Predictors in plant ecology analysis

Lae, 19th -20th February 2018

Presented by:
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Important Predictors for plants

Summary

Introduction

Typologies of predictors

Regulators, Disturbances, Resources

Proximal vs Distal

Relationships between predictors

Important Predictors

Temperature

Water

Nutrient substrate

Light

Biotic interactions

Disturbances

Topography and Land Use

Database of predictors

WorldClim

Digital Elevation Model

Soil Grid

Envirem

Collinearity

Ecologically sound reasoning for the choice of predictors in the Ecological modeling and analysis should be common practice, and the models and predictions should always be interpreted through the perspective of the set of predictors used.

A good strategy is to select variables that:

a) ***are ecologically relevant;***

b) ***are feasible to collect data on;***

c) ***are closer to the mechanism (in the sequence resource-direct-indirect-proxy variables).***

Typologies of predictors

Regulators, Disturbances, Resources

Typologies of predictors

- *REGULATORS* (modulating the organism physiology, gradual response) or *LIMITING FACTORS* (causing linear or step responses): factors controlling a species' metabolism (e.g. low temperatures);

- *DISTURBANCES*: perturbations affecting environmental system (natural or human-induced);

- *RESOURCES*: compounds that can be consumed by organisms (e.g. radiations, water or nutrients for plants, prey for animals)

Typologies of predictors

Predictors can be

Proximal: direct physiological effect on plant growth or competition

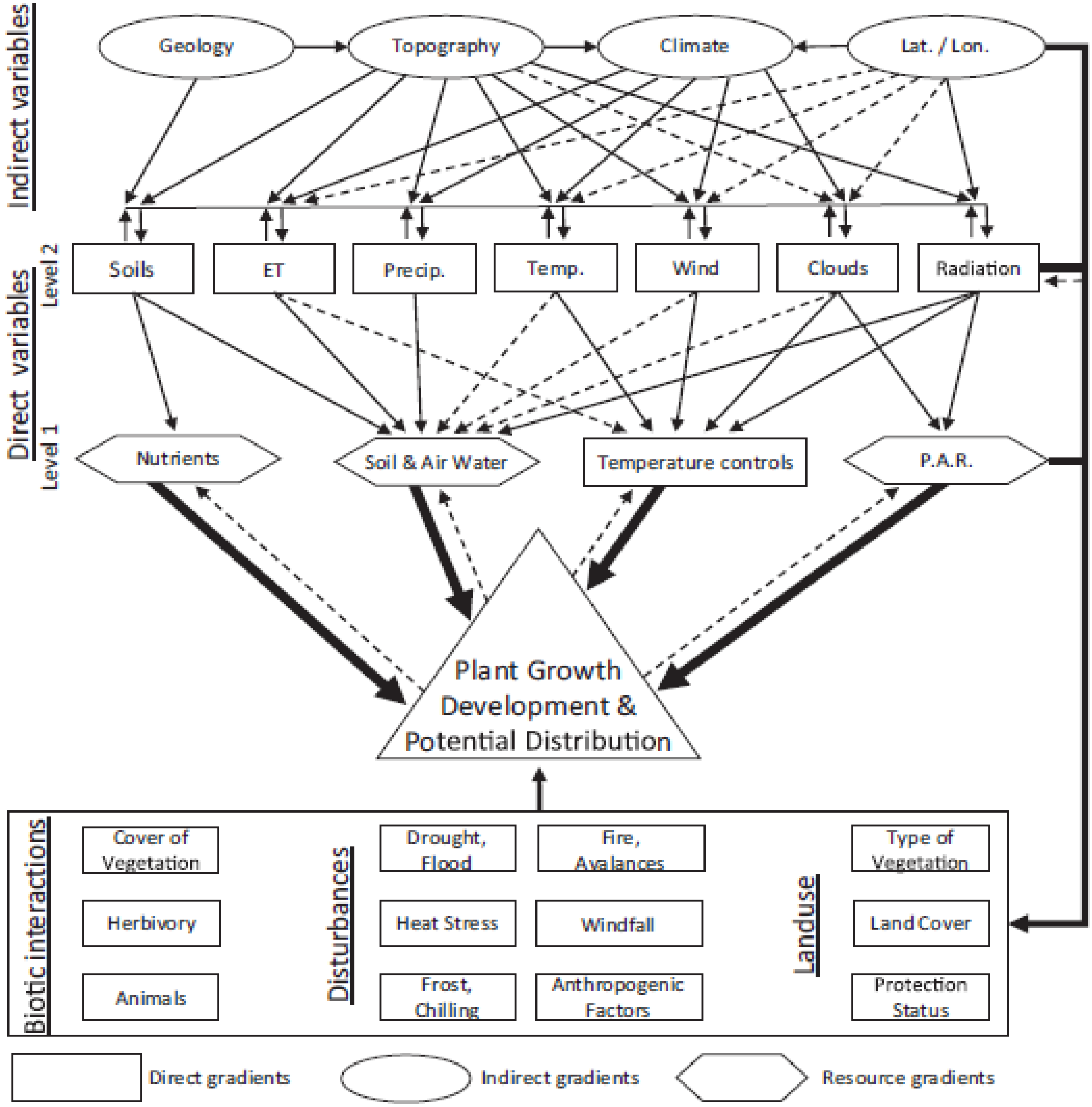
Distal: no direct physiological effect on plant growth or competition

e.g. Temperature, pH…

e.g. altitude, longitude, latitude

Typologies of predictors

Relationships between predictors



From *Mod et al. 2016*

Important Predictors for plants

Most important Predictors for plants

(Mod et al. 2016; Körner 2014; Austin 2002)

- Temperature
- Water
- Nutrients
- Light
- Disturbances
- Biotic interactions

Categories	Temperature	Water	Substrate	Radiation	Biotic Interactions	Disturbance	Topography	Land Use
Classes	Mean (annual, seasonal, monthly) temperature	Mean/summed (annual, seasonal, monthly) precipitation	pH, bedrock	Radiation, clouds	Variables related to other organisms	Geomorphological processes, fire	Slope, aspect, elevation,	Land use classes
	Extreme temperatures	Extreme precipitation	Nutrients			Anthropogenic variables		
	Seasonality	Seasonality						
		Water balance						
		Soil moisture						

Important Predictors for plants

Temperature

TEMPERATURE

Determines the speed of growth and, in case of strong seasonality, defines the growing season length. Additionally, minimum and maximum temperatures can reflect physiological thresholds for plants by frost or heat resistance.

But be carefull!

- large variety of temperature data products, with different impacts on model performance;

- their resolution and accuracy can be coarse compared with the species data

Important Predictors for plants

Temperature

TEMPERATURE variables

Mean temperature

- (annual / monthly) mean temperature (of coldest / warmest / driest / wettest quarter / summer / winter)
- soil temperature
- warmth index (the annual sum of positive differences between monthly mean temperatures and e.g. 5 degrees, i.e. a measure of the effective warmth for plants)

Extreme temperature

- (annual) min / max temperature (of coldest / warmest driest / wettest quarter / month / season)
- mean temperature of coldest / warmest / driest / wettest month
- mean daily max / min temperature (for DJF / MAM / JJA / SON)

Temperature seasonality

- seasonality, annual / diurnal range
- growing degree days (all thresholds) / freezing degree days (FDD) (soil / air) / non-FDD / chilling degree days
- isothermality
- heat units (annual sum of daily temperatures exceeding X degrees)
- frost duration
- winter / summer cold / heat wave duration

Important Predictors for plants

Water

WATER photosynthesis, cooling by transpiration and maintaining turgor.

In ecological models “water” is usually reflected by either precipitation alone or in combination with evapotranspiration (e.g. water balance). These environmental variables are considered a proxy for plant available water.

But be careful!

- this might not be the case if soils and topography are heterogeneous, as available water is strongly influenced by both soil type and topographic position.
- The seasonality of available water/precipitation might lead to temporal flooding, drought or snow cover and thus requires special adaptations by plant species

Important Predictors for plants

Water

WATER variables

Mean precipitation
- (annual / monthly) mean / summed precipitation (of coldest / warmest / driest / wettest quarter / season)
- rainfall intensity

Extreme precipitation
- mean / summed / min / max precipitation of coldest / warmest / driest / wettest month
- highest 5-day precipitation

Precipitation seasonality
- seasonality, annual range
- snow (cover duration, annual snowfall)
- dry / wet season /day length / intensity / frequency
- % of annual precipitation falling during the growing season
- average flood duration
- the standard deviation of hydrographs

Water-balance
- (annual / seasonal / monthly) water balance
- (annual / seasonal) evapo-transipiration, vapour pressure
- (mean / annual / seasonal / soil) water / moisture deficit / surplus / availability /stress
- (annual / seasonal / plant available) water/ wetness / moisture / aridity index
- water content
- flow accumulation
- average water level
- soil moisture (days; days when soil moisture - air temperature ratio is favourable for plant growth)
- waterlogging index

Soil water capacity
- soil water capacity, measured soil moisture
- soil drainage class
- hydraulic soil presence class

Important Predictors for plants

Nutrient substrate

NUTRIENTS SUBSTRATE

They are taken up with water by roots (often with the help of mycorrhiza). Many ***micronutrients*** are essential for plant survival including *potassium, calcium, magnesium, sulphur, boron, chlorine, manganese, molybdenum* and *zinc* but most significant for productivity are usually the contents of ***nitrogen*** and ***phosphorus***.

Nutrients in a wider sense can also influence the pH of the soils, whereas **bedrock together with living organism are the primary regulators of available nutrients** in soils. Therefore, while deriving nutrient content of the soils might not be effective, bedrock, soil pH and soil texture are often used as surrogates in the ecological models.

Important Predictors for plants

Nutrient substrate

NUTRIENTS SUBSTRATE variables

Substrate

bedrock, lithology, rock type

- pH
- surface geology, geological substrate

Nutrients

- nutrients, fertility, Cation-exchange capacity, calcareous
- soil material / depth / order / quality / texture / type
- organic matter, loaminess, alluvial, clay / silt / sand content, salt, gypsum
- soil grain size, bulk density
- FAO soil group
- remote sensed Normalized difference soil index, soil production index
- water regime (ordered classes from dry to waterlogged)

LIGHT

- **Global radiation** and therefore energy (W/m2) driving temperature (air, leaf, and soil) and evapotranspiration.
- **Photo active radiation (PAR)** and is thereby directly related to photosynthesis.
- light might also contain important **signals for plant development** (e.g. germination and photoperiodism).

- While radiation can be easily modelled and is relatively independent of the vegetation, PAR is strongly affected by the canopy structure of the vegetation.

Variables

- solar radiation (daily, annual, seasonal)
- most / least radiated quarter
- mean hours of sunshine
- clouds

Important Predictors for plants

Light

BIOTIC INTERACTIONS

They have **intra and interspecific effects** and have both **positive and negative impacts** by prohibiting or ameliorating growth. Impact of other species can be direct (e.g. competition, herbivory) or indirect (e.g. ameliorating harsh microclimatic conditions, shading, nutrient addition by manure). Biotic interactions have been included to the ecological models as e.g. presence or cover of dominant species, remote sensed vegetation index or interaction matrices for multispecies co-occurrence datasets.

While radiation can be easily modelled and is relatively independent of the vegetation, PAR is strongly affected by the canopy structure of the vegetation.

Important Predictors for plants

<u>BIOTIC INTERACTIONS variables</u>

- NDVI, Landsat bands, Enhanced Vegetation Indices, remote sensed vegetation (indices / classes)
- vegetation height / density / volume/ cover
- canopy / forest / tree cover
- productivity, Net Primary Production
- ecological classification, succession time
- pollinators
- litter
- distance to moorland, moorland presence / absence
- stand basal area
- % of sparsely / dense vegetated brownfield
- % of brownfield with low / high vegetation

Important Predictors for plants

Disturbance

DISTURBANCE

The type and necessity of including disturbance variables in models are highly environment-specific

DISTURBANCE variables

Natural

- fire, volcanic ash
- geomorphological disturbance
- trampling, grazing
- % area of disturbed terrain

Anthropogenic

- population / settlement / building density
- distance to urban areas / roads / harbour / roads
- agriculture, afforestation, soil drainage, roads, human perturbation, forest / etc. management
- human footprint, anthropization degree
- brick rubble
- ownership status (measure of land management)
- predominance of exotic species

Important Predictors for plants

Topography and Land Use

TOPOGRAPHY AND LAND USE

- They improve ecological models and are easy to get

But be careful!!

- **Distal effects:** they do not directly impact plants, but they do alter light, moisture, temperature and nutrient conditions (*Moeslund et al. 2013*);

- It is difficult to interpret the causal relationships between these variables and the target species (*Austin 2007*)

Important Predictors for plants

TOPOGRAPHY AND LAND USE variables

Topography

- altitude (range), terrain curvature, topographic position, slope, flatness, meso-topography, % of steep topography, slope type
- aspect, eastness, northness
- rockiness, ruggedness, topographic wetness index
- topographic diversity

Land-Use

- Corine, land-use classes (if only "biotic" land-use -> ‘biotic’ class)
- distance to potential forest, age of forest

WorldClim - Global Climate Data

Free climate data for ecological modeling and GIS

WorldClim is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km^2. These data can be used for mapping and spatial modeling.

http://www.worldclim.org/

Current conditions (interpolations of observed data, representative of 1960-1990; new Version 2.0, 1970-2000, current climate only)

Future conditions: downscaled global climate model (GCM) data from CMIP5 (IPPC Fifth Assessment)

Past conditions (downscaled global climate model output)

Database of Predictors

WorldClim

CURRENT CONDITIONS – Version 2

variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavg 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (kJ m^{-2} day^{-1})	srad 10m	srad 5m	srad 2.5m	srad 30s
wind speed (m s^{-1})	wind 10m	wind 5m	wind 2.5m	wind 30s
water vapor pressure (kPa)	vapr 10m	vapr 5m	vapr 2.5m	vapr 30s

Database of Predictors

WorldClim

FUTURE CLIMATE DATA

rcp: REPRESENTATIVE CONCENTRATION PATHWAYS

2041-2060

GCM	code	rcp26	rcp45	rcp60	rcp85
ACCESS1-0 (#)	AC		tn, tx, pr, bi		tn, tx, pr, bi
BCC-CSM1-1	BC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CCSM4	CC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CESM1-CAM5-1-FV2	CE		tn, tx, pr, bi		
CNRM-CM5 (#)	CN	tn, tx, pr, bi	tn, tx, pr, bi		tn, tx, pr, bi

tn - monthly average minimum temperature (degrees C * 10)
tx - monthly average maximum temperature (degrees C * 10)
pr - monthly total precipitation (mm)
bc - 'bioclimatic' variables

Database of Predictors

WorldClim

FUTURE CLIMATE DATA

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Database of Predictors

WorldClim

Home About Bioclim Last Glacial Maximum Climate Timeseries Future (CMIP5)

Downloads Known issues

CHELSA

Climatologies at high resolution for the earth's land surface areas

CHELSA – Free climate data at high resolution

CHELSA (Climatologies at high resolution for the earth's land surface areas) is a high resolution (30 arc sec) climate data set for the earth land surface areas currently hosted by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL (Dr. Dirk N. Karger, Prof. Dr. Niklaus Zimmermann), and has been developed in coorporation climatologists from the Department of Geography of the University of Hamburg (Prof. Dr. Jürgen Böhner, Dr. Olaf Conrad, Tobias Kawohl), the University of Zurich (Dr. Michael Kessler, Prof. Dr. Peter Linder), and the University of Göttingen (Prof. Dr. Holger Kreft).

It includes monthly mean temperature and precipitation patterns for the time period 1979-2013.
CHELSA is based on a quasi-mechanistical statistical downscaling of the ERA

CHELSA Bioclim

Bioclimatic variables are derived variables from the monthly mean, max, mean temperature, and mean precipitation values. They are developed for species distribution modelling and related ecological applications. They represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is defined as a period of three months (1/4 of the year). The code follows those of Worldclim and ANUCLIM:

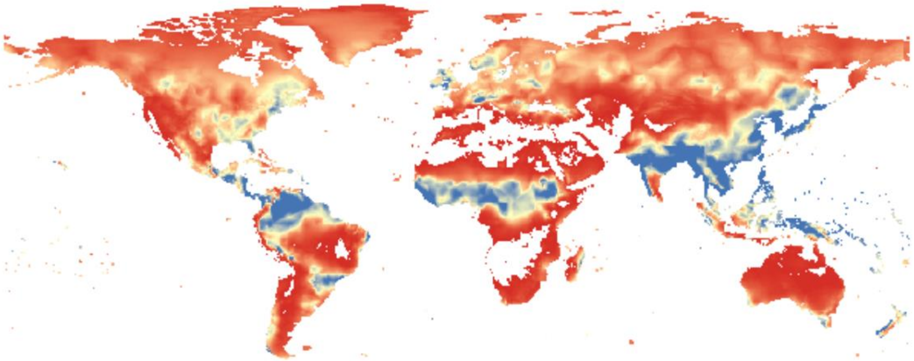
THE LAYERS CAN BE DOWNLOADED HERE

Codes:

Bio1 = Annual Mean Temperature
Bio2 = Mean Diurnal Range
Bio3 = Isothermality
Bio4 = Temperature Seasonality
Bio5 = Max Temperature of Warmest Month
Bio6 = Min Temperature of Coldest Month
Bio7 = Temperature Annual Range
Bio8 = Mean Temperature of Wettest Quarter
Bio9 = Mean Temperature of Driest Quarter
Bio10 = Mean Temperature of Warmest Quarter
Bio11 = Mean Temperature of Coldest Quarter
Bio12 = Annual Precipitation
Bio13 = Precipitation of Wettest Month
Bio14 = Precipitation of Driest Month
Bio15 = Precipitation Seasonality
Bio16 = Precipitation of Wettest Quarter
Bio17 = Precipitation of Driest Quarter
Bio18 = Precipitation of Warmest Quarter
Bio19 = Precipitation of Coldest Quarter

Database of Predictors

Digital Elevation Model



DIGITAL ELEVATION DATA

http://www.cgiar-csi.org/data

Globally available 90m (30m for the US) dataset **SRTM** is a helpful data source, especially since it offers seamless availability for all areas between 60° N and 60° S.

http://asterweb.jpl.nasa.gov/gdem.asp

ASTER-DEM. 83° N-83° S, globally available, 30m resolution.

Database of Predictors

Soil Grid

SOILGRIDS

Powered by ISRIC World Soil Information

http://www.isric.org/explore/soilgrids

A system for automated soil mapping based on global compilation of soil profile data and publicly available remote sensing data. Resolution 1km or 250m

Physical Soil Property

Bulk density (fine earth) in kg / cubic–meter
Clay content (0–2 micro meter) mass fraction in %
Coarse fragments volumetric in %
Silt content (2–50 micro meter) mass fraction in %
Sand content (50–2000 micro meter) mass fraction in %

Chemical soil property

Cation exchange capacity
Soil organic Carbon content
Soil pH

Soil Classification

TAXNWRB
TAXOUSDA

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B.M., Ruiperez Gonzalez, M., Kilibarda, M. et al. (2017) SoilGrids250m: global gridded soil information based on Machine Learning. PLoS ONE 12(2): e0169748. doi:10.1371/journal.pone.0169748.

Database of Predictors

VARIABLES REGIONS R CODE

ENVIREM

ENVIRONMENTAL RASTERS FOR ECOLOGICAL MODELING

http://envirem.github.io/

Environmental variables that are thought to be relevant to species' ecology and geographic distribution are essential for applications such as species distribution modeling. However, the number of such variables that are available, that span multiple time periods, and that can easily be integrated with other datasets is very limited.

ENVIREM dataset provides a number of climatic and topographic variables that have been described in the literature, and make them available at the same resolutions as are available at WorldClim, and for both current and past time periods. Additionally, it provides an R package that makes it possible to generate these variables for other input datasets, such as future climate scenarios.

Title, P.O., Bemmels, J.B. 2017. ENVIREM: An expanded set of bioclimatic and topographic variables increases flexibility and improves performance of ecological niche modeling. Ecography doi: 10.1111/ecog.02880.

Database of Predictors

Envirem

ENVIREM

ENVIRONMENTAL RASTERS FOR ECOLOGICAL MODELING

variable abbreviation	brief description
annualPET	annual potential evapotranspiration: a measure of the ability of the atmosphere to remove water through evapotranspiration processes, given unlimited moisture
aridityIndexThornthwaite	Thornthwaite aridity index: Index of the degree of water deficit below water need
climaticMoistureIndex	a metric of relative wetness and aridity
continentality	average temp. of warmest month - average temp. of coldest month
embergerQ	Emberger's pluviothermic quotient: a metric that was designed to differentiate among Mediterranean type climates
growingDegDays0	sum of mean monthly temperature for months with mean temperature greater than 0°C multiplied by number of days
growingDegDays5	sum of mean monthly temperature for months with mean temperature greater than 5°C multiplied by number of days

Collinearity

Be carefull
<u>COLLINEARITY</u>!!!!

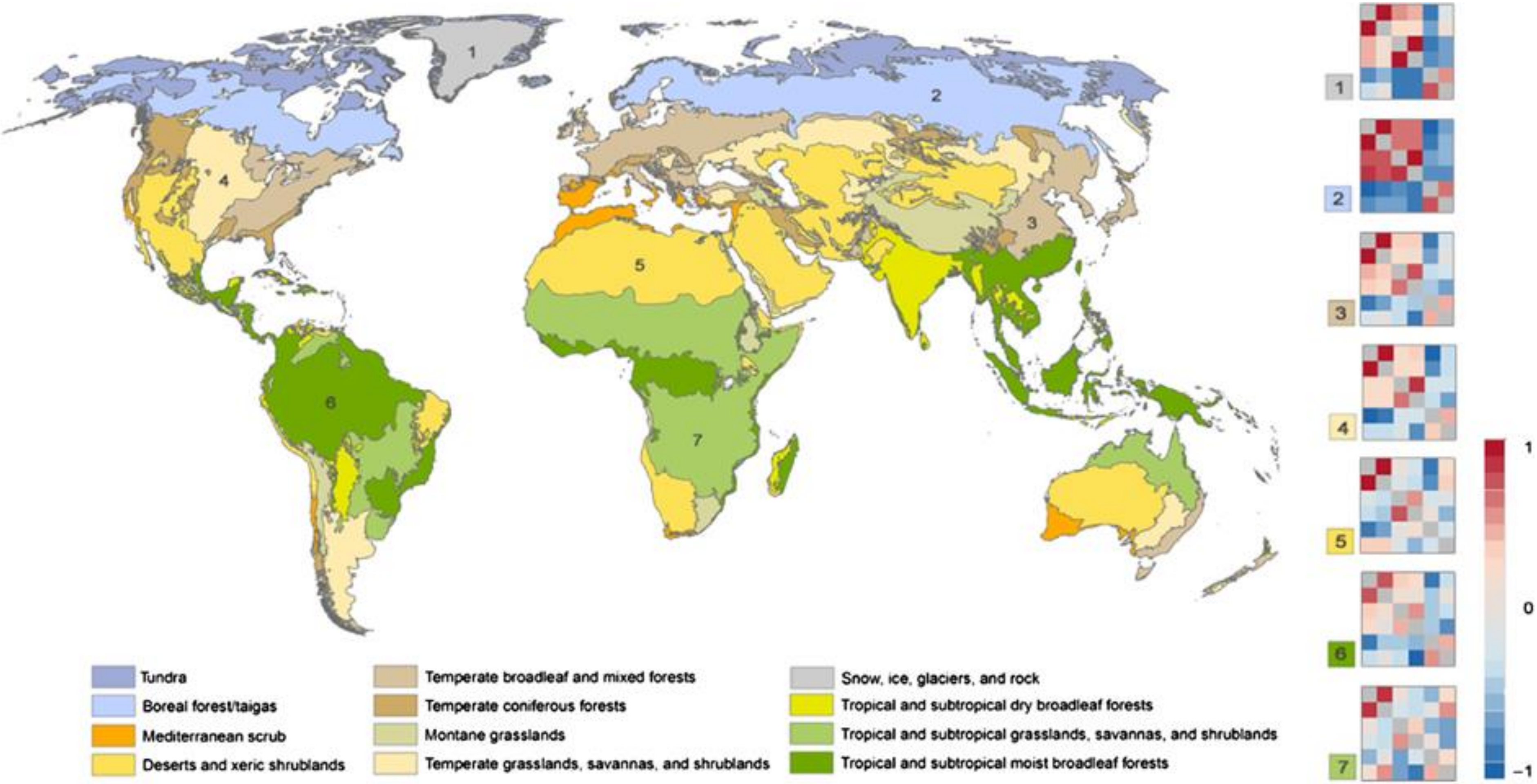
Collinearity refers to the **non independence of predictor variables**, usually in a regression-type analysis. It is a common feature of any descriptive ecological data set and can be a problem for parameter estimation because it inflates the variance of regression parameters and hence potentially leads to the wrong identification of relevant predictors in a statistical model.

In all real world data, there is some degree of collinearity between predictor variables.

Examples: - we could try to explain the jumping distance of a collembolan by the length of its furca, its body length or its weight. Since they are all representations of body size, they will all be highly correlated;

- **compositional** data (data where the whole set of information is described by relative quantities;
- **incidental**, meaning that variables may be collinear by chance, for example when sample size is low, because not all combinations of environmental conditions exist;
- ……..

Collinearity



Correlation matrix of the following six bioclimatic variables (WorldClime): **mean annual temperature, temperature seasonality**, **mean temperature of coldest quarter, annual precipitation, precipitation of driest month, precipitation seasonality.**

Dormann, C. F. *et al.* Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography (Cop.).* **36,** 27–46 (2013)

Collinearity

What can we do about collinearity?

- **Know your data** well enough to be aware of patterns of collinearity in the data sets;

- **Quantify the collinearity** through *correlation coefficient*, *condition index*, *variance inflation factors*…..there are several statistical methods to identify clusters of collinear predictors.

Methods for removing collinearity prior to analysis:

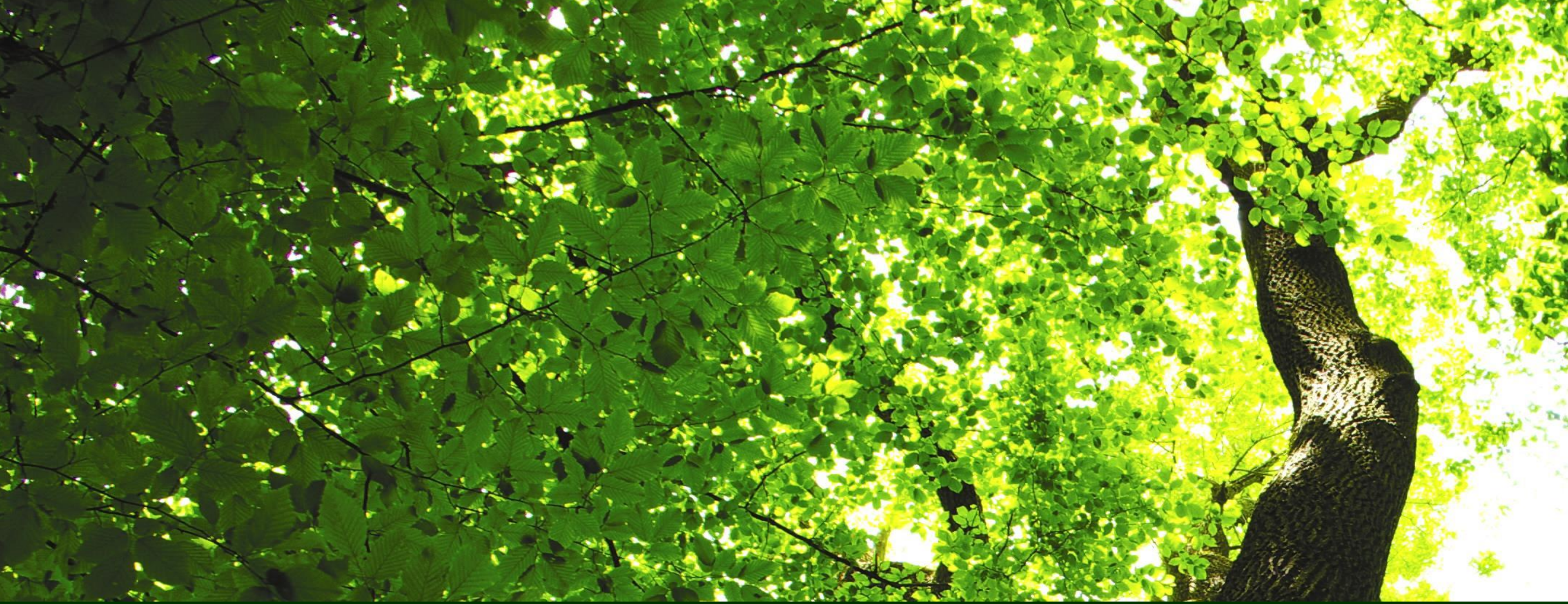
1) Principal Component Analysis;
2) represent the cluster by the variable closest to the cluster centroid;
3) represent the cluster by the variables with highest univariate predictive value for the response;
4) Cluster independent methods

Collinearity

What can we do about collinearity?

Modelling with latent variables

Some methods are designed to incorporate collinear variables. They deal with collinearity by constructing so-called ‘ latent ’ variables, i.e. unobserved variables which underlie the observed collinear variables. As a result of the methods used, most variance in the observed explanatory variables is concentrated in the first few new latent variables and usually the less important latent variables are discarded, leading to a reduction in dimensions. Methods differ in how the latent variables are derived, whether the response variable is included in this derivation and how many latent variables are extracted



thank you

Mountain Partnership

Italian Development Cooperation
Ministry of Foreign Affairs

FAO
FIAT PANIS

SAPIENZA
UNIVERSITÀ DI ROMA