

A tutorial for Step Selection Function

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November 25, 2014

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1 Introduction

—KORRIGIERTE "ALTE" VERSION—

In addition to Resources Selection Functions (RSF) another powerful tool for evaluating data on animal movements and habitat selection are Step Selection Functions (SSF). The latter are used to estimate resource selection by comparing observed habitat use with available structures. Given GPS locations of a collared individual each observation is connected by a linear segment. These segments are considered as steps. The time intervals influencing the step length should be chosen carefully (i.e. by conducting a pilot study) to meet the requirements of the study questions and the target species. The SSF then calculates random steps by taking measured angle and distance along steps and using the observed position as starting points. These alternative positions represent the available habitat beside observed positions. Finally, a comparison of spatial attributes of both, the available and the chosen locations, describes the habitat selection made by animals [2].

So far, SSF models were mainly done using Geospatial Modelling Environment (GME) that works with a GIS (www.spataleecology.com/gme/). However, more and more packages for analyzing animal movements are provided in R. None of these packages is designed for doing a SSF only but different ones provide helpful functions that perform single steps of the Selection Function. Therefore, the aim of this tutorial is to collect all functions necessary to conduct a SSF and order them in a way that intuitively makes you understand how to run a SSF with your own data. Each step will be explained using an exemplary dataset of GPS locations collected from seven Cougars (*Puma concolor*) in the year 2010 (in the following addressed as `xmp1`).

Figure 1 provides an overview of necessary steps and potential options to conduct a SSF. The initial data needs to be stored in two independent datasets:

1. a raster file of your spatial attributes and
2. GPS locations of your individuals assigned with a time stamp

. The main focus lays on the right side of the workflow, describing preparation of the waypoint data. After loading the table into R you need to create an so-called `ltraj` object. This data class can be modified if necessary, as random steps should only be calculated for equal time intervals. Accumulations of relocations with the same time lag can be combined to several "bursts". Each burst has a unique ID (often including an ID for the individual and the time stamp). While there are many options to adjust your waypoint data the raster data describing your spatial attributes needs not much input. Once you created random steps for your observed positions you can extract the spatial attributes for each of those positions by using the function `extract`. At this point waypoint and raster data will be combined and your final model can be written.

In our tutorial we use telemetry data from Cougars/Mountain Lion (*Puma concolor*) collected by Simone Ciuti¹. As spatial parameters x tables for ruggedness, slope, canopy cover etc. are available. Describe study area...

—HENNIS "NEUE" VERSION—

In addition to Resources Selection Functions (RSF) another powerful tool for evaluating data on animal movements and habitat selection are Step Selection Functions (SSF). The latter are used to estimate resource selection by comparing observed habitat use with available structures. Given GPS locations of a collared individual each observation is connected by a linear segment. These segments are considered as steps. The time intervals influencing the step length should be chosen carefully (i.e. by conducting a pilot study) to meet the requirements of the study questions and the target species. The SSF then calculates random steps by taking measured angle and distance along steps and using the observed positions as starting points. These alternative steps represent the available habitat within a realistic step length of the

¹we might have to specify that and name and thank the institute.../collected/containing

observed positions. Finally, we can compare spatial attributes on both and test for effects that explain habitat selection by animals [2].

So far, SSF models were mainly done using Geospatial Modelling Environment (GME) that works with a GIS². However, more and more packages for analyzing animal movements are provided in R. Non of these packages is designed for doing a SSF only but quite a number provide already helpful functions to perform single steps of the Selection Function. Therefore, the aim of this tutorial is to collect all functions necessary to conduct a SSF and order them in a way that intuitively makes you understand how to run a SSF with your own data. Each step will be explained using an exemplary dataset of GPS locations collected from seven Cougars (*Puma concolor*) in the year 2010 (in the following addressed as `xmpl`).

Figure 1 provides an overview of all necessary steps and potential options to conduct a SSF. This tutorial will guide you through each step and gives brief instructions on how to implement the functions and what to consider beforehand. To conduct a SSF using this tutorial we need you to store your initial data in two independant datasets:

1. A raster file of your spatial attributes (*Raster data*) and
2. GPS locations of your individuals assigned with a time stamp (*Waypoint data*).

We will start with the *Waypoint data* because these need to transformed a couple of times to be able to work with them. You can find the single steps on the right side of Figure 1. After loading the table into R you need to create an so-called `ltraj` object. This data class can now be further transformed by ... Random steps should only be calculated for equal time intervals. These can be defined by creating bursts. Each burst has an unique ID (often including an ID for the individual and the time stamp). While there are many options to adjust your *Waypoint data* the *Raster data* describing your spatial attributes needs not much of change. Once you created random steps for your observed positions you can extract the spatial attributes for each of those positions by using the function `extract`. At this point *Waypoint* and *Raster data* will be combined and your final model can be written.

DO WE NEED A EQUATION??

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p)$$

Why did we not use the data (Wildboar) prepared for the `adehabitatLT` package? - No information on details, metadata provided, it is hard to understand when to use which dataset and why.

1.1 Preparations

Before you can actually start using the tutorial for conducting SSF you need to load a bunch of packages in R. Some of them require others so that you have to add all these to your library:

1.2 Packages - what we need

Installing packages:

```
## for implementing SSF

install.packages("adehabitatHR")
install.packages("adehabitatHS")
install.packages("adehabitatLT")
```

²www.spatialecology.com/gme/

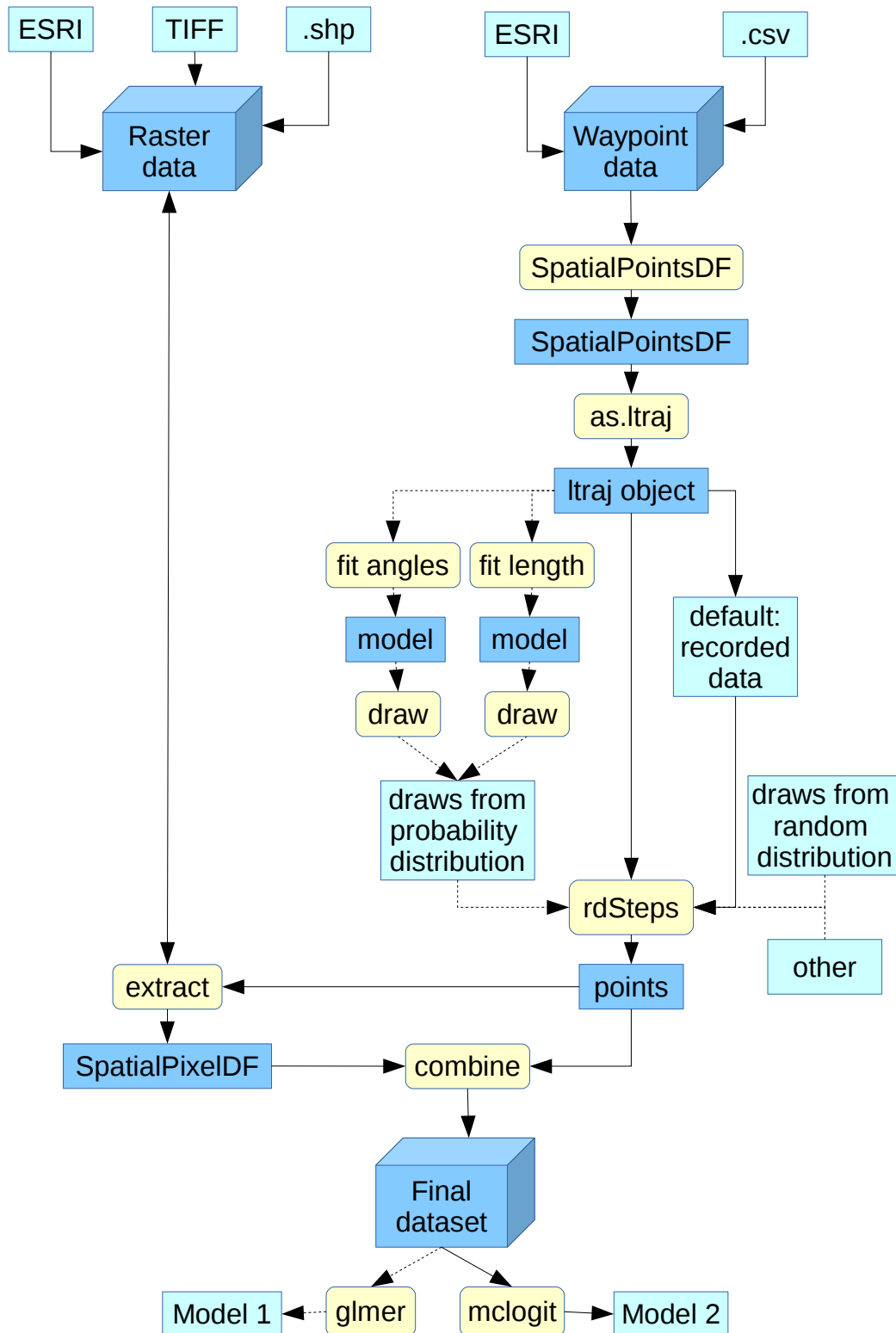


Figure 1: Conducting a Step Selection Function using existing R-packages. The yellow boxes show the name of the function applied while the blue boxes provide the type of object or data. Following the arrows a step by step instruction is provided ...

```
install.packages("adehabitatMA")
# Keep fingers off the "adehabitat" package! It is outdated.

install.packages("tkrplot")
install.packages("hab", repos = "http://ase-research.org/R/") # regular
install.packages("hab", repos = "http://ase-research.org/R/", type = "source") # for self-c

# for handling raster data
install.packages("move")
install.packages("raster")
install.packages("rgdal")
```

Loading packages:

```
require(hab)
require(adehabitatMA)
require(adehabitatHR)
require(adehabitatHS)
require(adehabitatLT)

require(sp)
require(raster)
#require(move)
#require(rgdal)
#require(tkrplot)
```

2 Processing the waypoint data (or telemetry?)

2.1 Loading waypoint data (*.csv, ESRI)

The data for the analysis should be saved in a simple *.csv file format. The table should have column headings in the first line and for each observation include at least the following values:

1. x-coordinate (easting)
2. y-coordinate (northing)
3. date and/or time
4. animal ID

Note that the coordinates need to be provided in the same coordinate system and spatial projection as the raster data.

Depending on your analysis you can include further values such as:

1. ID for each record
2. GPS precision
3. other recording parameters such as season
4. temperature / elevation at the moment of record
5. other values that might be of interest in the further analysis

Use the following commands to set your working directory and read the data:

```
setwd("/your/working/directory")
xmpl = read.csv("xmpl.csv", head=T)
```

You can execute `head(xmpl)` and `str(xmpl)` to check, whether the data were successfully read.

2.2 Broken stick model

2.3 Creating a Spatial Points Data Frame

The functions used along the rest of the toolchain can only process data that are stored as objects of class "SpatialPointsDataFrame". This object class stores the coordinates separately and can be created using the according function from package "sp".

```
require(sp)

xmpl.spdf = SpatialPointsDataFrame(coords = xmpl[,c("easting", "northing")], data = xmpl)

names(xmpl)
```

In the "coords" argument of the function you should specify the coordinate vectors for your dataset. In our example, we simply assign the two coordinate columns of the example dataset, but you can read the coordinates from a separate file if you want.

2.4 Creating an ltraj object

After storing the data in a Spatial Points Data Frame, you now need to connect the single points and turn them into a set of trajectories. This operation is carried out by the function `as.ltraj` from the "hab" package and produces objects of class "ltraj". The function `as.ltraj` requires at least three arguments to work:

1. "xy" (x- and y- coordinates for each point)
2. "date" (timestamp for each point, given as POSIXct class)
3. "id" (the animal id)

Both coordinates and animal id can easily be adopted from the Spatial Points Data Frame. The timestamp however, is not stored in the required format yet and you therefore need to convert it first:

```
date <- as.POSIXct(strptime(paste(xmpl.spdf$LMT_DATE, xmpl.spdf$LMT_TIME), "%d/%m/%Y %H:%M"))
```

It is necessary to combine date and time in one POSIXct value. If your dataset already features a POSIXct timestamp, you can skip this step.

Now you can proceed and actually create the ltraj object by executing the following command:

```
xmpl.ltr <- hab:::as.ltraj(xy = xmpl.spdf@coords, date = date, id = xmpl.spdf$cat)
```

Two comments to the function as used: By typing `hab:::as.ltraj` you tell R to use the `as.ltraj` function from the "hab" package which is speed optimized against its `adehabitatLT` sibling. Unlike the `"xmpl.spdf@coords"` prompt which works for any SPDF object, the `xmpl.spdf$cat` prompt is specific to your dataset. In the example dataset, animal ID's

are stored as an integer vector called "cat". If this differs in your dataset and you should change the prompt accordingly.

You now may want to have a closer look at the created `ltraj` object. Display its structure with by executing `str(xmpl.ltr)`.

```
str(xmpl.ltr)
```

When scrolling through the output you will first notice that it consists of 7 elements - the number of individuals in the example dataset. This is because `as.ltraj()` automatically splits the dataset into subsets one for each individual. We will refine these subsets in the next chapter. Furthermore, the `ltraj` contains information on the distances and turning angles between consecutive locations. To get a visual impression of your data you can plot the trajectory for all or for one particular animal:

```
plot(xmpl.ltr)
unique(xmpl.spdf$cat) # prompts a list of all cat ID's. Choose one that you are interested
plot(xmpl.ltr, id=10289)
```

2.5 Creating Bursts

As described in the previous section, the relocations stored in the `ltraj` object are already divided into the different individuals. This partition is called a "burst". For analysing the data, there might be the need to create "sub-bursts" for each animal within your trajectory. For example, if the animals were only recorded during the day, the monitoring took place over two consecutive years or the time lag between the relocations differs remarkably, each accumulation of relocations can be defined as a different burst. Looking at those different parts separately might be necessary for different reasons. The function `cutltraj` splits the given bursts of your `ltraj` object into smaller bursts according to a specified criterion. In contrast, the function `bindltraj` combines the bursts of an object of class "ltraj" with the same attribute "id" to one unique burst. To find out if there are more missing values, you can plot the `ltraj` object. For that, you need to define the time interval you are looking at. [1]

In our example, the locations of the cougars were recorded every 3 hours, starting at 3 AM. The location at midnight is always missing. We now want to split the existing bursts (individuals) into "sub-bursts" where the time lag is smaller than 3 hours. To get an impression about the time lags we plotted the different bursts (individuals). "dt", the time between successive relocations is measured in seconds.

```
plotltr(xmpl.ltr, "dt/3600/3")
```

To cut our data at our desired interval, we need a function which defines "dt". Because we want to keep relocations which are only a few minutes "wrong", we added 10 extra minutes.

```
foo = function(dt) {return(dt> (3800*3))}
```

Then we split the object of class `ltraj` into smaller bursts using `cutltraj` and the function above. The bursts we had before applying this function still remain.

```
xmpl.cut <- cutltraj(xmpl.ltr, "foo(dt)", nextr = TRUE)
```

There are two options of cutting the trajectory depending on `nextr`. If it is set as `FALSE`, the burst stops before the first relocation matching the criterion. if it is set as `TRUE`, it stops after. [1]

2.6 Creating random steps

Given your final bursts of at least three positions (this is because for calculating random steps the angle from the point before but the distance to the point afterwards is used) you need to check for correlation between angle and distance. In case your species tends to move long distances by turning in small angles (e.g. Cougars while searching for prey or wandering around) you want to pick the distance and the angle as pairs dependent on each other. If no correlation is found you can pick both variables independently.

AUTOCORRELATION ???

```
## Loading required package: adehabitatLT
## Loading required package: sp
## Loading required package: ade4
## Loading required package: adehabitatMA
## Loading required package: CircStats
## Loading required package: MASS
## Loading required package: boot
## Error in inherits(ltraj, "ltraj"): Objekt 'xmpl.cut' nicht gefunden
```

```
with(xmpl.cut.df, plot(dist, rel.angle))

## Error in with(xmpl.cut.df, plot(dist, rel.angle)): Objekt 'xmpl.cut.df'
nicht gefunden
```

The plot shows a correlation of step length and turning angle and therefore the random steps should be taken as pairs (`simult = T`). Per default the angle and distance for each random step is drawn from the observed values you provide with `x`. If your random steps shall be taken from a different data set you can do so by writing it in `rand.dist = .`. Here you can also specify a distribution for estimating angle and distance to draw from.

```
xmpl.steps <- rdSteps(x = xmpl.cut, nrs = 10, simult = T, rand.dis = NULL,
                     distMax = Inf, reproducible = TRUE, only.others = FALSE)
# use simult = FALSE if your data is not correlated
```

The function `rdSteps` uses several default settings for calculating the random steps. You can easily change the number of steps taken from the observed data by defining `nrs` (default is 10) or if you only need steps shorter than a certain value specify `dist.Max` to that value (per default all steps are taken). By setting `reproducible = TRUE` a seed is used to get reproducible random steps. If you want to exclude your current step to draw angle and distance from than set `only.others = TRUE`.

```
head(xmpl.steps)

## Error in head(xmpl.steps): Objekt 'xmpl.steps' nicht gefunden
```

You see that the function `rdSteps` does give you the difference (column `dx` and `dy`) of your observed positions for each random step. To get new coordinates for your random steps we simply add the x-coordinates to the `dx` and the same for the y-coordinates. Thereby, the first observed position will be overwritten as the first random step. That is necessary because there is no random step to compare the first observed position with (no angle to calculate for!). Also the last observed position will be lost for similar reasons (there is no distance to calculate the random step with!).


```
xmpl.steps$new_x <- xmpl.steps$x + xmpl.steps$dx
xmpl.steps$new_y <- xmpl.steps$y + xmpl.steps$dy
```

```
head(xmpl.steps)
```

```
## Error in head(xmpl.steps): Objekt 'xmpl.steps' nicht gefunden
```

Your final table includes a column for the differences of the observed positions to each random step (dx and dy) and now also a column for the actual coordinates of each random position. Depending on your analysis you might want to compare only the endpoints (observed positions) of your species or also the spatial attributes along the path.

strata ?? case ??

3 Processing spatial covariates

This section explains the handling of spatial parameters that will be tested for selection by the target species. You should store these data in raster files (ESRI *.adf or georeferenced *.tif). These should have the same coordinate system as your telemetry data and should (for time reasons) already be clipped to your study area and. For instructions how to do this in R, please read the GIS instructions from the other group ;)

3.1 Load raster data (ESRI, *.tif, (*.shp))

With a simple function stored in the package **raster** you are able to upload any raster file into R. Exemplarily we use raster data on the following parameters for the study area:

1. ruggedness of the terrain
2. land cover
3. canopy cover
4. distance to the nearest highway
5. distance to the nearest road

For reading the raster data, three packages are required:

```
require(raster)
require(rgdal)
require(sp)
```

The source files for the raster data can be stored in the working directory or loaded by specifying the exact path. The **raster()** function is a universal and very powerful tool for loading all kinds of raster data. For reading shapefiles, use the **readOGR()** function. Below is an example of how to read a set of raster layers.

```
# First, make sure that your working directory is still the one specified earlier:
getwd()

# Now read the layers:
ruggedness <- raster("ruggedness.adf")
landcover <- raster("landcover.adf")
```

```
canopycover <- raster("canopycover.adf")
disthighway <- raster("disthighway.adf")
distrdoad <- raster("distrdoad.adf")
# In the ESRI directory system, raster layers are usually stored in files called "w001001.a
```

You can plot the data for a first overview. As this can take a while with large datasets, uncomment the following chunk if you please!

```
plot(ruggedness)
plot(landcover)
plot(canopycover)
plot(disthighway)
plot(distrdoad)
```

3.2 Checking for collinearity

3.3 Raster extraction

Now that you have generated the random steps and loaded the raster data, you can take the next step and actually connect the trajectories with the spatial covariates. There are different functions that can do this. When choosing one, you need to consider that raster files are large and juggling with them occupies lots of memory and computing power. For this reason we suggest using the `extract()` function that allows for querying single pixel values without loading the whole source file into working memory. The code for compiling the final dataset involves three steps: Converting the `xmpl.steps` data frame into a Spatial Points Data frame, extracting the raster values and combining them to the final dataset. Converting `xmpl.steps` into a `SpatialPointsDataFrame`:

```
xmpl.steps.spdf <- SpatialPointsDataFrame(coords = xmpl.steps[,c("new_x", "new_y")], data = xmpl.steps[,c("new_x", "new_y")])
```

Extracting the values from each raster layer:

```
ruggedness.extr <- extract(ruggedness, xmpl.steps.spdf, method='simple', sp=F, df=T)
canopycover.extr <- extract(canopycover, xmpl.steps.spdf, method='simple', sp=F, df=T)
disthighway.extr <- extract(disthighway, xmpl.steps.spdf, method='simple', sp=F, df=T)
distrdoad.extr <- extract(distrdoad, xmpl.steps.spdf, method='simple', sp=F, df=T)
landcover.extr <- extract(landcover, xmpl.steps.spdf, method='simple', sp=F, df=T)
```

The extraction is done separately for each layer. The option `method = 'simple'` extracts value from nearest cell whereas `method = 'bilinear'` interpolates from the four nearest cells. You can adjust this option according to the resolution of your dataset and ecological considerations. `df=T` returns the result as a data frame and `sp=F` ensures that the output is not added to the original dataset right away.

Automatically adding the extracted values to the original dataset sounds like a handy option. For two reasons we do not use it here: Firstly, we want to set the column names manually for not ending up with several columns called "w001001". Secondly, our data include a categorical covariate (landcover) that we want to reclassify and flag as a factor.

This is the code for compiling the final dataset:

```
xmpl.steps.spdf$ruggedness <- ruggedness.extr[,2]
xmpl.steps.spdf$canopycover <- canopycover.extr[,2]
xmpl.steps.spdf$disthighway <- disthighway.extr[,2]
```

```
xmpl.steps.spdf$distroad <- distroad.extr[,2]

# The landcover covariate comes coded in integers between 0 and 10 and is by default (mis)in
unique(landcover.extr[,2])
# Re-classifying landcover:
xmpl.steps.spdf$landcover <- as.factor(
  ifelse(landcover.extr[,2] == 0, "NA",
  ifelse(landcover.extr[,2] < 5, "forest",
  ifelse(landcover.extr[,2] < 8, "open", "NA"))))
```

Now your final dataset should be ready for analysis. Examine it:

```
head(xmpl.steps.spdf)
```

4 Final SSF model

Using the function `cs`, we get comparable values for each predictor. The according equation is:

$$f(x) = (x - \text{mean})/\text{sd}(x)$$

5 Acknowledgements

Don't forget to thank TeX and R and other opensource communities if you use their products! The correct way to cite R is shown when typing `"citation()"`, and `"citation("mgcv")"` for packages.

Special thanks to ♥ ♥ Simone ♥♥♥ ♥♣♣! You were our best team member! ♣
Save Models!

6 Appendix

Session Info:

```
## R version 3.1.2 (2014-10-31)
## Platform: x86_64-redhat-linux-gnu (64-bit)
##
## locale:
##  [1] LC_CTYPE=de_DE.UTF-8      LC_NUMERIC=C
##  [3] LC_TIME=de_DE.UTF-8      LC_COLLATE=de_DE.UTF-8
##  [5] LC_MONETARY=de_DE.UTF-8  LC_MESSAGES=de_DE.UTF-8
##  [7] LC_PAPER=de_DE.UTF-8     LC_NAME=C
##  [9] LC_ADDRESS=C             LC_TELEPHONE=C
## [11] LC_MEASUREMENT=de_DE.UTF-8 LC_IDENTIFICATION=C
##
## attached base packages:
## [1] stats      graphics  grDevices  utils      datasets  methods   base
##
## other attached packages:
## [1] adehabitatLT_0.3.16 CircStats_0.2-4      boot_1.3-13
## [4] MASS_7.3-35      adehabitatMA_0.3.8  ade4_1.6-2
## [7] sp_1.0-16         knitr_1.7
```

```
##  
## loaded via a namespace (and not attached):  
## [1] evaluate_0.5.5  formatR_1.0      grid_3.1.2       highr_0.4  
## [5] lattice_0.20-29 stringr_0.6.2    tools_3.1.2
```

References

- [1] C. Calenge. Package adehabitatlt. 2014.
- [2] Henrik Thurfjell, Simone Ciuti, and Mark S Boyce. Applications of step-selection functions in ecology and conservation. *Movement Ecology*, 2(1):4, 2014.