

Species distribution modeling with R

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Chapter 1

Introduction

This document is an introduction to species distribution modeling with R . Species distribution modeling (SDM) is also known under other names including envelope-modeling and (environmental or ecological) niche-modeling. In SDM, the following steps are usually taken: (1) locations of occurrence (and perhaps non-occurrence) of a species (or other phenomenon) are compiled. (2) values of environmental predictor variables (such as climate) at these locations are determined. (3) the environmental values are used as to fit a model predicting presence/absence, or another measure, such as abundance, associated with the points. (4) The model is used to predict the likelihood of presence at all locations of an area of interest (and perhaps in a future climate).

This document is not a general introduction to species distribution modeling itself. We assume that you are familiar with most of the concepts in this field. If in doubt, you could consult Richard Pearson's introduction to the subject: http://biodiversityinformatics.amnh.org/index.php?section_id=111. More advanced readers may want to consult the recent review of the field by Elith and Leathwick (2009).

We also assume that you are already familiar with the R language and environment. It would be particularly useful if you already had some experience with statistical model fitting (e.g. the `glm` function) and with the `raster` package.

SDM have been implemented in R in many different ways. Here we focus on the functions in from the `dismo` and the `raster` packages (but we also refer to other packages such as `BIOMOD`). If you want to test, or build on, some of the examples presented here, make sure you have the latest versions of these libraries, and their dependencies, installed. If you are using a recent version of R , you can do that with:

```
install.packages(c('rJava', 'XML', 'sp', 'rgdal', 'raster'))
install.packages("dismo", repos="http://R-Forge.R-project.org")
```


Chapter 2

Data preparation

Data preparation is often the most time consuming part of a species distribution modeling project. You need to collect a sufficient number of occurrence records that document presence (and perhaps absence) of the species of your interest. A particularly important concern in species distribution modeling is whether, apart from the species identification, the coordinates of the location data are accurate enough (and whether uncertainty about the coordinates is known or not). You also need to have accurate and relevant spatial predictor variables at a sufficiently high spatial resolution.

2.1 Occurrence data

Importing occurrence data into R is easy. But collecting, georeferencing, and cross-checking coordinate data is tedious. While we'll show you some useful data preparation steps you can do in R, it is necessary to use additional tools as well. Discussions about species distribution modeling often focus on comparing modeling methods, but if you are dealing with species with few and uncertain records, your focus probably ought to be on improving the quality of the occurrence data. All methods do better if your occurrence data is unbiased and free of error (Graham et al., 2007) and you have a relatively large number of records (Wisz et al., 2008).

2.1.1 Importing occurrence data

In most cases you will have a file with point locality data representing the known distribution of a species. Here is an example of using `read.table` to read records that are stored in a text file. We are using an example file that is installed with the `dismo` package, and for that reason we use a complex way to construct the filename, but you can replace that with your own filename (remember to use forward slashes!)

```

> library(dismo)
> filename <- paste(system.file(package="dismo"), '/ex/bradypus.csv', sep='')
> filename

[1] "c:/Temp/Rinst22853100/dismo/ex/bradypus.csv"

> bradypus <- read.table(filename, header=TRUE, sep=',')
> head(bradypus)

      species      lon      lat
1 Bradypus variegatus -65.4000 -10.3833
2 Bradypus variegatus -65.3833 -10.3833
3 Bradypus variegatus -65.1333 -16.8000
4 Bradypus variegatus -63.6667 -17.4500
5 Bradypus variegatus -63.8500 -17.4000
6 Bradypus variegatus -64.4167 -16.0000

> bradypus <- bradypus[,2:3]
> head(bradypus)

      lon      lat
1 -65.4000 -10.3833
2 -65.3833 -10.3833
3 -65.1333 -16.8000
4 -63.6667 -17.4500
5 -63.8500 -17.4000
6 -64.4167 -16.0000

```

You can also read such data directly out of Excel or from a database (see e.g. the RODBC package). No matter how you do it, the objective is to get a matrix (or a `data.frame`) with at least 2 columns to hold the coordinates (typically longitude and latitude). In many cases you will have additional columns, e.g., a column to indicate the species if you are modeling multiple species; and a column to indicate whether this is a 'presence' or an 'absence' record (a much used convention is to code presence with a 1 and absence with a 0).

If you do not have any species distribution data you can get started by downloading data from the Global Biodiversity Inventory Facility (GBIF) (<http://www.gbif.org/>). In the `dismo` package there is a function `'gbif'` that you can use for this. The data used below were downloaded using the `gbif` function like this:

```
acaule = gbif('solanum', 'acaule', geo=FALSE)
```

Many records may not have coordinates. Out of the 699 records that `gbif` returned (March 2010), there were only 54 records with coordinates.

```

> data(acaule)
> dim(acaule)

```

2.1. OCCURENCE DATA

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```
[1] 699 23
```

```
> acgeo = subset(acaule, !is.na(lat) & !is.na(lon))
> dim(acgeo)
```

```
[1] 54 23
```

```
> acgeo[1:4, c(1:5,7:10)]
```

	species	continent	country	adm1	adm2	lat	lon
13	Solanum acaule	<NA>	BOL	<NA>	<NA>	-18.8167	-65.90
426	Solanum acaule Bitter	America	Argentina	Jujuy		-22.9000	-66.24
428	Solanum acaule Bitter	America	Bolivia	La Paz	Pacajes	-17.4200	-68.85
429	Solanum acaule Bitter	America	Bolivia	La Paz	Pacajes	-17.1200	-68.77
	coordUncertaintyM	alt					
13	NA	3960					
426	NA	4050					
428	NA	3811					
429	NA	3800					

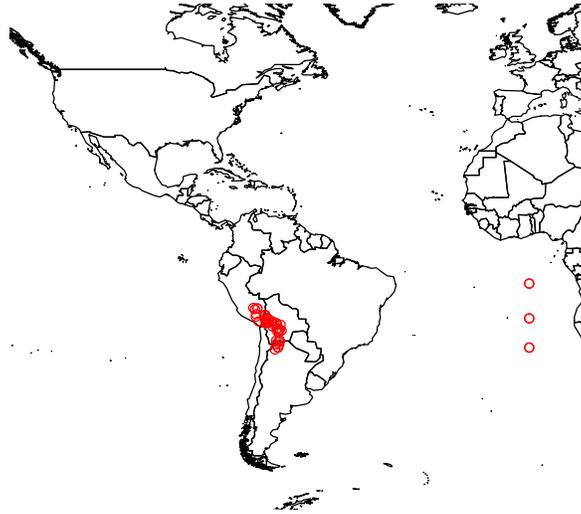
Here is a simple way to make a map of the occurrence localities of *Solanum acaule*:

```
> library(maptools)
```

```
Note: polygon geometry computations in maptools
depend on the package gpclib, which has a
restricted licence. It is disabled by default;
to enable gpclib, type gpclibPermit()
```

```
Checking rgeos availability as gpclib substitute:
FALSE
```

```
> data(wrld_simpl)
> plot(wrld_simpl, xlim=c(-130,10), ylim=c(-60,60))
> points(acgeo$lon, acgeo$lat, col='red')
```



The "wrld_simpl" dataset contains rough country outlines. You can use other datasets of polygons (or lines or points) as well. For example, you can read a shapfile into R using the `readOGR` function in the `rgdal` package or the `readShapePoly` function in the `maptools` package.

2.1.2 Cross-checking

Solanum acaule is a species that occurs in the higher parts of the Andes mountains of Peru and Bolivia. Do you see any errors on the map? There are three records that have plausible latitudes, but longitudes of zero, which is clearly wrong, as this puts them in the Atlantic Ocean, south of West Africa. The `gbif` function (with default arguments) removes records that have (0, 0) as coordinates, but not if one of the coordinates is zero.

Let's have a look at these records:

```
> lonzero = subset(acaule, lon==0)
> lonzero[, 1:13]
```

	species	continent	country	adm1	adm2
544	<i>Solanum acaule</i>	Bitter	subsp. acaule	<NA>	BOL <NA> <NA>
551	<i>Solanum acaule</i>	Bitter	subsp. acaule	<NA>	BOL <NA> <NA>
567	<i>Solanum acaule</i>	Bitter	subsp. acaule	<NA>	PER <NA> <NA>
638	<i>Solanum acaule</i>	Bitter	subsp. acaule	<NA>	PER <NA> <NA>

640	Solanum	acaule	Bitter	subsp.	acaule	<NA>	ARG	<NA>	<NA>	
641	Solanum	acaule	Bitter	subsp.	acaule	<NA>	ARG	<NA>	<NA>	
						locality		lat	lon	
544						Llave	-16.083333		0	
551						Llave	-16.083333		0	
567			km	205	between	Puno	and	Cuzco	-6.983333	0
638			km	205	between	Puno	and	Cuzco	-6.983333	0
640	between	Quelbrada	del	Chorro	and	Laguna	Colorada		-23.716667	0
641	between	Quelbrada	del	Chorro	and	Laguna	Colorada		-23.716667	0
	coordUncertaintyM	alt	institution	collection	catalogNumber					
544	NA	3900	IPK	WKS	30050				304711	
551	NA	3900	IPK		GB			WKS	30050	
567	NA	4250	IPK	WKS	30048				304709	
638	NA	4250	IPK		GB			WKS	30048	
640	NA	3400	IPK	WKS	30027				304688	
641	NA	3400	IPK		GB			WKS	30027	

The records are from Bolivia (BOL), Peru (PER) and Argentina (ARG), confirming that coordinates are in error (it could have been that the coordinates were correct for a location in the Ocean, perhaps referring to a location a fish was caught rather than a place where *S. acaule* was collected). Interestingly, another data quality issue is revealed: each record occurs twice. This could happen because plant samples are often split and send to multiple herbariums. But in this case it seems that a single GBIF data provider (IPK) has these record duplicated in its database.

It is important to cross-check coordinates by visual and other means. One approach is to compare the country (and lower level administrative subdivisions) of the site as specified by the records, with the country implied by the coordinates (Hijmans et al., 1999). In the example below we use the 'coordinates' function from the 'sp' package to create a SpatialPointsDataFrame, and then the 'overlay' function, also from 'sp', to do a point-in-polygon query with the countries polygons.

```
> library(sp)
> coordinates(acgeo) = ~lon+lat
> ov = overlay(acgeo, wrld_simpl)
> cntr = as.character(wrld_simpl@data$NAME[ov])
> which(is.na(cntr))

[1] 43 44 45 46 47 48

> i = which(cntr != acgeo@data$country)
> cbind(cntr, acgeo@data$country)[i,]

      cntr
[1,] "Bolivia" "BOL"
[2,] "Bolivia" "BOL"
```

```
[3,] "Peru"    "PER"
[4,] "Peru"    "PER"
[5,] "Peru"    "PER"
```

Note that the polygons that we used in the example above are not very precise, and they should not be used in a real analysis (see <http://www.gadm.org/> for more detailed administrative division files, or use the 'getData' function from the raster package (e.g. `getData('gadm', country='PER', level=0)` to get the national borders of Peru. The overlay function returned indices (row numbers) that we stored in variable 'i'. We used these in the next line to get the country for each point. Then we ask which countries are 'NA' (i.e., points in oceans), and which countries have non matching names (in this case these are all caused by using abbreviations in stead of full names).

```
> acgeo = acgeo[coordinates(acgeo)[,'lon'] < 0, ]
```

2.1.3 Georeferencing

If you have records with locality descriptions but no coordinates, you should consider georeferencing these. Not all the records can be georeferenced. Sometimes even the country is unknown (`country=="UNK"`). Here we select only records that do not have coordinates, but that do have a locality description.

```
> georef = subset(acaule, (is.na(lon) | is.na(lat)) & ! is.na(locality) )
> dim(georef)
```

```
[1] 89 23
```

```
> georef[1:3,1:13]
```

	species	continent	country				
30	Solanum acaule Bitter subsp. acaule (Juz.) Hawkes & Hjert.	<NA>	PER				
42	Solanum acaule Bitter subsp. acaule (Juz.) Hawkes & Hjert.	<NA>	BOL				
81	Solanum acaule Bitter subsp. acaule (Juz.) Hawkes & Hjert.	<NA>	ARG				
	adm1	adm2	locality	lat	lon	coordUncertaintyM	alt
30	<NA>	<NA>	km 205 between Puno and Cuzco	NA	NA	NA	4250
42	<NA>	<NA>	Llave	NA	NA	NA	3900
81	<NA>	<NA>	da Pena	NA	NA	NA	NA
	institution	collection	catalogNumber				
30	DEU159	DEU	WKS 30048				
42	DEU159	DEU	WKS 30050				
81	DEU159	DEU	WKS 30417				

Among the first records is an old acquaintance. The record, with catalog number WKS 30048 was also in the set of records that had a longitude of zero degrees. This time it seems that it is served to gbif via another institution 'DEU' (I suspect that these duplicates occur because GBIF has records from

aggregators such as EURISCO and national nodes, as well as from individual institutes).

We recommend using a tool like BioGeomancer: <http://bg.berkeley.edu/latest> (Guralnick et al., 2006) to georeference textual locality descriptions. An important feature of BioGeomancer is that it attempts to capture the uncertainty associated with each georeference (Wieczorek et al., 2004). The `dismo` package has a function `biogeomancer` that you can use for this, and that we demonstrate below, but its use is generally not recommended because you really need a detailed map interface for accurate georeferencing.

Here is an example for one of the records with longitude = 0. We put the `biogeomancer` function into a 'try' function, to assure elegant error handling if the computer is not connected to the Internet.

```
> args(biogeomancer)

function (country = "", adm1 = "", adm2 = "", locality = "",
         singleRecord = TRUE, progress = "text")
NULL

> b = try( biogeomancer('Peru', locality=lonzero$locality[3], progress='') )
> b

   id      lon      lat coordUncertaintyM
1  1 -74.99063 -9.19397          1145076

> lonzero$lat[3]

[1] -6.983333
```

Note that the uncertainty (expressed in meters) is quite high, and that the latitude is rather different from the original latitude (whereas the original latitude might in fact be correct).

2.2 Sampling bias

2.3 Random points

Many of the early species distribution models, such as Bioclim and Domain are known as 'profile' methods because they only use 'presence' data. Other methods also use 'absence' data or 'background' data. Logistic regression is the classical approach to analyzing presence and absence data (and it is still much used, often implemented in a generalized linear modeling (GLM) framework; and the 'maxent' algorithm is also closely related to logistic regression). If you have a large dataset with presence/absence from a well designed survey, you should use a method that can use these data (i.e. do not use a modeling method that only considers presence data). If you only have presence data, you can still use

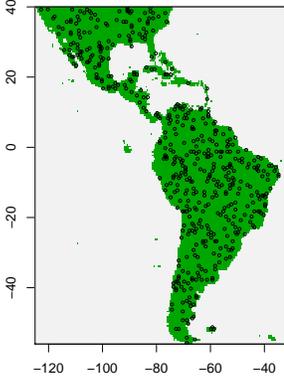
a method that needs absence data, by substituting absence data with background data.

Background data, also referred to as 'random absence' is, in many cases, not *that* different from 'true absence' data. If you have a species with a range that is relatively small compared to they study area, there will only a few background points where the species is actually present. Moreover, the species might be absent (not observable) at these sites at a given time of sampling (depending on scale, detectability, ...). In fact, if you are modeling at, say, a 1 km² resolution, all species that are present within a grid cell will also be absent somewhere within that cell. Background data establishes the environmental domain of the study, presence data should establish under which conditions a species is more likely to be present than on average. 'True' absence data can be less noisy, and help detect more subtle interactions in variables that determine distribution and/or biogeographic barriers. However, absence data can also be biased and incomplete and in such cases probably less useful than presence data.

dismo has a function to sample random points (background data) from a study area. You can use a 'mask' to exclude area with no data NA, e.g. areas not on land. You can use an 'extent' to further restrict the area from which random locations are drawn.

```
> files <- list.files(path=paste(system.file(package="dismo"), '/ex', sep=''),
+                    pattern='grd', full.names=TRUE )
> mask <- raster(files[[1]])
> bg <- randomPoints(mask, 500 )
> par(mfrow=c(1,2))
> plot(!is.na(mask), legend=FALSE)
> points(bg, cex=0.5)
> # now with an extent
> e = extent(-80, -53, -39, -22)
> bg2 <- randomPoints(mask, 50, ext=e)
> plot(!is.na(mask), legend=FALSE)
> plot(e, add=TRUE, col='red')
> points(bg2, cex=0.5)
```

2.3. RANDOM POINTS



Chapter 3

Raster data

3.1 Predictor variables

In species distribution modeling, predictor variables are typically organized as raster (grid) type files. Each predictor should be a 'raster' representing a variable of interest. Variables can include climatic, soil and terrain, vegetation, land use, and other variables. These data are typically stored in files in some kind of GIS format. Almost all relevant formats can be used (including ESRI grid, geoTiff, netCDF, IDRISI, and ASCII). Avoid ASCII files if you can, as they tend to considerably slow down processing speed. For any particular study the layers all should have the same spatial extent, resolution, and origin (if necessary, see the 'raster' package to prepare your predictor variable data). The set of predictor variables (raster) can be used to make a 'RasterStack', which can be thought of as a collection of 'RasterLayer' objects (see the `raster` package for more info).

Here we make a list of files that are installed with the `dismo` package and then create a `rasterStack` from these, show the names of each layer, and finally plot them all.

```
> files <- list.files(path=paste(system.file(package="dismo"),
+                               '/ex', sep=''), pattern='grd', full.names=TRUE )
> files

[1] "c:/Temp/Rinst22853100/dismo/ex/bio1.grd"
[2] "c:/Temp/Rinst22853100/dismo/ex/bio12.grd"
[3] "c:/Temp/Rinst22853100/dismo/ex/bio16.grd"
[4] "c:/Temp/Rinst22853100/dismo/ex/bio17.grd"
[5] "c:/Temp/Rinst22853100/dismo/ex/bio5.grd"
[6] "c:/Temp/Rinst22853100/dismo/ex/bio6.grd"
[7] "c:/Temp/Rinst22853100/dismo/ex/bio7.grd"
[8] "c:/Temp/Rinst22853100/dismo/ex/bio8.grd"
[9] "c:/Temp/Rinst22853100/dismo/ex/biome.grd"
```

```

> predictors <- stack(files)
> predictors

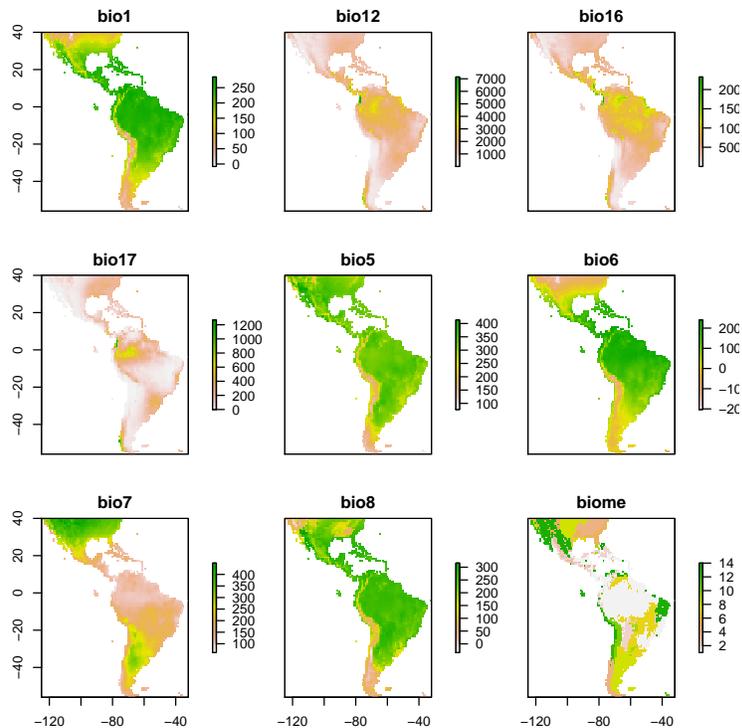
class       : RasterStack
filename    :
nlayers     : 9
nrow        : 192
ncol        : 186
ncell       : 35712
projection  : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
min value   : -23 0 0 0 61 -212 60 -66 1
max value   : 289 7682 2458 1496 422 242 461 323 14
xmin        : -125
xmax        : -32
ymin        : -56
ymax        : 40
xres        : 0.5
yres        : 0.5

> layerNames(predictors)

[1] "bio1" "bio12" "bio16" "bio17" "bio5" "bio6" "bio7" "bio8" "biome"

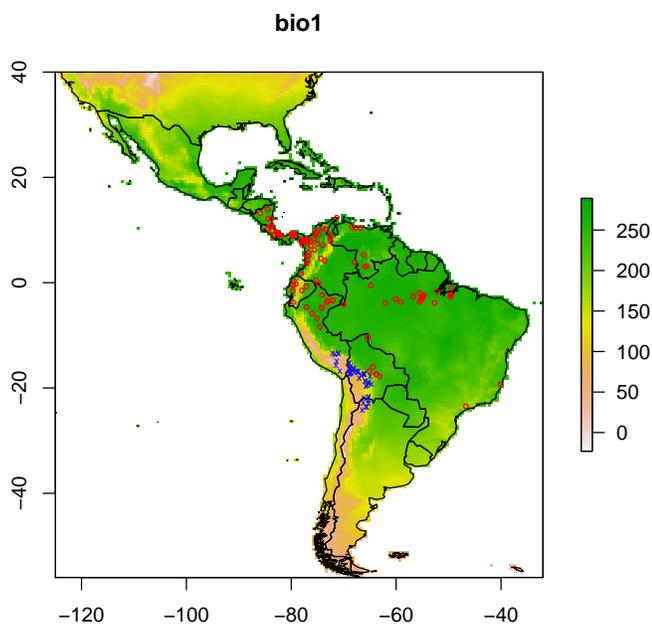
> plot(predictors)

```



We can also make a plot of a single layer in a RasterStack, and plot some additional data on top of it:

```
> plot(predictors, 1)
> plot(wrld_simpl, add=TRUE)
> points(bradypus, col='red', cex=0.5)
> points(acgeo, col='blue', pch='x', cex=0.5)
```



The example above uses data representing 'bioclimatic variables' from the WorldClim database (<http://www.worldclim.org>, Hijmans et al., 2004) and 'terrestrial biome' data from the WWF (<http://www.worldwildlife.org/science/data/item1875.html>, Olsen et al., 2001). You can go to these websites if you want higher resolution data. You can also use the `getData` function from the `raster` package to download WorldClim climate data (as well as other geographic data).

Variable selection is obviously important, particularly if the objective of a study is explanation. See, e.g., Austin and Smith (1987), Austin (2002). In SDM, the objective tends to be prediction, in which case variable selection might be less important (as long as there are enough variables with different spatial patterns); but this is an area that needs further research.

3.2 Extracting values from rasters

We now have a set of predictor variables (rasters) and occurrence points. The next step is to extract the values of the predictors at the locations of the points. (This step can be skipped for the modeling methods that are implemented in the `dismo` package). This is very straightforward thing to do using the `xyValues` function from the `raster` package. In the example below we use that function first for the *Bradypus* occurrence points, then for 500 random background points. We combine these into a single `data.frame` in which the first column (variable 'pb') indicates whether this is a presence or a background point. 'biome' is categorical variable (called a 'factor' in R) and it is important to explicitly define it that way (so that it won't be treated like any other numerical variable).

```
> presvals <- xyValues(predictors, bradypus)
> backgr <- randomPoints(predictors, 500)
> absvals <- xyValues(predictors, backgr)
> pb <- c(rep(1, nrow(presvals)), rep(0, nrow(absvals)))
> sdmdata <- data.frame(cbind(pb, rbind(presvals, absvals)))
> sdmdata[, 'biome'] = as.factor(sdmdata[, 'biome'])
> head(sdmdata)
```

	pb	bio1	bio12	bio16	bio17	bio5	bio6	bio7	bio8	biome
1	1	263	1639	724	62	338	191	147	261	1
2	1	263	1639	724	62	338	191	147	261	1
3	1	253	3624	1547	373	329	150	179	271	1
4	1	243	1693	775	186	318	150	168	264	1
5	1	243	1693	775	186	318	150	168	264	1
6	1	252	2501	1081	280	326	154	172	270	1

```
> tail(sdmdata)
```

	pb	bio1	bio12	bio16	bio17	bio5	bio6	bio7	bio8	biome
611	0	243	1927	982	13	330	163	167	238	3
612	0	143	1455	421	285	311	-31	341	75	4
613	0	274	1733	931	85	338	215	123	270	1
614	0	259	2759	1240	211	318	206	112	261	1
615	0	252	2308	1087	34	354	154	199	250	1
616	0	267	1403	740	41	304	227	77	263	13

```
> summary(sdmdata)
```

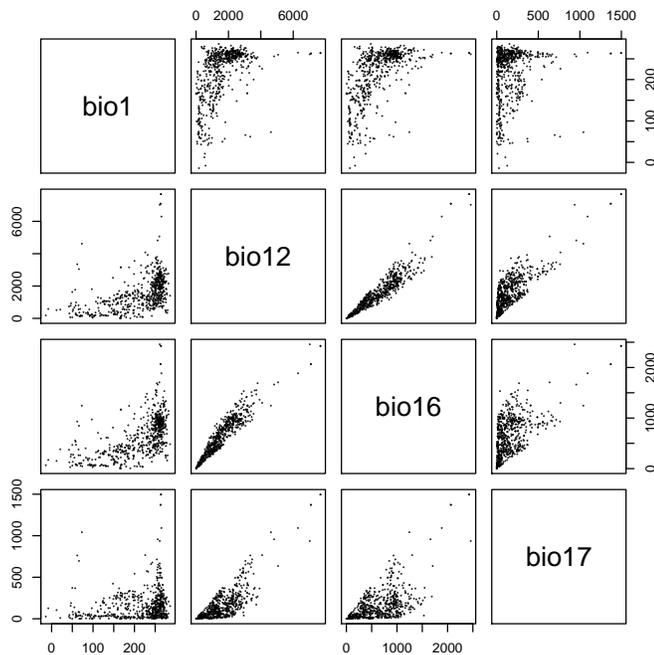
	pb	bio1	bio12	bio16
Min.	:0.0000	Min. : 4.0	Min. : 0.0	Min. : 0.0
1st Qu.:	0.0000	1st Qu.:172.8	1st Qu.: 819.5	1st Qu.: 337.5
Median :	0.0000	Median :241.0	Median :1505.5	Median : 661.5
Mean :	0.1883	Mean :212.6	Mean :1610.5	Mean : 658.7
3rd Qu.:	0.0000	3rd Qu.:260.0	3rd Qu.:2250.8	3rd Qu.: 926.5

Max. :1.0000 Max. :285.0 Max. :7682.0 Max. :2458.0

bio17	bio5	bio6	bio7
Min. : 0.0	Min. : 77.0	Min. : -183.00	Min. : 77.0
1st Qu.: 38.0	1st Qu.:299.0	1st Qu.: 41.75	1st Qu.:119.0
Median : 104.0	Median :319.0	Median : 156.50	Median :161.0
Mean : 160.9	Mean :307.2	Mean : 119.30	Mean :187.9
3rd Qu.: 226.5	3rd Qu.:333.0	3rd Qu.: 202.00	3rd Qu.:234.0
Max. :1496.0	Max. :383.0	Max. : 231.00	Max. :427.0

bio8	biome
Min. : -38.0	1 :283
1st Qu.:211.0	13 : 71
Median :251.0	7 : 62
Mean :221.9	8 : 52
3rd Qu.:262.0	2 : 39
Max. :292.0	4 : 30
	(Other): 79

```
> pairs(sdmdata[,2:5], cex=0.1, fig=TRUE)
```



Chapter 4

Model fitting, prediction, and evaluation

4.1 Model fitting

Model fitting is quite similar across the modeling methods that exist in R. Most methods take a 'formula' identifying the dependent and independent variables, accompanied with a `data.frame` that holds these variables. Details on specific methods are provided further down on this document, in the sections on specific modeling methods.

A simple formula could look like: $y \sim x1 + x2 + x3$, i.e. y is a function of $x1$, $x2$, and $x3$. Another example is $y \sim .$, which means that y is a function of all other variables in the `data.frame` provided to the function. See `help('formula')` for more details about the formula syntax. In the example below, the function 'glm' is used to fit generalized linear models. `glm` returns a model object.

```
> m1 = glm(pb ~ bio1 + bio5 + bio12, data=sdmdata)
> class(m1)

[1] "glm" "lm"

> summary(m1)

Call:
glm(formula = pb ~ bio1 + bio5 + bio12, data = sdmdata)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.93026 -0.24274 -0.10350  0.08338  0.90895

Coefficients:
```

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	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	1.785e-01	1.079e-01	1.653	0.098794 .
bio1	1.558e-03	4.044e-04	3.853	0.000129 ***
bio5	-1.708e-03	4.907e-04	-3.481	0.000535 ***
bio12	1.244e-04	1.634e-05	7.613	1.02e-13 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.1210492)

Null deviance: 94.156 on 615 degrees of freedom
 Residual deviance: 74.082 on 612 degrees of freedom
 AIC: 453.4

Number of Fisher Scoring iterations: 2

```
> m2 = glm(pb ~ ., data=sdmdata)
> m2
```

```
Call: glm(formula = pb ~ ., data = sdmdata)
```

Coefficients:

(Intercept)	bio1	bio12	bio16	bio17	bio5
0.2605873	-0.0006826	0.0003157	-0.0003379	-0.0005782	0.0189778
bio6	bio7	bio8	biome2	biome3	biome4
-0.0190976	-0.0200403	0.0005437	-0.0889992	-0.1772171	-0.0996828
biome5	biome7	biome8	biome9	biome10	biome12
-0.0133415	-0.1956252	-0.0040291	0.0096332	-0.0244613	-0.0370911
biome13	biome14				
0.0506482	-0.0961413				

Degrees of Freedom: 615 Total (i.e. Null); 596 Residual
 Null Deviance: 94.16
 Residual Deviance: 70.01 AIC: 450.6

Models implemented in *dismo* do not use a formula (and most models only take presence points). For example:

```
> bc = bioclim(sdmdata[,c('bio1', 'bio5', 'bio12')])
> class(bc)
```

```
[1] "Bioclim"
attr(,"package")
[1] "dismo"
```

```
> bc
```

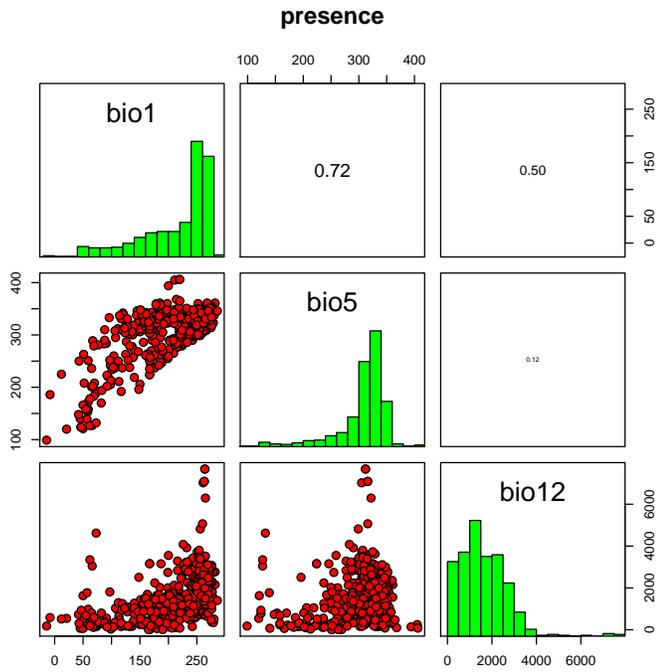
4.1. MODEL FITTING

```
class      : Bioclim
```

```
variables: bio1 bio5 bio12
```

```
presence points: 616  
      bio1 bio5 bio12  
[1,] 263 338 1639  
[2,] 263 338 1639  
[3,] 253 329 3624  
[4,] 243 318 1693  
[5,] 243 318 1693  
[6,] 252 326 2501  
[7,] 240 317 1214  
[8,] 275 335 2259  
[9,] 271 327 2212  
[10,] 274 329 2233  
      (... ... ...)
```

```
> pairs(bc)
```



4.2 Model prediction

Different modeling methods return different type of 'model' objects (typically they have the same name as the modeling method used). All of these 'model' objects, irrespective of their exact class, can be used with the `predict` function to make predictions for any combination of values of the independent variables. This is illustrated in the example below where we make predictions with model object 'm1' for three records with values for variables bio1, bio5 and bio12 (the variables used in the example above to create object m1)

```
> bio1 = c(40, 150, 200)
> bio5 = c(60, 115, 290)
> bio12 = c(600, 1600, 1700)
> pd = data.frame(cbind(bio1, bio5, bio12))
> pd

  bio1 bio5 bio12
1   40   60   600
2  150  115  1600
3  200  290  1700

> predict(m1, pd)

      1      2      3
0.2129028 0.4146878 0.2061158

> predict(bc, pd)

[1] 0.000000000 0.003246753 0.384740260
```

4.3 Model evaluation

Traditional measures of fit used in regression, such as r^2 and textitp-values have little place in species distribution modeling. For some methods these metrics do not apply. But even if they do, they should normally not be used as all the classic assumptions on which they are based (independence of data, normality of distributions) are typically strongly violated. In stead, most modelers rely on cross-validation. This consists of creating a model with one 'training' data set, and testing it with another data set of known occurrences. Typically, training and testing data are created through random sampling (without replacement) from a single data set. Only in a few cases, e.g. Elith et al., 2006, training and test data are from different sources and pre-defined.

Different measures can be used to evaluate the quality of a prediction (Fielding and Bell, 1997), perhaps depending on the goal of the study. Many measures are 'threshold dependent'. That means that a threshold must be set first (e.g. 0.5). Predicted values above that threshold indicate a prediction of 'presence', and values below the threshold indicate 'absence'. Some measures emphasize

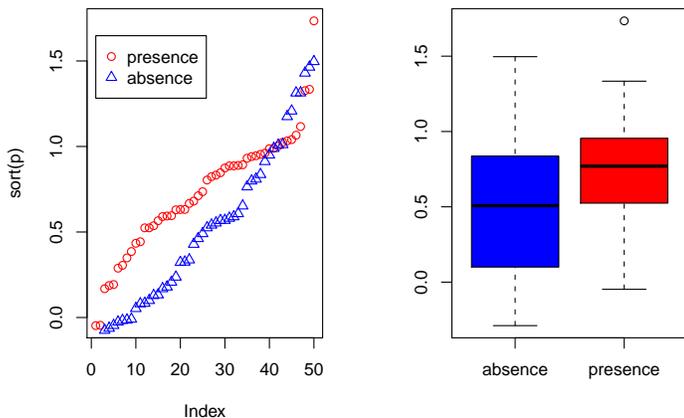
the weight of false absences, others give more weight to false presences. Cohen's *kappa* is an example of a threshold dependent model evaluation statistic.

Much used statistics that are threshold independent are the correlation coefficient and the Area Under the Receiver Operator Curve (AUROC, generally further abbreviated to AUC). AUC is a measure of rank-correlation. If it is high, it indicates that high predicted scores tend to be areas of known presence and locations with lower model prediction scores tend to areas where the species is known to be absent (or a random point). An AUC score of 0.5 means that the model is as good as a random guess.

Below we illustrate the computation of the correlation coefficient, AUC with two random variables. *p* (presence) represents the predicted value for 50 known cases (locations) where the species is present. and *a* (absence) represents the predicted value for 50 known cases (locations) where the species is absent.

Create two variables with random normally distributed values and plot them:

```
> p = rnorm(50, mean=0.7, sd=0.3)
> a = rnorm(50, mean=0.4, sd=0.4)
> par(mfrow=c(1, 2))
> plot(sort(p), col='red', pch=21)
> points(sort(a), col='blue', pch=24)
> legend(1, 0.95 * max(a,p), c('presence', 'absence'), pch=c(21,24), col=c('red', 'blue'))
> comb = c(p,a)
> group = c(rep('presence', length(p)), rep('absence', length(a)))
> boxplot(comb~group, col=c('blue', 'red'))
```



The two variables clearly have different distributions, and the values for 'presence' tend to be higher than for 'absence'. Below we compute the correlation coefficient and the AUC:

```
> group = c(rep(1, length(p)), rep(0, length(a)))
> cor.test(comb, group)$estimate
```

```

      cor
0.2508189

> mv <- wilcox.test(p,a)
> auc <- as.numeric(mv$statistic) / (length(p) * length(a))
> auc

[1] 0.6548

```

This is how you can computing these, and other statistics, with the `dismo` package (and see the `ROCR` package for similar functionality):

```

> e = evaluate(p=p, a=a)
> class(e)

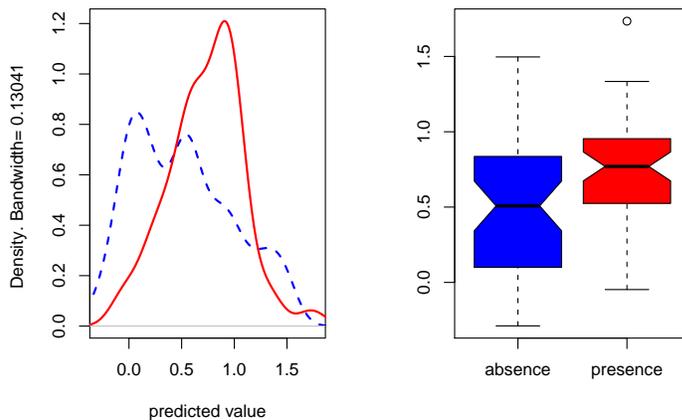
[1] "ModelEvaluation"
attr(,"package")
[1] "dismo"

> e

class           : ModelEvaluation
n presences     : 50
n absences      : 50
AUC             : 0.6548
cor            : 0.2508189
TPR+TNR threshold: 0.592

> par(mfrow=c(1, 2))
> density(e)
> boxplot(e, col=c('blue', 'red'))

```

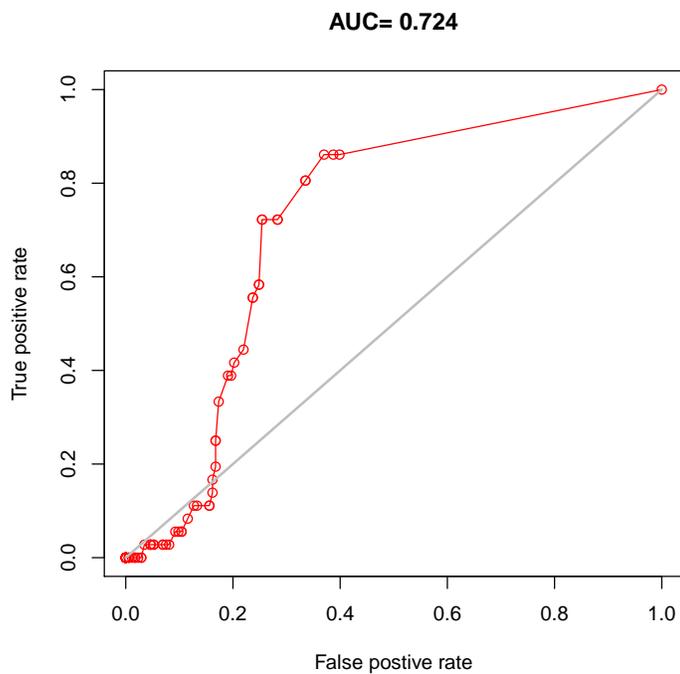


Now back to some real data, presence-only in this case. We'll divide the data in two random sets, one for training a Bioclim model, and one for evaluating the model.

```
> rand <- round(0.75 * runif(nrow(sdmdata)))
> traindata <- sdmdata[rand==0,]
> traindata <- traindata[traindata[,1] == 1, 2:9]
> testdata <- sdmdata[rand==1,]
> bc <- bioclim(traindata)
> e <- evaluate(testdata[testdata==1,], testdata[testdata==0,], bc)
> e
```

```
class           : ModelEvaluation
n presences     : 39
n absences      : 160
AUC             : 0.7967949
cor             : 0.3113558
TPR+TNR threshold: 0.026
```

```
> plot(e, 'ROC')
```



4.4 Data partitioning

The `kfold` function facilitates data partitioning. It creates a vector that assigns each row in the data matrix to a group (between 1 to `k`).

Let's first create presence and background data.

```
> pres <- sdmdata[sdmdata[,1] == 1, 2:9]
> back <- sdmdata[sdmdata[,1] == 0, 2:9]
```

The background data will only be used for model testing and does not need to be partitioned. We now partition the data into 5 groups.

```
> k <- 5
> group <- kfold(pres, k)
> group[1:10]

[1] 2 1 3 1 5 3 1 3 5 1

> unique(group)

[1] 2 1 3 5 4
```

Now we can fit and test our model five times. In each run, the records corresponding to one of the five groups is only used to evaluate the model, while the other four groups are only used to fit the model. The results are stored in a list called 'e'.

```
> e <- list()
> for (i in 1:k) {
+   train <- pres[group != i,]
+   test <- pres[group == i,]
+   bc <- bioclim(train)
+   e[[i]] <- evaluate(p=test, a=back, bc)
+ }
```

We can extract several things from the objects in 'e', but let's restrict ourselves to the AUC values and the "maximum of the sum of the sensitivity (true positive rate) and specificity (true negative rate)" (this is sometimes used as a threshold for setting cells to presence or absence).

```
> auc <- sapply(e, function(x){slot(x, 'auc')})
> auc

[1] 0.7840435 0.7663913 0.8041250 0.7694348 0.7374348

> mean(auc)

[1] 0.7722859

> sapply(e, function(x){ x@t[which.max(x@TPR + x@TNR)] })

[1] 0.065 0.100 0.040 0.040 0.060
```

Chapter 5

Modeling methods

A large number of algorithms have been used in species distribution modeling. They can be classified as 'profile', 'regression', and 'machine learning' methods. Profile methods only consider 'presence' data, not absence or background data. Regression and machine learning methods use both presence and absence or background data. The distinction between regression and machine learning methods is not sharp, but it is perhaps still useful as way to classify models. Below we discuss examples of these different types of models.

We will use the same data for all models, except that some models cannot use categorical variables. So we drop that from the predictors stack.

```
> pred_nf <- dropLayer(predictors, 'biome')
```

We'll use the *Bradypus* data for presence of a species. Lets make a training and a testing set.

```
> group <- kfold(bradypus, 5)
> pres_train <- bradypus[group != 1, ]
> pres_test <- bradypus[group == 1, ]
```

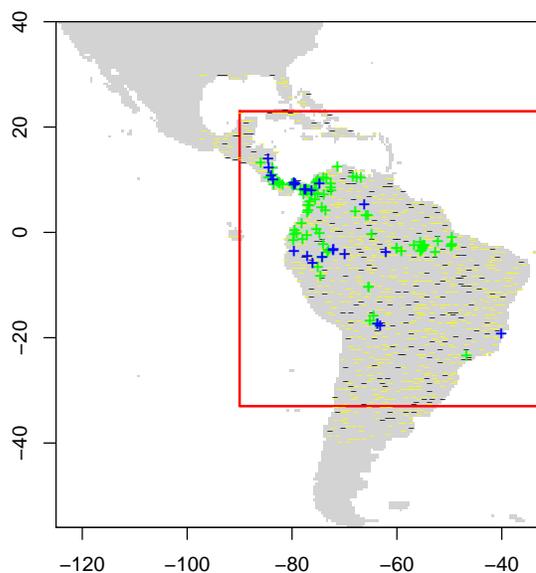
To speed up processing, let's restruct the predictions to a more restricted area (defined by a rectangular extent):

```
> ext = extent(-90, -32, -33, 23)
```

Background data for training and a testing set. The first layer in the Raster-Stack is used as a 'mask'. That ensures that random points only occur within the spatial extent of the rasters, and within cells that are not NA, and that there is only a single absence point per cell. Here we further restrict the background points to be within 15% of our specified extent 'ext'.

```
> backg <- randomPoints(pred_nf, n=1000, ext=ext, extf = 1.25)
> colnames(backg) = c('lon', 'lat')
> group <- kfold(backg, 5)
> backg_train <- backg[group != 1, ]
> backg_test <- backg[group == 1, ]
```

```
> r = raster(pred_nf, 1)
> plot(!is.na(r), col=c('white', 'light grey'), legend=FALSE)
> plot(ext, add=TRUE, col='red', lwd=2)
> points(backg_train, pch='-', cex=0.5, col='yellow')
> points(backg_test, pch='-', cex=0.5, col='black')
> points(pres_train, pch='+', col='green')
> points(pres_test, pch='+', col='blue')
```



5.1 Profile methods

The three methods described here, Bioclim, Domain, and Mahal. These methods are implemented in the `dismo` package. The procedures to use these models is therefore the same for all three.

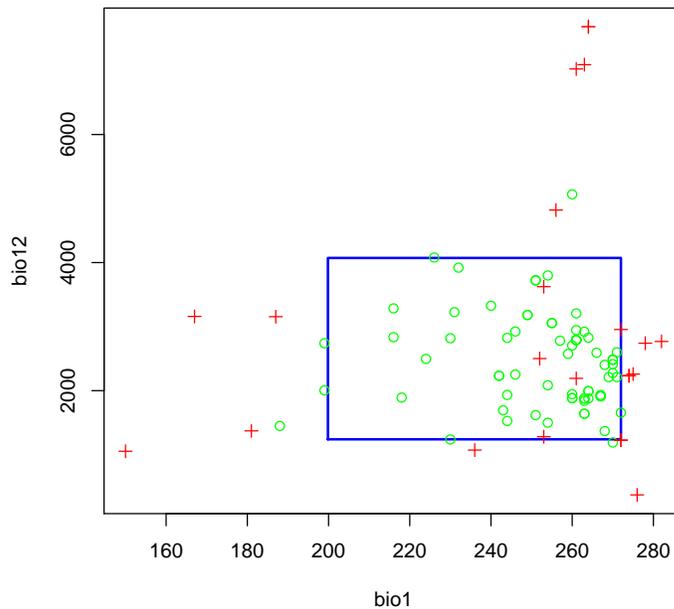
5.1.1 Bioclim

The BIOCLIM algorithm has been extensively used for species distribution modeling. BIOCLIM is a classic 'climate-envelope-model'. Although it generally does not perform as good as some other modeling methods (Elith et al. 2006, Hijmans and Graham, 2006), it is still used, among other reasons because the algorithm is easy to understand and thus useful in teaching species distribution

modeling. The BIOCLIM algorithm computes the similarity of a location by comparing the values of environmental variables at any location to a percentile distribution of the values at known locations of occurrence ('training sites'). The closer to the 50th percentile (the median), the more suitable the location is. The tails of the distribution are not distinguished, that is, 10 percentile is treated as equivalent to 90 percentile. In the 'dismo' implementation, the values of the upper tail values are transformed to the lower tail, and the minimum percentile score across all the environmental variables is used (i.e. BIOCLIM using an approach like Liebig's law of the minimum). This value is subtracted from 1 and then multiplied with two so that the results are between 0 and 1. The reason for scaling this way is that the results become more like that of other distribution modeling methods and are thus easier to interpret. The value 1 will rarely be observed as it would require a location that has the median value of the training data for all the variables considered. The value 0 is very common as it is assigned to all cells with a value of an environmental variable that is outside the percentile distribution (the range of the training data) for at least one of the variables.

Earlier on, we fitted a Bioclim model using data.frame with each row representing the environmental data at known sites of presence of a species. Here we fit a bioclim model simply using the predictors, and the occurrence points.

```
> bc <- bioclim(pred_nf, pres_train)
> plot(bc, a=1, b=2, p=0.85)
```



And evaluate it in a similar way, by providing presenced and background (absence) points, and a RasterStack:

```
> e <- evaluate(pres_test, backg_test, bc, pred_nf)
> e
```

```
class           : ModelEvaluation
n presences     : 23
n absences      : 200
AUC             : 0.7601087
cor             : 0.2508533
TPR+TNR threshold: 0.065
```

And use the RasterStack with predictor variables to make a prediction to a RasterLayer:

```
> pb <- predict(pred_nf, bc, ext=ext, progress='')
> pb
```

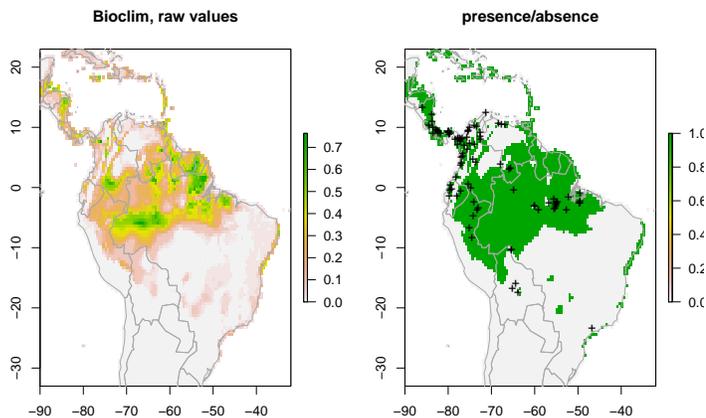
```
class           : RasterLayer
filename        :
nrow            : 112
ncol            : 116
ncell           : 12992
```

```

min value : 0
max value : 0.7634409
projection : +proj=longlat +datum=WGS84 +ellps=WGS84 +towgs84=0,0,0
xmin      : -90
xmax      : -32
ymin      : -33
ymax      : 23
xres      : 0.5
yres      : 0.5

> par(mfrow=c(1,2))
> plot(pb, main='Bioclim, raw values')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e@t[which.max(e@TPR + e@TNR)]
> plot(pb > threshold, main='presence/absence')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')

```



Please note the order of the arguments in the `predict` function. In the example above, we used `predict(pred_nf, bc)` (first the `RasterStack`, then the model object), which is little bit less efficient than `predict(bc, pred_nf)` (first the model, than the `RasterStack`). The reason for using the order we have used, is that this will work for all models, whereas the other option only works for the models defined in the `dismo` package, such as `Bioclim`, `Domain`, and `Maxent`, but not for models defined in other packages (random forest, boosted regression trees, glm, etc.).

5.1.2 Domain

The `Domain` algorithm (Carpenter et al. 1993) that has been extensively used for species distribution modeling. It did not perform very well in a model

comparison (Elith et al. 2006) and very poorly when assessing climate change effects (Hijmans and Graham, 2006). The Domain algorithm computes the Gower distance between environmental variables at any location and those at any of the known locations of occurrence ('training sites').

The distance between the environment at point A and those of the known occurrences for a single climate variable is calculated as the absolute difference in the values of that variable divided by the range of the variable across all known occurrence points (i.e., the distance is scaled by the range of observations). For each variable the minimum distance between a site and any of the training points is taken. The Gower distance is then the mean of these distances over all environmental variables. The Domain algorithm assigns to a place the distance to the closest known occurrence (in environmental space).

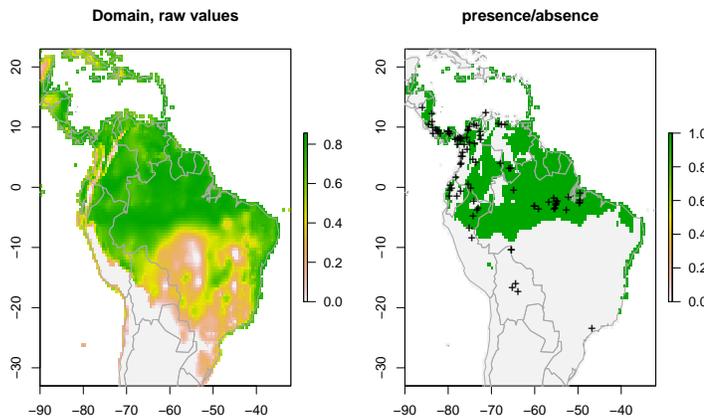
To integrate over environmental variables, the distance to any of the variables is used. This distance is subtracted from one, and (in this R implementation) values below zero are truncated so that the scores are between 0 (low) and 1 (high).

Below we fit a domain model, evaluate it, and make a prediction. We map the prediction, as well as a map subjectively classified into presence / absence.

```
> dm <- domain(pred_nf, pres_train)
> e <- evaluate(pres_test, backg_test, dm, pred_nf)
> e
```

```
class           : ModelEvaluation
n presences     : 23
n absences      : 200
AUC             : 0.7663043
cor             : 0.2666756
TPR+TNR threshold: 0.731
```

```
> pd = predict(pred_nf, dm, ext=ext, progress='')
> par(mfrow=c(1,2))
> plot(pd, main='Domain, raw values')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e@t[which.max(e@TPR + e@TNR)]
> plot(pd > threshold, main='presence/absence')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')
```



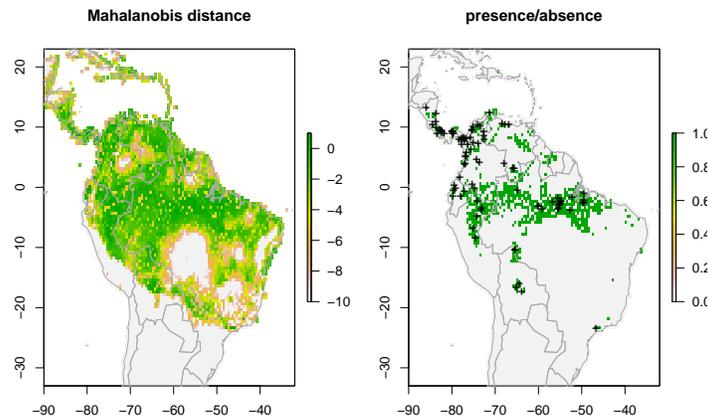
5.1.3 Mahalanobis

The `mahal` function implements a species distribution model based on the Mahalanobis distance (Mahalanobis, 1936). Mahalanobis distance takes into account the correlations of the variables in the data set, and it is not dependent on the scale of measurements.

```
> mm <- mahal(pred_nf, pres_train)
> e <- evaluate(pres_test, backg_test, mm, pred_nf)
> e

class          : ModelEvaluation
n presences    : 23
n absences     : 200
AUC            : 0.8216304
cor            : 0.1390922
TPR+TNR threshold: -0.206

> pm = predict(pred_nf, mm, ext=ext, progress='')
> par(mfrow=c(1,2))
> pm[pm < -10] <- -10
> plot(pm, main='Mahalanobis distance')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e@t[which.max(e@TPR + e@TNR)]
> plot(pm > threshold, main='presence/absence')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')
```



5.2 Regression models

The remaining models need to be fit presence textifand absence (background) data. With the exception of 'maxent', we cannot fit the model with a Raster-Stack and points. Instead, we need to extract the environmental data values ourselves, and fit the models with these values.

```
> train <- rbind(pres_train, backg_train)
> pb_train <- c(rep(1, nrow(pres_train)), rep(0, nrow(backg_train)))
> envtrain <- xyValues(predictors, train)
> envtrain <- data.frame( cbind(pa=pb_train, envtrain) )
> envtrain[, 'biome'] = factor(envtrain[, 'biome'], levels=1:14)
> head(envtrain)
```

	pa	bio1	bio12	bio16	bio17	bio5	bio6	bio7	bio8	biome
1	1	263	1639	724	62	338	191	147	261	1
2	1	263	1639	724	62	338	191	147	261	1
3	1	253	3624	1547	373	329	150	179	271	1
4	1	243	1693	775	186	318	150	168	264	1
5	1	252	2501	1081	280	326	154	172	270	1
6	1	275	2259	956	208	335	231	104	270	1

```
> testpres <- data.frame( xyValues(predictors, pres_test) )
> testbackg <- data.frame( xyValues(predictors, backg_test) )
> testpres[, 'biome'] = factor(testpres[, 'biome'], levels=1:14)
> testbackg[, 'biome'] = factor(testbackg[, 'biome'], levels=1:14)
```

5.2.1 Generalized Linear Models

A generalized linear model (GLM) is a generalization of ordinary least squares regression. Models are fit using maximum likelihood and by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value. Depending on how a GLM is specified it can be equivalent to (multiple) linear regression, logistic regression or Poisson regression. See Guisan et al (2002) for an overview of the use of GLM in species distribution modeling.

In R, GLM is implemented in the 'glm' function, and the link function and error distribution are specified with the 'family' argument. Examples are:

```
family = binomial(link = "logit")
family = gaussian(link = "identity")
family = poisson(link = "log")
```

Here we fit two basic glm models. All variables are used, but without interaction terms.

```
> gm1 <- glm(pa ~ bio1 + bio5 + bio6 + bio7 + bio8 + bio12 + bio16 + bio17,
+           family = binomial(link = "logit"), data=envtrain)
> gm2 <- glm(pa ~ bio1 + bio5 + bio6 + bio7 + bio8 + bio12 + bio16 + bio17,
+           family = gaussian(link = "identity"), data=envtrain)
> e1 = evaluate(testpres, testbackg, gm1)
> e2 = evaluate(testpres, testbackg, gm2)
> e1
```

```
class          : ModelEvaluation
n presences    : 23
n absences     : 200
AUC            : 0.8127174
cor            : 0.2783048
TPR+TNR threshold: -1.858
```

```
> e2
```

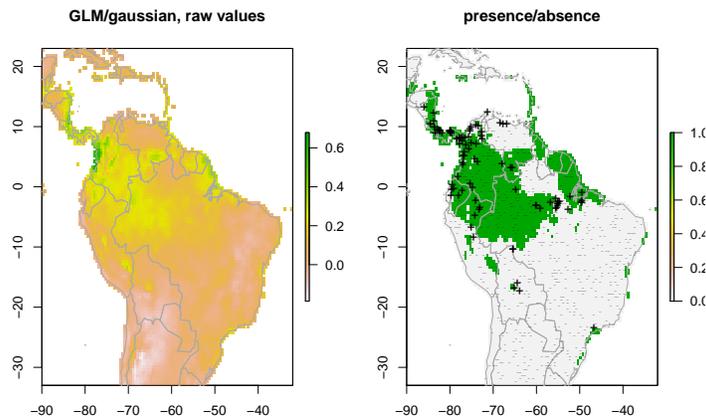
```
class          : ModelEvaluation
n presences    : 23
n absences     : 200
AUC            : 0.8161957
cor            : 0.3537634
TPR+TNR threshold: 0.173
```

```
> pg <- predict(predictors, gm2, ext=ext)
> par(mfrow=c(1,2))
> plot(pg, main='GLM/gaussian, raw values')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e2@t[which.max(e@TPR + e@TNR)]
> plot(pg > threshold, main='presence/absence')
```

```

> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')
> points(backg_train, pch='-', cex=0.25)

```



5.2.2 Generalized Additive Models

Generalized additive models (GAMs; Hastie and Tibshirani, 1990; Wood, 2006) are an extension to GLMs. In GAMs, the linear predictor is the sum of smoothing functions. This makes GAMs very flexible, and they can fit very complex functions. It also makes them very similar to machine learning methods. In R, GAMs are implemented in the 'mgcv' package. The 'grasp' package implements species distribution modeling with gam (Lehman et al., 2002).

5.3 Machine learning methods

There is a variety of machine learning (sometimes referred to data mining) methods in R. For a long time there have been packages to do Artificial Neural Networks (ANN) and Classification and Regression Trees (CART). More recent methods include Random Forests, Boosted Regression Trees, and Support Vector Machines. Through the dismo package you can also use the Maxent program, that implements the most widely used method (maxent) in species distribution modeling. Breiman (2001a) provides an accessible introduction to machine learning, and how it contrasts with 'classical statistics' (model based probabilistic inference). Hastie et al., 2009 provide what is probably the most extensive overview of these methods.

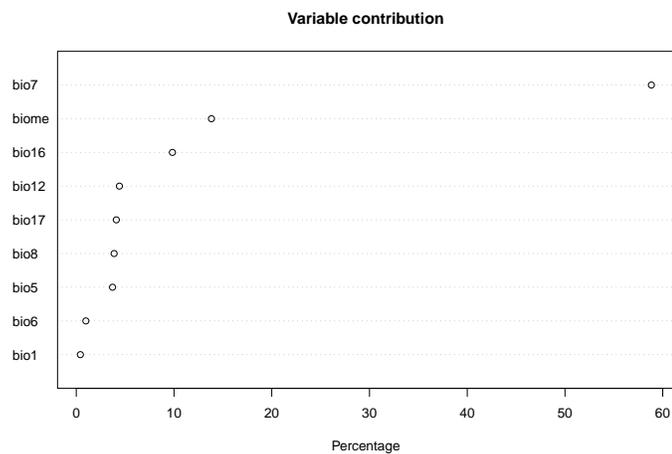
All the model fitting methods discussed here can be tuned in several ways. We do not explore that, and only show the general approach. If you want to use one of the methods, then you should consult the R help pages (and other sources) to find out how to best implement the model fitting procedure.

5.3.1 Maxent

The Maxent (Maximum Entropy) species distribution model (Phillips et al., 2004, 2006) is a stand alone Java program. Dismo has a function 'maxent' that communicates with this program. To use it you must first download the program from <http://www.cs.princeton.edu/~schapire/maxent/>. Put the file 'maxent.jar' in the 'java' folder of the 'dismo' package. That is the folder returned by `system.file("java", package="dismo")`. Please note that this program (maxent.jar) can not be redistributed or used for commercial purposes.

Because maxent is implemented in dismo you can fit it like the profile methods (e.g. Bioclim). That is, you can provide presence points and a RasterStack. However, you can also fit it like the other methods such as glm. Note, however, that in that case you cannot use the formula notation.

```
> jar <- paste(system.file(package="dismo"), "/java/maxent.jar", sep='')
> if (file.exists(jar)) {
+   xm <- maxent(predictors, pres_train, factors='biome')
+   plot(xm)
+ } else {
+   cat('cannot run this example because maxent is not available on this system!')
+   plot(1)
+ }
```

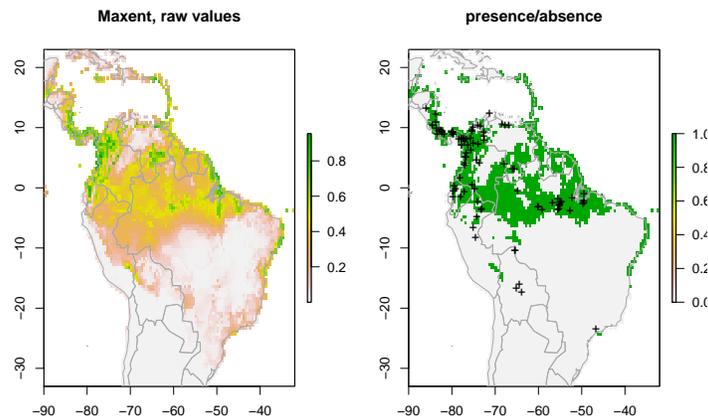


```
> if (file.exists(jar)) {
+   e <- evaluate(pres_test, backg_test, xm, predictors)
+   e
+   px = predict(predictors, xm, ext=ext, progress='')
+   par(mfrow=c(1,2))
+   plot(px, main='Maxent, raw values')
+   plot(wrld_simpl, add=TRUE, border='dark grey')
```

```

+     threshold <- e@t[which.max(e@TPR + e@TNR)]
+     plot(px > threshold, main='presence/absence')
+     plot(wrld_simpl, add=TRUE, border='dark grey')
+     points(pres_train, pch='+')
+ } else {
+     plot(1)
+ }

```



5.3.2 Boosted Regression Trees

Boosted Regression Trees (BRT) is, unfortunately, known by a large number of different names. It was developed by Friedman (2001), who referred to it as a "Gradient Boosting Machine" (GBM). It is also known as "Gradient Boost", "Stochastic Gradient Boosting", "Gradient Tree Boosting". The method is implemented in the 'gbm' package in R.

The article by Elith, Leathwick and Hastie (2009) describes the use of BRT in the context of species distribution modeling. Their article is accompanied by a number of R functions and a tutorial. The functions have been slightly adjusted and incorporated into the 'dismo' package. These functions extend the functions in the 'gbm' package, with the goal to make these easier to apply to ecological data, and to enhance interpretation. The adapted tutorial is available as a vignette to the dismo package. You can access it via the index of the help pages, or with this command: `vignette('gbm', 'dismo')`

5.3.3 Random Forest

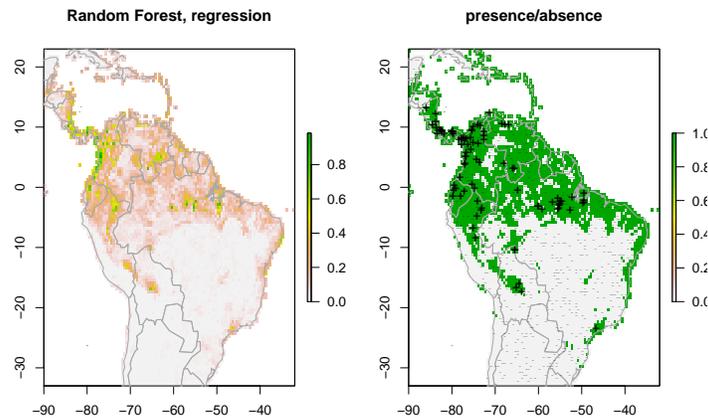
The Random Forest (Breiman, 2001b) method is an extension of Classification and regression trees (CART; Breiman et al., 1984). In R it is implemented in the function 'randomForest' in a package with the same name. The function randomForest can take a formula or, in two separate arguments, a data.frame

with the predictor variables, and a vector with the response. If the response variable is a factor (categorical), `randomForest` will do classification, otherwise it will do regression. Whereas with species distribution modeling we are often interested in classification (species is present or not), it is my experience that using regression provides better results. `rf1` does regression, `rf2` and `rf3` do classification (they are exactly the same models). See the function `tuneRF` for optimizing the model fitting procedure.

```
> library(randomForest)
> model <- pa ~ bio1 + bio5 + bio6 + bio7 + bio8 + bio12 + bio16 + bio17
> rf1 <- randomForest(model, data=envtrain)
> model <- factor(pa) ~ bio1 + bio5 + bio6 + bio7 + bio8 + bio12 + bio16 + bio17
> rf2 <- randomForest(model, data=envtrain)
> rf3 <- randomForest(envtrain[,1:8], factor(pb_train))
> e = evaluate(testpres, testbackg, rf1)
> e
```

```
class           : ModelEvaluation
n presences     : 23
n absences      : 200
AUC             : 0.8344565
cor             : 0.3897359
TPR+TNR threshold: 0.04
```

```
> pr <- predict(predictors, rf1, ext=ext)
> par(mfrow=c(1,2))
> plot(pr, main='Random Forest, regression')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e@t[which.max(e@TPR + e@TNR)]
> plot(pr > threshold, main='presence/absence')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')
> points(backg_train, pch='-', cex=0.25)
```



5.3.4 Support Vector Machines

Support Vector Machines (SVMs; Vapnik, 1998) apply a simple linear method to the data but in a high-dimensional feature space non-linearly related to the input space, but in practice, it does not involve any computations in that high-dimensional space. This simplicity combined with state of the art performance on many learning problems (classification, regression, and novelty detection) has contributed to the popularity of the SVM (Karatzoglou et al., 2006). They were first used in species distribution modeling by Guo et al. (2005).

There are a number of implementations of svm in R. The most useful implementations in our context are probably function 'ksvm' in package 'kernlab' and the 'svm' function in package 'e1071'. 'ksvm' includes many different SVM formulations and kernels and provides useful options and features like a method for plotting, but it lacks a proper model selection tool. The 'svm' function in package 'e1071' includes a model selection tool: the 'tune' function (Karatzoglou et al., 2006)

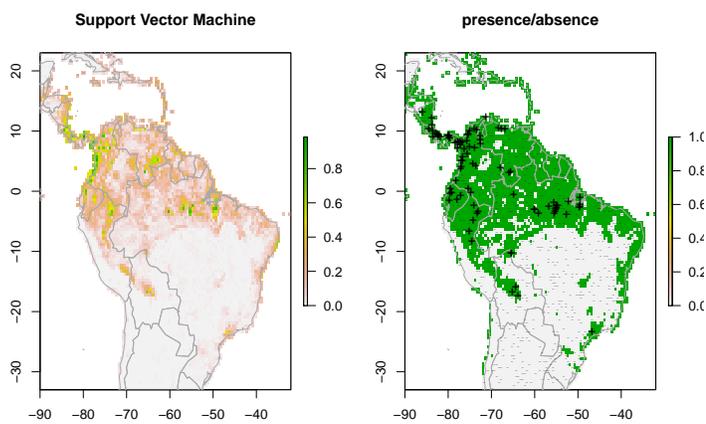
```
> library(kernlab)
> svm <- ksvm(pa ~ bio1 + bio5 + bio6 + bio7 + bio8 + bio12 + bio16 + bio17, data=envt)
```

Using automatic sigma estimation (sigest) for RBF or laplace kernel

```
> e = evaluate(testpres, testbackg, svm)
> e
```

```
class          : ModelEvaluation
n presences    : 23
n absences     : 200
AUC            : 0.6716304
cor           : 0.1761199
TPR+TNR threshold: 0.031
```

```
> ps <- predict(predictors, rf1, ext=ext)
> par(mfrow=c(1,2))
> plot(ps, main='Support Vector Machine')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> threshold <- e@t[which.max(e@TPR + e@TNR)]
> plot(ps > threshold, main='presence/absence')
> plot(wrld_simpl, add=TRUE, border='dark grey')
> points(pres_train, pch='+')
> points(backg_train, pch='-', cex=0.25)
```



The remainder of this document is to be completed.

5.3.5 Other methods

Neural networks, ...

Chapter 6

More...

6.1 Multi-species models

6.1.1 mars

6.1.2 gdm

6.2 Model transfer

6.2.1 space

6.2.2 time: climate change

6.3 Model averaging

See the BIOMOD for on multi-model inference.

6.4 Dealing with uncertainty

Chapter 7

Geographic models

The 'geographic models' described here are not commonly used in species distribution modeling. They are an attempt to formalize methods to draw 'expert range maps'. They can also be interpreted as null-models. To be completed.

7.1 Geographic models (presence-only)

7.1.1 Distance

7.1.2 Convex hulls

7.1.3 Circles

7.2 Geographic models (presence-absence)

7.2.1 Inverse distance

7.2.2 Voronoi hulls

Chapter 8

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