886, 44.41116507155628),  
  lon = c(7.29944187639308, 8.620470913953753, 7.694126932260661, 8.602656606613502, 7.5293445893633315, 8.954489176583474))
```

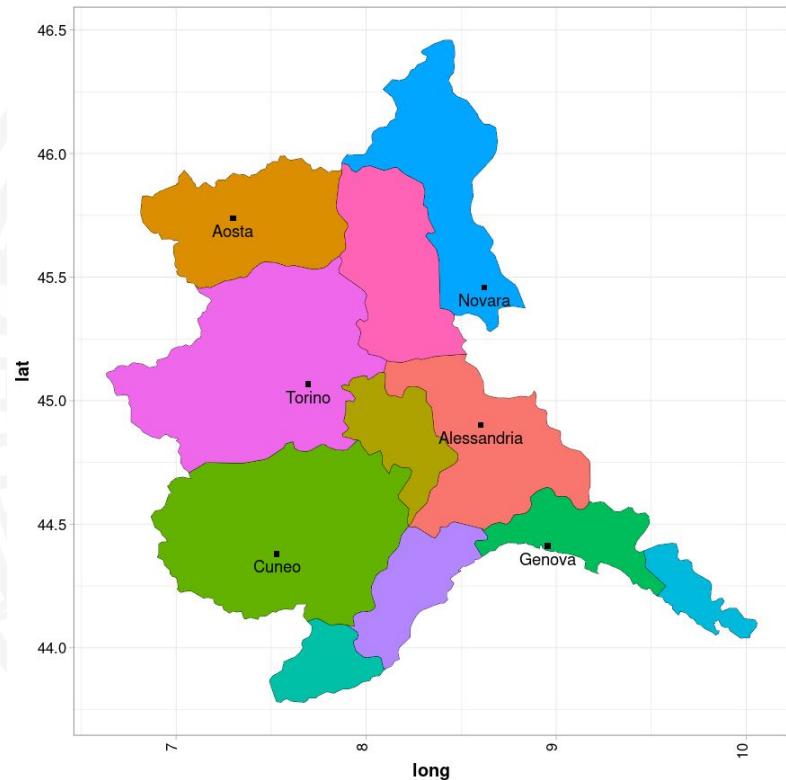
A dataframe containing coordinates corresponding to cities ... you can extract the directly from GoogleMaps ...



# mapping countries on ggplot2

Exercise:

plot cities points and their names over the NW-Italy map



# mapping countries on ggplot2

Exercise:

plot cities points over the NW-Italy map

ggplot() +

```
geom_spatvector(data = NW, aes(fill = NAME_2), col = "black") +
```

```
scale_color_brewer(palette = "Dark2") +
```

```
geom_point(data = cities, aes(x = lon, y = lat), color = "black", shape = 15) +
```

```
geom_text(data = cities, aes(x = lon, y = lat, label = cities), vjust = 1.5) +
```

```
theme_void() + theme(legend.position = "none")
```

# mapping countries on ggplot2

sometime it could be great to associate quantitative data to your map:

for example from the ISTAT website it is easy to obtain several statistics about agronomic production ...

I created a specific dataframe called Frumento.tsv

## Exercise:

generate a map where provinces are filled with the wheat production by year using a gradient. This exercise is going to summarize several different steps we explained in the previous two lessons!

you can use the function **merge()** to associate the Frumento dataframe with the NW SpatVector

# mapping countries on ggplot2

```
frumento <- read.delim("Downloads/Frumento.tsv")
```

```
NW2 <- merge(NW, frumento, by.x = 'NAME_2', by.y = "Province")
```

```
NW2
```

```
ggplot() +
```

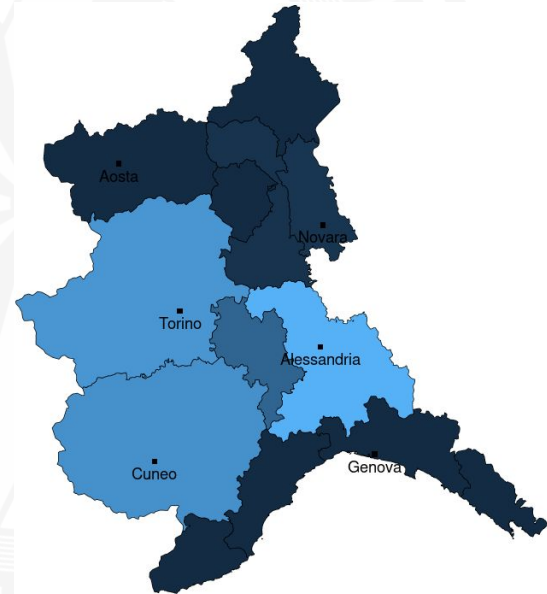
```
  geom_spatvector(data = NW2, aes(fill = Frumento2023), col = "black") +
```

```
  scale_color_brewer(palette = "Dark2") +
```

```
  geom_point(data = cities, aes(x = lon, y = lat), color = "black", shape = 15) +
```

```
  geom_text(data = cities, aes(x = lon, y = lat, label = cities), vjust = 1.5) +
```

```
  theme_void() + theme(legend.position = "none")
```





# mapping countries on ggplot2

```
frumento <- read.delim("Downloads/Frumento.tsv")
```

```
NW2 <- merge(NW, frumento, by.x = 'NAME_2', by.y = "Province")
```

```
NW2
```

```
ggplot() +
```

```
  geom_spatvector(data = NW2, aes(fill = log(Frumento2023)), col = "black") +
```

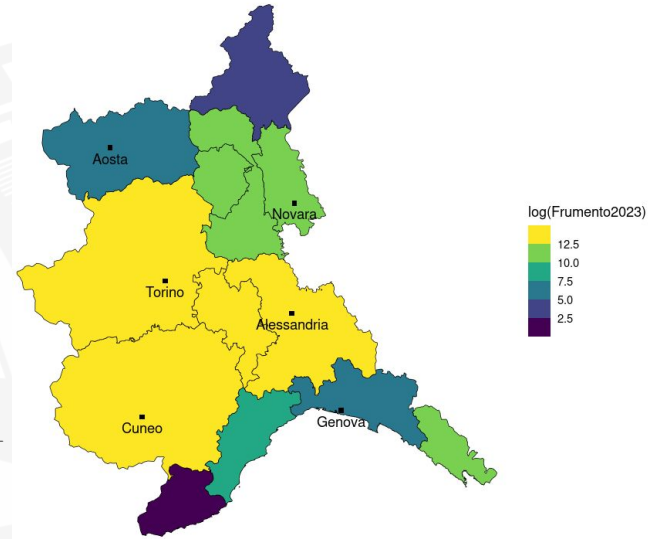
```
  scale_color_brewer(palette = "Dark2") +
```

```
  scale_fill_viridis_b() +
```

```
  geom_point(data = cities, aes(x = lon, y = lat), color = "black", shape = 15) +
```

```
  geom_text(data = cities, aes(x = lon, y = lat, label = cities), vjust = 1.5) +
```

```
  theme_void()
```



# dealing with rasters

The dpi dilemma



# WORKING WITH RASTERS



```
library(geodata)
```

```
library(terra)
```

these are the three packages we are going to use in the next complex few steps:

# WORKING WITH RASTERS

using geodata we download rasters from four ecologically meaningful abiotic factors

```
> h3 <- elevation_30s("Italy", path = tempdir(), mask=FALSE)
```

```
> h3
```

```
class      : SpatRaster
```

```
dimensions : 1428, 1464, 1  (nrow, ncol, nlyr)> pixels by row and by column
```

```
resolution : 0.008333333, 0.008333333  (x, y)-> corresponding to 30s!
```

```
extent      : 6.5, 18.7, 35.3, 47.2  (xmin, xmax, ymin, ymax)
```

```
coord. ref. : lon/lat WGS 84 (EPSG:4326)
```

```
source      : ITA_elv.tif
```

```
name        : ITA_elv
```

```
min value   :      -73
```

```
max value   :    4498
```

# WORKING WITH RASTERS

using geodata we download rasters from four ecologically meaningful abiotic factors

```
> tavg <- worldclim_country("Italy", "tavg", path= tempdir(), res = 0.5)
```

```
> tavg
```

```
class      : SpatRaster
```

```
dimensions : 1500, 1500, 12  (nrow, ncol, nlyr)> 12 layers! Monthly data
```

```
resolution : 0.008333333, 0.008333333  (x, y)
```

```
extent      : 6.5, 19, 35, 47.5  (xmin, xmax, ymin, ymax)> extent is different!
```

```
...
```

these are monthly data!

# WORKING WITH RASTERS

To simplify the analysis is better to create a single ANNUAL layer.

```
tavg[[1]] = January, tavg[[2]] = February, tavg[[1]] = March, ...
```

```
tavg_mean <- mean(tavg)
```

```
names(tavg_mean)                                # always check the variable name!
```

```
names(tavg_mean) <- "annual_tavg"               # always check the variable name!
```

```
tavg_mean
```

**exercise:** download and convert also precipitation and wind speed!



# WORKING WITH RASTERS

we need that all rasters share the same resolution, coordinate system and extent

```
> stack <- c(tavg_mean, prec_mean, wind_mean, h3) # does not work!
```

Error: [rast] extents do not match

```
>stack1 <- c(tavg_mean, prec_mean, wind_mean)# create a stack with only the WorldClim guys
```

```
>stack1_crop <- crop(stack1, ext(h3))# Crop them on the base of the h3 extent
```

**ext()** is the function to extract the extent value of a map

**crop()** is the function to cut the rectangle defined in the raster extent

```
>stack <- c(stack1_crop, h3) # Then you can stack all!
```

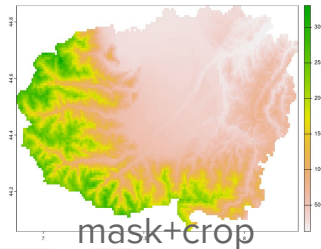
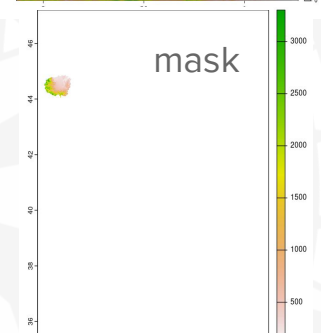
# WORKING WITH RASTERS

The two functions **crop()** and **mask()** are similar but different!

```
h3_crop <- crop(h3, ext(subset(NW, NW$NAME_2 == "Cuneo")))
plot(h3_crop)

h3_mask <- mask(h3, subset(NW, NW$NAME_2 == "Cuneo"))
plot(h3_mask)

h3_mask_crop <- crop(mask(h3, subset(NW, NW$NAME_2 == "Cuneo")),
  ext(subset(NW, NW$NAME_2 == "Cuneo")))
plot(h3_mask_crop)
```



# WORKING WITH RASTERS

using the Italy shape obtained by GADM we can mask our raster to see only the Italy shape

```
> IT <- gadm("Italy", level=0, path= tempdir(), version="latest", resolution=1)
```

```
level 0 = country border
```

```
level 1 = regions
```

```
...
```

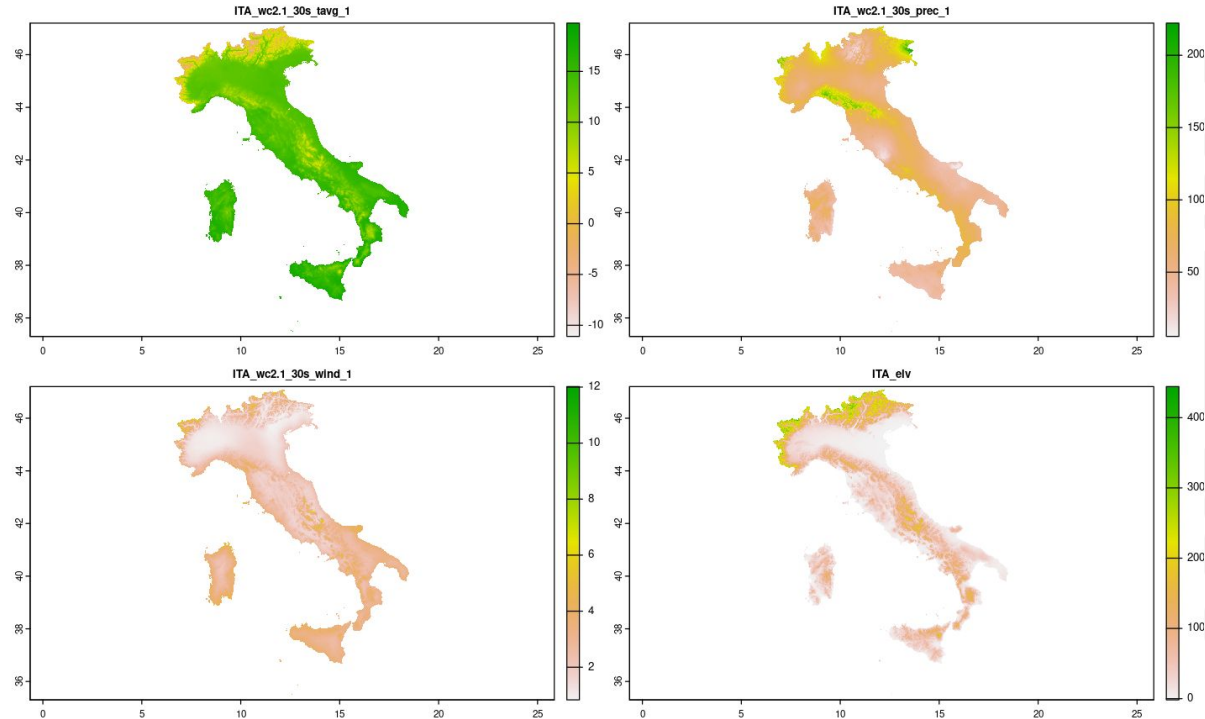
```
> stack_mask <- mask(stack, IT) # mask the stack using the Italy shape
```

```
plot(stack_mask)
```

```
stack_mask
```

# WORKING WITH RASTERS

```
plot(stack_mask)
```



# WORKING WITH RASTERS

```
> stack_mask

class      : SpatRaster

dimensions  : 1428, 1464, 4 (nrow, ncol, nlyr)

resolution  : 0.008333333, 0.008333333 (x, y)

extent      : 6.5, 18.7, 35.3, 47.2 (xmin, xmax, ymin, ymax)

coord. ref. : lon/lat WGS 84 (EPSG:4326)

source(s)   : memory

names       : ITA_wc2~_tavg_1, ITA_wc2~_prec_1, ITA_wc2~_wind_1, ITA_elv

min values  :      -11.10000,      5.2500,      0.8333333,      -73

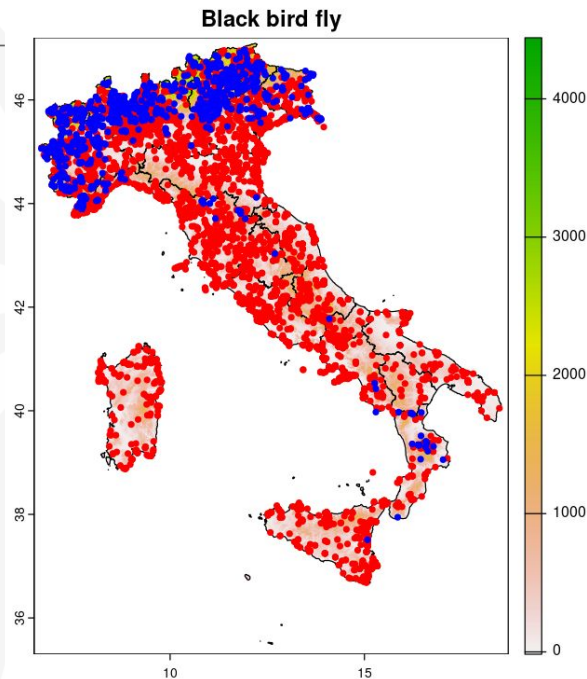
max values  :      19.84167,     230.9167,     12.0166667,     4442
```

# PLOT RASTERS

Load the birds.tsv containing occurrences of two species (Great tit and Woodpecker)

This is the Rbase method to plot maps ... I like it because it is raw and fast

```
# plot dots over the maps METHOD1 -----  
plot(stack2[["ITA_elv"]], main = "Black bird fly")  
plot(ITA1, add = TRUE)  
points(birds[which(birds$acceptedScientificName == "Parus major"),2:3],  
col = "red", pch = 20)  
points(birds[which(birds$acceptedScientificName == "Dryocopus martius"),2:3],  
col ="blue",pch = 20)
```



# PLOT RASTERS

We can extract raster's data corresponding to our occurrences!

## STEP1

verify the occurrences!

```
birds2 <- subset(birds, coordinateUncertaintyInMeters <= 1000)
```

## STEP2

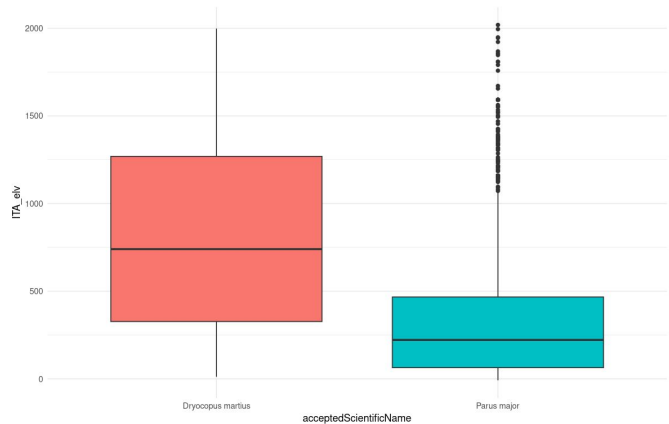
extraction using the terra package

```
feat <- extract(stack2, birds2[,2:3]) # optionally xy = TRUE  
pred <- cbind.data.frame(birds2, feat) # association with original data  
pred <- na.omit(pred) # deleting NAs
```

# PLOT RASTERS

Extracted data are useful to calculate whatever you want, models, stats, ... and so on

```
ggplot(pred, aes(x=acceptedScientificName, y = ITA_elv)) +  
  geom_boxplot(aes(fill = acceptedScientificName)) +  
  theme_minimal() + theme(legend.position="none")
```



Black woodpecker usually lives at higher elevations than *Parus major* ... blah blah blah



# PLOT RASTERS

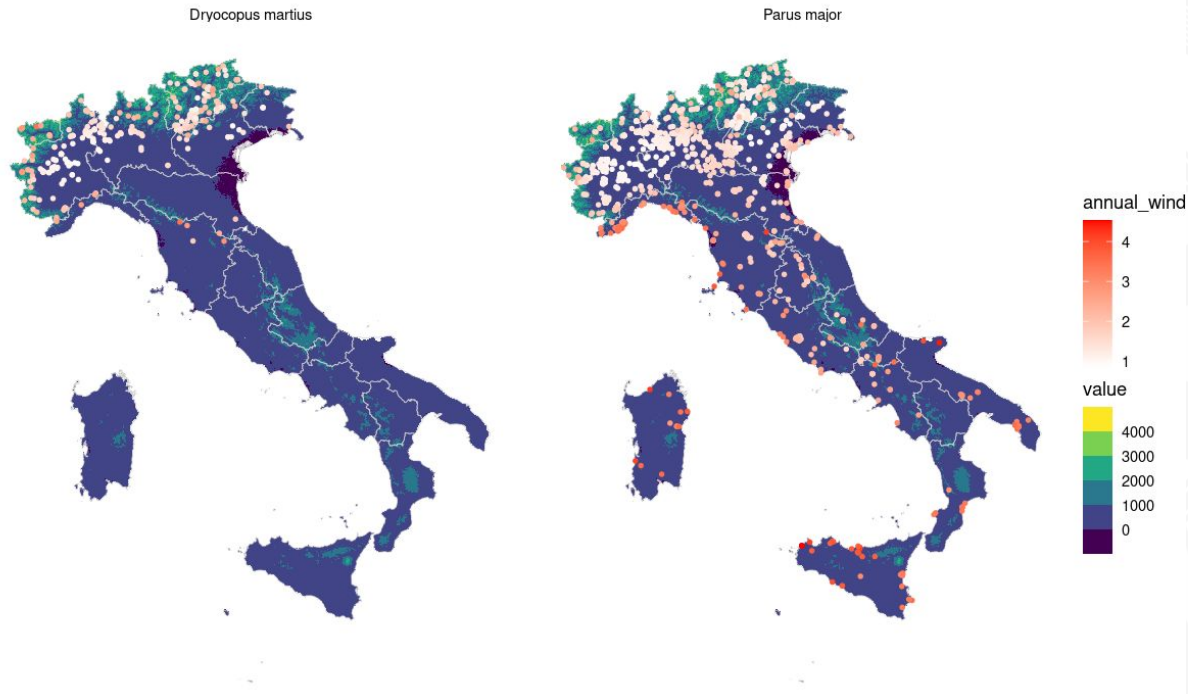
## FINAL EXERCISE

using the **geom\_spatraster()** function of **tidyterra** plot over the elevation map of Italy:

- regional boundaries
- species occurrences colored by wind speed

# PLOT RASTERS

## FINAL EXERCISE



# PLOT RASTERS

## FINAL EXERCISE

```
ggplot() +  
  geom_spatraster(data = stack2[[4]]) +  
  scale_fill_viridis_b(na.value="white") +  
  geom_spatvector(data = IT1, fill = NA, color = "grey80") +  
  geom_point(data = pred, aes(x = decimalLongitude, y = decimalLatitude, color = annual_wind), shape = 20) +  
  scale_color_gradient(low="white", high="red") +  
  facet_grid(~acceptedScientificName) +  
  theme_void()
```

