Capture-Mark-Resight Mabuias

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Mabuyas

The present analysis focused on determining the density of mabuyas (*Trachylepis atlantica*) in different habitats on the island of Fernando de Noronha. The `R` package used for the present analysis is the `RMark` and the code is hosted in `github` (https://github.com/tati-micheletti/mabuyas). This `.rmd` file will guide you on how to reproduce the analysis. Make sure you also have program Mark and RStudio installed in your computer. Mark needs to be installed in the ProgramFiles folder (`C:\ProgramFiles\`).

Getting your project

1. Go to github website.
2. Click on the blue button that says `clone or download`, and click on the `download ZIP` to download the folder.
3. Now you are set to start working on your project, so open the file `mabuyas.Rproj` in `RStudio`.
4. Now, on the lower-right pannel, click on the file mabuyasAnalysisDirectDownload.Rmd and you will open this source file.
5. Run all code chuncks below by pressing `Ctrl + Alt + R` or clicking in `Run` and `Run All` in the tab above.

Description of analysis using `RMark` package in `R`

Analysis were performed using the `Poisson-log normal mark-resight model`.

1. Install and load the libraries:

```
suppressWarnings(library("RMark"))
```

```
## This is RMark 2.2.4
##  Documentation available at http://www.phidot.org/software/mark/rmark/RMarkDocumentation.zip
```

```
suppressWarnings(library("xlsx"))
```

```
## Loading required package: rJava
```

```
## Loading required package: xlsxjars
```

```
suppressWarnings(library("reproducible"))
```

If you don't have the libraries above, install and run them again:

```
install.packages("RMark")
install.packages("xlsx")
install.packages("reproducible")
```

Create your data.frame and variables

First of all, to analyse your data, you need to bring it to `R`.

2. Create a data.frame in R from `excel` to be analysed by Mark:

```
directory <- getwd()
ch <- read.xlsx(file = file.path(getwd(), "data/dataMabuya.xlsx"),
                        header = TRUE,
                        sheetName = "ch",
                        as.data.frame = TRUE)
ch$ch <- as.character(ch$ch) # Convert factor to character

covars <- read.xlsx(file = file.path(getwd(), "data/dataMabuya.xlsx"),
                        header = TRUE,
                        sheetName = "covars",
                        as.data.frame = TRUE)
```

3. Create the variables you will need for the model(s) in form of a vector or matrix from your datasets:

```
nocc <- 6 # Number of occasions
groupsNames <- unique(covars$colonies) # Names of groups
nGroups <- length(groupsNames) # Number of groups

unmarkedSeen <- matrix(covars[, "unmarkedSeen"],
                       nrow = nGroups,
                       ncol = nocc,
                       byrow = TRUE) # counts of unmarked individuals seen
markedUnidentified <- matrix(covars[, "markedUnidentified"],
                             nrow = nGroups,
                             ncol = nocc,
                             byrow = TRUE) # counts of marked individuals unidentified
knownMarks <- matrix(covars[, "knownMarks"],
                     nrow = nGroups,
                     ncol = nocc,
                     byrow = TRUE) # counts of known marked individuals
effort <- matrix(covars[, "effort"],
                 nrow = nGroups,
                 ncol = nocc,
                 byrow = TRUE) # effort of observation in each colony at each time
```

Now you have all the basic data to run your models. But first, you need the models.

Defining your model(s)

To define your models, you have to think of which variables will influence your parameters. For example: different effort in each occasion will influence the probability of observing individuals (α), so α could vary in function of effort or even, both effort and colony ('colonies') depending if you think that it is harder or easier to observe the individuals in different places. We can also come up with extra categories related to disturbance level (i.e. capim-açu is less disturbed than boldro), for example. Here I ran only one model so far, but you should later work on more models and we can develop a comparison test. :)

Basically you have to give a formula to each variable. for example: the basic formula `formula = ~1` means that the parameter that this formula is assigned to is constant. We can also make this parameter vary with `effort` (`formula = ~ effort`) or even to `effort` and `colonies` as suggested before (`formula = ~ effort + colonies`). Within a model formula you can also set parameters to fixed values. For example, we know that no mabuyas died within a week of work, so we can set survival (`Phi`) to `1`. We do that by using the constant formula and adding the argument `fixed = 1` (`formula = ~ 1, fixed = 1`). It is also important that all models are in a `list()`. All parameters are descibed below in section *6. Make a data design.*

4. Defining the model

```
alpha.effort <- list(formula = ~ effort)
Phi <- list(formula = ~ 1, fixed = 1)
U <- list(formula = ~ colonies)
constant <- list(formula = ~ 1) # Here I create a generic constant
                                # model to be used to terms that I need
zero <- list(formula = ~ 1, fixed = 0) # Here I create a generic zero
                                       # model to be used to terms that I need
```

Process your data to make it ready for the analysis

To have the data ready **with** the covariates you want to consider (i.e. `effort`), you need to go through 2 steps before running your model:
1. Process your data: use the function `process.data()`
2. Make a data design: use the function `make.design.data()`

5. Process your data

```
mabuya.process <- process.data(ch,
                               model = "PoissonMR",
                               time.intervals = rep(1, times = (nocc-1)),
                               groups = "colonies",
                               counts = list("Unmarked Seen" = unmarkedSeen,
                                             "Marked Unidentified" = markedUnidentified,
                                             "Known Marks" = knownMarks))
mabuya.process
```

```
## $data
##              ch      colonies NA. group
## 1  010101010101     Americano  NA     1
## 2  +0+001+0+0+0     Americano  NA     1
## 3  +0+0+0+0+0+0     Americano  NA     1
## 4  +0+0+0+0+0+0     Americano  NA     1
## 5  +0+0+0+0+0+0     Americano  NA     1
## 6  01+001+0+0+0     Americano  NA     1
## 7  01010101+001     Americano  NA     1
## 8  +0+0+001+0+0     Americano  NA     1
## 9  +0+0+0+0+0+0     Americano  NA     1
## 10 01+0+0+001+0     Americano  NA     1
## 11 +001+0+0+0+0     Americano  NA     1
## 12 +0+0+0+0+0+0     Americano  NA     1
## 13 +0+0+0+0+0+0     Americano  NA     1
## 14 +0+0+0+0+001     Americano  NA     1
## 15 +0+0+0+0+0+0     Americano  NA     1
## 16 +0+001+0+0+0     Americano  NA     1
## 17 01+001+0+0+0      CapimAcu  NA     2
## 18 01+0+0+0+001      CapimAcu  NA     2
## 19 +001+0+001+0      CapimAcu  NA     2
## 20 +0+0+0+00101      CapimAcu  NA     2
## 21 +001+0+0+0+0      CapimAcu  NA     2
## 22 010101010101   ForteBoldro  NA     3
## 23 +0+00101+0+0   ForteBoldro  NA     3
## 24 +0+0+0+0+0+0   ForteBoldro  NA     3
## 25 +0+0+0+0+0+0   ForteBoldro  NA     3
```

```
## 26 +00101+0+001    ForteBoldro  NA     3
## 27 +0+00101+0+0    ForteBoldro  NA     3
## 28 +0+0+001+001    ForteBoldro  NA     3
## 29 +0+001+0+0+0    ForteBoldro  NA     3
## 30 010101+0+0+0    ForteBoldro  NA     3
## 31 +0+0+0+0+0+0    ForteBoldro  NA     3
## 32 +0+001+0+0+0    ForteBoldro  NA     3
## 33 +0+0+0+001+0    ForteBoldro  NA     3
## 34 +001+001+0+0    ForteBoldro  NA     3
## 35 +0+001+0+0+0    ForteBoldro  NA     3
## 36 +0+0+0+0+001           Leao  NA     4
## 37 +0+0+0010101           Leao  NA     4
## 38 +001+0+0+0+0           Leao  NA     4
## 39 +0+0+0+0+001           Leao  NA     4
## 40 +0+0+0+0+0+0           Leao  NA     4
## 41 +001+0+0+0+0 PedreiraSueste  NA     5
## 42 +0+0+0+00101 PedreiraSueste  NA     5
## 43 010101+0+0+0 PedreiraSueste  NA     5
## 44 +0+0+0+0+0+0 PedreiraSueste  NA     5
## 45 +0+0+0+00101 PedreiraSueste  NA     5
## 46 +0+0+0+0+0+0 PedreiraSueste  NA     5
## 47 01+0+001+001       Piquinho  NA     6
## 48 0101010101+0       Piquinho  NA     6
## 49 +0+0+001+0+0       Piquinho  NA     6
## 50 0101+0+00101       Piquinho  NA     6
## 51 01+0+0+0+0+0    PraiaBoldro  NA     7
## 52 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 53 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 54 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 55 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 56 +0+0010101+0    PraiaBoldro  NA     7
## 57 0101+0+001+0    PraiaBoldro  NA     7
## 58 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 59 01+0+0+0+0+0    PraiaBoldro  NA     7
## 60 01+0+0+0+001    PraiaBoldro  NA     7
## 61 +0+0+001+0+0    PraiaBoldro  NA     7
## 62 01+0+0+0+0+0    PraiaBoldro  NA     7
## 63 01+0+0+0+0+0    PraiaBoldro  NA     7
## 64 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 65 0101010101+0    PraiaBoldro  NA     7
## 66 +00101010101    PraiaBoldro  NA     7
## 67 +0+0+0+0+001    PraiaBoldro  NA     7
## 68 +0+0+001+0+0    PraiaBoldro  NA     7
## 69 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 70 +0+0+0+0+0+0    PraiaBoldro  NA     7
## 71 +001010101+0        TejuAcu  NA     8
## 72 +0+0+0+0+0+0        TejuAcu  NA     8
## 73 +00101+00101        TejuAcu  NA     8
##
## $model
## [1] "PoissonMR"
##
## $mixtures
## [1] 1
```

```
##
## $freq
##    coloniesAmericano coloniesCapimAcu coloniesForteBoldro coloniesLeao
## 1                  1                0                   0            0
## 2                  1                0                   0            0
## 3                  1                0                   0            0
## 4                  1                0                   0            0
## 5                  1                0                   0            0
## 6                  1                0                   0            0
## 7                  1                0                   0            0
## 8                  1                0                   0            0
## 9                  1                0                   0            0
## 10                 1                0                   0            0
## 11                 1                0                   0            0
## 12                 1                0                   0            0
## 13                 1                0                   0            0
## 14                 1                0                   0            0
## 15                 1                0                   0            0
## 16                 1                0                   0            0
## 17                 0                1                   0            0
## 18                 0                1                   0            0
## 19                 0                1                   0            0
## 20                 0                1                   0            0
## 21                 0                1                   0            0
## 22                 0                0                   1            0
## 23                 0                0                   1            0
## 24                 0                0                   1            0
## 25                 0                0                   1            0
## 26                 0                0                   1            0
## 27                 0                0                   1            0
## 28                 0                0                   1            0
## 29                 0                0                   1            0
## 30                 0                0                   1            0
## 31                 0                0                   1            0
## 32                 0                0                   1            0
## 33                 0                0                   1            0
## 34                 0                0                   1            0
## 35                 0                0                   1            0
## 36                 0                0                   0            1
## 37                 0                0                   0            1
## 38                 0                0                   0            1
## 39                 0                0                   0            1
## 40                 0                0                   0            1
## 41                 0                0                   0            0
## 42                 0                0                   0            0
## 43                 0                0                   0            0
## 44                 0                0                   0            0
## 45                 0                0                   0            0
## 46                 0                0                   0            0
## 47                 0                0                   0            0
## 48                 0                0                   0            0
## 49                 0                0                   0            0
## 50                 0                0                   0            0
## 51                 0                0                   0            0
```

```
## 52                 0               0                  0            0
## 53                 0               0                  0            0
## 54                 0               0                  0            0
## 55                 0               0                  0            0
## 56                 0               0                  0            0
## 57                 0               0                  0            0
## 58                 0               0                  0            0
## 59                 0               0                  0            0
## 60                 0               0                  0            0
## 61                 0               0                  0            0
## 62                 0               0                  0            0
## 63                 0               0                  0            0
## 64                 0               0                  0            0
## 65                 0               0                  0            0
## 66                 0               0                  0            0
## 67                 0               0                  0            0
## 68                 0               0                  0            0
## 69                 0               0                  0            0
## 70                 0               0                  0            0
## 71                 0               0                  0            0
## 72                 0               0                  0            0
## 73                 0               0                  0            0
##    coloniesPedreiraSueste coloniesPiquinho coloniesPraiaBoldro
## 1                       0                0                   0
## 2                       0                0                   0
## 3                       0                0                   0
## 4                       0                0                   0
## 5                       0                0                   0
## 6                       0                0                   0
## 7                       0                0                   0
## 8                       0                0                   0
## 9                       0                0                   0
## 10                      0                0                   0
## 11                      0                0                   0
## 12                      0                0                   0
## 13                      0                0                   0
## 14                      0                0                   0
## 15                      0                0                   0
## 16                      0                0                   0
## 17                      0                0                   0
## 18                      0                0                   0
## 19                      0                0                   0
## 20                      0                0                   0
## 21                      0                0                   0
## 22                      0                0                   0
## 23                      0                0                   0
## 24                      0                0                   0
## 25                      0                0                   0
## 26                      0                0                   0
## 27                      0                0                   0
## 28                      0                0                   0
## 29                      0                0                   0
## 30                      0                0                   0
## 31                      0                0                   0
```

```
## 32                      0                 0                   0
## 33                      0                 0                   0
## 34                      0                 0                   0
## 35                      0                 0                   0
## 36                      0                 0                   0
## 37                      0                 0                   0
## 38                      0                 0                   0
## 39                      0                 0                   0
## 40                      0                 0                   0
## 41                      1                 0                   0
## 42                      1                 0                   0
## 43                      1                 0                   0
## 44                      1                 0                   0
## 45                      1                 0                   0
## 46                      1                 0                   0
## 47                      0                 1                   0
## 48                      0                 1                   0
## 49                      0                 1                   0
## 50                      0                 1                   0
## 51                      0                 0                   1
## 52                      0                 0                   1
## 53                      0                 0                   1
## 54                      0                 0                   1
## 55                      0                 0                   1
## 56                      0                 0                   1
## 57                      0                 0                   1
## 58                      0                 0                   1
## 59                      0                 0                   1
## 60                      0                 0                   1
## 61                      0                 0                   1
## 62                      0                 0                   1
## 63                      0                 0                   1
## 64                      0                 0                   1
## 65                      0                 0                   1
## 66                      0                 0                   1
## 67                      0                 0                   1
## 68                      0                 0                   1
## 69                      0                 0                   1
## 70                      0                 0                   1
## 71                      0                 0                   0
## 72                      0                 0                   0
## 73                      0                 0                   0
##    coloniesTejuAcu
## 1                0
## 2                0
## 3                0
## 4                0
## 5                0
## 6                0
## 7                0
## 8                0
## 9                0
## 10               0
## 11               0
```

```
## 12                     0
## 13                     0
## 14                     0
## 15                     0
## 16                     0
## 17                     0
## 18                     0
## 19                     0
## 20                     0
## 21                     0
## 22                     0
## 23                     0
## 24                     0
## 25                     0
## 26                     0
## 27                     0
## 28                     0
## 29                     0
## 30                     0
## 31                     0
## 32                     0
## 33                     0
## 34                     0
## 35                     0
## 36                     0
## 37                     0
## 38                     0
## 39                     0
## 40                     0
## 41                     0
## 42                     0
## 43                     0
## 44                     0
## 45                     0
## 46                     0
## 47                     0
## 48                     0
## 49                     0
## 50                     0
## 51                     0
## 52                     0
## 53                     0
## 54                     0
## 55                     0
## 56                     0
## 57                     0
## 58                     0
## 59                     0
## 60                     0
## 61                     0
## 62                     0
## 63                     0
## 64                     0
## 65                     0
```

```
## 66               0
## 67               0
## 68               0
## 69               0
## 70               0
## 71               1
## 72               1
## 73               1
##
## $nocc
## [1] 6
##
## $nocc.secondary
## NULL
##
## $time.intervals
## [1] 1 1 1 1 1
##
## $begin.time
## [1] 1
##
## $age.unit
## [1] 1
##
## $initial.ages
## [1] 0 0 0 0 0 0 0 0
##
## $group.covariates
##         colonies
## 1      Americano
## 2       CapimAcu
## 3    ForteBoldro
## 4           Leao
## 5 PedreiraSueste
## 6       Piquinho
## 7    PraiaBoldro
## 8        TejuAcu
##
## $nstrata
## [1] 1
##
## $strata.labels
## NULL
##
## $counts
## $counts$`Unmarked Seen`
##      [,1] [,2] [,3] [,4] [,5] [,6]
## [1,]   17    9   17    8   12   13
## [2,]    2    3    3    1    1    0
## [3,]    8    9   17   13   13   12
## [4,]    1    3    2    0    0    3
## [5,]    2    2    2    3    2    3
## [6,]    4    5    7    4    6    4
## [7,]   22   35   32   30   28   23
```

```
## [8,]    1    3    3    3    1    3
##
## $counts$`Marked Unidentified`
##      [,1] [,2] [,3] [,4] [,5] [,6]
## [1,]    0    0    0    0    0    0
## [2,]    0    0    0    0    0    0
## [3,]    0    0    0    0    0    0
## [4,]    0    0    0    0    0    0
## [5,]    0    0    0    0    0    0
## [6,]    0    0    0    0    0    0
## [7,]    0    0    0    0    0    0
## [8,]    0    0    0    0    0    0
##
## $counts$`Known Marks`
##      [,1] [,2] [,3] [,4] [,5] [,6]
## [1,]   16   16   16   16   16   16
## [2,]    5    5    5    5    5    5
## [3,]   14   14   14   14   14   14
## [4,]    5    5    5    5    5    5
## [5,]    6    6    6    6    6    6
## [6,]    4    4    4    4    4    4
## [7,]   20   20   20   20   20   20
## [8,]    3    3    3    3    3    3
##
##
## $reverse
## [1] FALSE
##
## $areas
## NULL
```

Now you can see a list that summarizes your data. You can see the variables by typing `names(mabuya.process)`:

```
names(mabuya.process)
```

```
##  [1] "data"             "model"            "mixtures"
##  [4] "freq"             "nocc"             "nocc.secondary"
##  [7] "time.intervals"   "begin.time"       "age.unit"
## [10] "initial.ages"     "group.covariates" "nstrata"
## [13] "strata.labels"    "counts"           "reverse"
## [16] "areas"
```

And you can access these elements by typing `mabuya.process$ELEMENT_NAME`.

6. Make a data design:

Now you need to make a data design that will identify the parameters in your data that are constant, and the variable ones for each model term, as well as set your covariates where they should be placed in:

```
mabuya.ddl <- make.design.data(mabuya.process)
```

Using the `names(mabuya.ddl)` you can check now your parameters.

```
names(mabuya.ddl)
```

```
## [1] "alpha"            "sigma"            "U"
## [4] "Phi"              "GammaDoublePrime" "GammaPrime"
## [7] "pimtypes"
```

The *Poisson-log normal mark-resight model*, has have *four* main parameters:

U[j] (`U`) = number of unmarked individuals in the population during primary interval j.
$\alpha[j]$ (`alpha`) = intercept (on log scale) for mean resighting rate during primary interval j. If there is no individual heterogeneity ($\sigma[j] = 0$), once back-transformed from the log scale the real parameter estimate can be interpreted as the mean resighting rate for the entire population.
$\varphi[j]$ (`Phi`) = apparent survival between primary intervals j and j + 1.
$\sigma^2[j]$ (`sigma`) = individual heterogeneity level (on the log scale) during primary interval j, i.e., the additional variance due to a random individual heterogeneity effect with mean zero.

Now we can check one of the parameters: `alpha`:

```
mabuya.ddl$alpha
```

```
##    par.index model.index          group age time Age Time       colonies
## 1          1           1      Americano   0    1   0    0      Americano
## 2          2           2      Americano   1    2   1    1      Americano
## 3          3           3      Americano   2    3   2    2      Americano
## 4          4           4      Americano   3    4   3    3      Americano
## 5          5           5      Americano   4    5   4    4      Americano
## 6          6           6      Americano   5    6   5    5      Americano
## 7          7           7       CapimAcu   0    1   0    0       CapimAcu
## 8          8           8       CapimAcu   1    2   1    1       CapimAcu
## 9          9           9       CapimAcu   2    3   2    2       CapimAcu
## 10        10          10       CapimAcu   3    4   3    3       CapimAcu
## 11        11          11       CapimAcu   4    5   4    4       CapimAcu
## 12        12          12       CapimAcu   5    6   5    5       CapimAcu
## 13        13          13    ForteBoldro   0    1   0    0    ForteBoldro
## 14        14          14    ForteBoldro   1    2   1    1    ForteBoldro
## 15        15          15    ForteBoldro   2    3   2    2    ForteBoldro
## 16        16          16    ForteBoldro   3    4   3    3    ForteBoldro
## 17        17          17    ForteBoldro   4    5   4    4    ForteBoldro
## 18        18          18    ForteBoldro   5    6   5    5    ForteBoldro
## 19        19          19           Leao   0    1   0    0           Leao
## 20        20          20           Leao   1    2   1    1           Leao
## 21        21          21           Leao   2    3   2    2           Leao
## 22        22          22           Leao   3    4   3    3           Leao
## 23        23          23           Leao   4    5   4    4           Leao
## 24        24          24           Leao   5    6   5    5           Leao
## 25        25          25 PedreiraSueste   0    1   0    0 PedreiraSueste
## 26        26          26 PedreiraSueste   1    2   1    1 PedreiraSueste
## 27        27          27 PedreiraSueste   2    3   2    2 PedreiraSueste
## 28        28          28 PedreiraSueste   3    4   3    3 PedreiraSueste
## 29        29          29 PedreiraSueste   4    5   4    4 PedreiraSueste
## 30        30          30 PedreiraSueste   5    6   5    5 PedreiraSueste
## 31        31          31       Piquinho   0    1   0    0       Piquinho
## 32        32          32       Piquinho   1    2   1    1       Piquinho
## 33        33          33       Piquinho   2    3   2    2       Piquinho
## 34        34          34       Piquinho   3    4   3    3       Piquinho
## 35        35          35       Piquinho   4    5   4    4       Piquinho
## 36        36          36       Piquinho   5    6   5    5       Piquinho
## 37        37          37    PraiaBoldro   0    1   0    0    PraiaBoldro
## 38        38          38    PraiaBoldro   1    2   1    1    PraiaBoldro
## 39        39          39    PraiaBoldro   2    3   2    2    PraiaBoldro
## 40        40          40    PraiaBoldro   3    4   3    3    PraiaBoldro
## 41        41          41    PraiaBoldro   4    5   4    4    PraiaBoldro
```

```
## 42          42           42    PraiaBoldro   5    6   5    5    PraiaBoldro
## 43          43           43        TejuAcu   0    1   0    0        TejuAcu
## 44          44           44        TejuAcu   1    2   1    1        TejuAcu
## 45          45           45        TejuAcu   2    3   2    2        TejuAcu
## 46          46           46        TejuAcu   3    4   3    3        TejuAcu
## 47          47           47        TejuAcu   4    5   4    4        TejuAcu
## 48          48           48        TejuAcu   5    6   5    5        TejuAcu
```

Now you can include the covariates (such as effort and/or disturbance level) with the following code:

```
mabuya.ddl$alpha$effort <- as.numeric(apply(X = mabuya.ddl$alpha, 1, function(x){
    col <- x[["group"]]
    occ <- as.numeric(x[["time"]])
    eff <- covars[covars$colonies==col&covars$occasion==occ, "effort"]
  })
)
```

And now we check again to see how this changed our `data.frame`:

```
mabuya.ddl$alpha
```

```
##    par.index model.index          group age time Age Time       colonies
## 1          1           1      Americano   0    1   0    0      Americano
## 2          2           2      Americano   1    2   1    1      Americano
## 3          3           3      Americano   2    3   2    2      Americano
## 4          4           4      Americano   3    4   3    3      Americano
## 5          5           5      Americano   4    5   4    4      Americano
## 6          6           6      Americano   5    6   5    5      Americano
## 7          7           7       CapimAcu   0    1   0    0       CapimAcu
## 8          8           8       CapimAcu   1    2   1    1       CapimAcu
## 9          9           9       CapimAcu   2    3   2    2       CapimAcu
## 10        10          10       CapimAcu   3    4   3    3       CapimAcu
## 11        11          11       CapimAcu   4    5   4    4       CapimAcu
## 12        12          12       CapimAcu   5    6   5    5       CapimAcu
## 13        13          13    ForteBoldro   0    1   0    0    ForteBoldro
## 14        14          14    ForteBoldro   1    2   1    1    ForteBoldro
## 15        15          15    ForteBoldro   2    3   2    2    ForteBoldro
## 16        16          16    ForteBoldro   3    4   3    3    ForteBoldro
## 17        17          17    ForteBoldro   4    5   4    4    ForteBoldro
## 18        18          18    ForteBoldro   5    6   5    5    ForteBoldro
## 19        19          19           Leao   0    1   0    0           Leao
## 20        20          20           Leao   1    2   1    1           Leao
## 21        21          21           Leao   2    3   2    2           Leao
## 22        22          22           Leao   3    4   3    3           Leao
## 23        23          23           Leao   4    5   4    4           Leao
## 24        24          24           Leao   5    6   5    5           Leao
## 25        25          25 PedreiraSueste   0    1   0    0 PedreiraSueste
## 26        26          26 PedreiraSueste   1    2   1    1 PedreiraSueste
## 27        27          27 PedreiraSueste   2    3   2    2 PedreiraSueste
## 28        28          28 PedreiraSueste   3    4   3    3 PedreiraSueste
## 29        29          29 PedreiraSueste   4    5   4    4 PedreiraSueste
## 30        30          30 PedreiraSueste   5    6   5    5 PedreiraSueste
## 31        31          31       Piquinho   0    1   0    0       Piquinho
## 32        32          32       Piquinho   1    2   1    1       Piquinho
## 33        33          33       Piquinho   2    3   2    2       Piquinho
## 34        34          34       Piquinho   3    4   3    3       Piquinho
```

```
## 35        35          35     Piquinho  4   5   4   4      Piquinho
## 36        36          36     Piquinho  5   6   5   5      Piquinho
## 37        37          37  PraiaBoldro  0   1   0   0   PraiaBoldro
## 38        38          38  PraiaBoldro  1   2   1   1   PraiaBoldro
## 39        39          39  PraiaBoldro  2   3   2   2   PraiaBoldro
## 40        40          40  PraiaBoldro  3   4   3   3   PraiaBoldro
## 41        41          41  PraiaBoldro  4   5   4   4   PraiaBoldro
## 42        42          42  PraiaBoldro  5   6   5   5   PraiaBoldro
## 43        43          43      TejuAcu  0   1   0   0       TejuAcu
## 44        44          44      TejuAcu  1   2   1   1       TejuAcu
## 45        45          45      TejuAcu  2   3   2   2       TejuAcu
## 46        46          46      TejuAcu  3   4   3   3       TejuAcu
## 47        47          47      TejuAcu  4   5   4   4       TejuAcu
## 48        48          48      TejuAcu  5   6   5   5       TejuAcu
##    effort
## 1      50
## 2      15
## 3      25
## 4      20
## 5      15
## 6      15
## 7      21
## 8      11
## 9      15
## 10     15
## 11     15
## 12     19
## 13     35
## 14     15
## 15     25
## 16     25
## 17     32
## 18     25
## 19     18
## 20     20
## 21     13
## 22     17
## 23     13
## 24     15
## 25     20
## 26     17
## 27     21
## 28     18
## 29     16
## 30     14
## 31     18
## 32     12
## 33     27
## 34     15
## 35     15
## 36     10
## 37     18
## 38     32
## 39     40
```

```
## 40      28
## 41      12
## 42      40
## 43      15
## 44       8
## 45       8
## 46      10
## 47      10
## 48      10
```

Here, we added effort to alpha (which is the mean resighting rate during primary interval), as more effort increases the chances of observing an individual and the effort varied on occasions and colonies.

Now we are ready to run the model(s).

Running the analysis

7. Model coding

```
setwd(dir = file.path(getwd(), "outputs")) # Changing directory for outputs
mabuya.model <- mark(data = mabuya.process,      # Here we use the processed data
                     ddl = mabuya.ddl,           # Here we use the designed data
                     model.parameters = list(    # Here are the parameters's
                             alpha = alpha.effort, # models set on step 4.
                             Phi = Phi,
                             U = U,
                             sigma = zero,
                             GammaDoublePrime = constant,
                             GammaPrime = constant
                     )
                 )
```

```
##
## Note: only 10 parameters counted of 12 specified parameters

## AICc and parameter count have been adjusted upward

##
## Output summary for PoissonMR model
## Name : alpha(~effort)sigma(~1)U(~colonies)Phi(~1)Gamma''(~1)Gamma'(~1)
##
## Npar :  12  (unadjusted=10)
## -2lnL:  708.574
## AICc :  733.2336  (unadjusted=729.03716)
##
## Beta
##                                estimate          se           lcl
## alpha:(Intercept)            -1.3990600   0.1409582    -1.6753381
## alpha:effort                  0.0019278   0.0045554    -0.0070009
## U:(Intercept)                 3.8871439   0.1473813     3.5982766
## U:coloniesCapimAcu           -2.0136670   0.3241977    -2.6490945
## U:coloniesForteBoldro        -0.0649545   0.1619430    -0.3823628
## U:coloniesLeao               -1.9003323   0.3436288    -2.5738448
## U:coloniesPedreiraSueste     -1.9110580   0.2892956    -2.4780774
## U:coloniesPiquinho           -0.9915231   0.2169601    -1.4167649
## U:coloniesPraiaBoldro         0.7962687   0.1369308     0.5278843
```

```
## U:coloniesTejuAcu             -1.8249691    0.2900483    -2.3934638
## GammaDoublePrime:(Intercept) -22.6346940 4292.5022000 -8435.9392000
## GammaPrime:(Intercept)        -0.1000000 1130.1295000 -2215.1539000
##                                      ucl
## alpha:(Intercept)             -1.1227819
## alpha:effort                   0.0108564
## U:(Intercept)                  4.1760112
## U:coloniesCapimAcu            -1.3782395
## U:coloniesForteBoldro          0.2524538
## U:coloniesLeao                -1.2268197
## U:coloniesPedreiraSueste      -1.3440387
## U:coloniesPiquinho            -0.5662813
## U:coloniesPraiaBoldro          1.0646530
## U:coloniesTejuAcu             -1.2564744
## GammaDoublePrime:(Intercept) 8390.6699000
## GammaPrime:(Intercept)       2214.9539000
##
##
## Real Parameter alpha
##                                      1         2         3         4
## Group:coloniesAmericano      0.2718047 0.2540705 0.2590159 0.2565313
## Group:coloniesCapimAcu       0.2570263 0.2521189 0.2540705 0.2540705
## Group:coloniesForteBoldro    0.2640576 0.2540705 0.2590159 0.2590159
## Group:coloniesLeao           0.2555441 0.2565313 0.2530928 0.2550520
## Group:coloniesPedreiraSueste 0.2565313 0.2550520 0.2570263 0.2555441
## Group:coloniesPiquinho       0.2555441 0.2526054 0.2600165 0.2540705
## Group:coloniesPraiaBoldro    0.2555441 0.2625349 0.2666151 0.2605182
## Group:coloniesTejuAcu        0.2540705 0.2506650 0.2506650 0.2516333
##                                      5         6
## Group:coloniesAmericano      0.2540705 0.2540705
## Group:coloniesCapimAcu       0.2540705 0.2560372
## Group:coloniesForteBoldro    0.2625349 0.2590159
## Group:coloniesLeao           0.2530928 0.2540705
## Group:coloniesPedreiraSueste 0.2545608 0.2535812
## Group:coloniesPiquinho       0.2540705 0.2516333
## Group:coloniesPraiaBoldro    0.2526054 0.2666151
## Group:coloniesTejuAcu        0.2516333 0.2516333
##
##
## Real Parameter sigma
##                               1  2  3  4  5  6
## Group:coloniesAmericano      NA NA NA NA NA NA
## Group:coloniesCapimAcu       NA NA NA NA NA NA
## Group:coloniesForteBoldro    NA NA NA NA NA NA
## Group:coloniesLeao           NA NA NA NA NA NA
## Group:coloniesPedreiraSueste NA NA NA NA NA NA
## Group:coloniesPiquinho       NA NA NA NA NA NA
## Group:coloniesPraiaBoldro    NA NA NA NA NA NA
## Group:coloniesTejuAcu        NA NA NA NA NA NA
##
##
## Real Parameter U
##                                      1          2          3          4
## Group:coloniesAmericano       48.771390  48.771390  48.771390  48.771390
```

```
## Group:coloniesCapimAcu         6.510895   6.510895   6.510895   6.510895
## Group:coloniesForteBoldro     45.704164  45.704164  45.704164  45.704164
## Group:coloniesLeao             7.292246   7.292246   7.292246   7.292246
## Group:coloniesPedreiraSueste   7.214449   7.214449   7.214449   7.214449
## Group:coloniesPiquinho        18.094731  18.094731  18.094731  18.094731
## Group:coloniesPraiaBoldro    108.138470 108.138470 108.138470 108.138470
## Group:coloniesTejuAcu          7.863052   7.863052   7.863052   7.863052
##                                       5          6
## Group:coloniesAmericano       48.771390  48.771390
## Group:coloniesCapimAcu         6.510895   6.510895
## Group:coloniesForteBoldro     45.704164  45.704164
## Group:coloniesLeao             7.292246   7.292246
## Group:coloniesPedreiraSueste   7.214449   7.214449
## Group:coloniesPiquinho        18.094731  18.094731
## Group:coloniesPraiaBoldro    108.138470 108.138470
## Group:coloniesTejuAcu          7.863052   7.863052
##
##
## Real Parameter Phi
## Group:coloniesAmericano
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesCapimAcu
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesForteBoldro
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesLeao
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesPedreiraSueste
##   1 2 3 4 5
## 1
```

```
## 2
## 3
## 4
## 5
##
## Group:coloniesPiquinho
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesPraiaBoldro
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
## Group:coloniesTejuAcu
##   1 2 3 4 5
## 1
## 2
## 3
## 4
## 5
##
##
## Real Parameter GammaDoublePrime
## Group:coloniesAmericano
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesCapimAcu
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesForteBoldro
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
```

```
##
## Group:coloniesLeao
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesPedreiraSueste
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesPiquinho
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesPraiaBoldro
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
## Group:coloniesTejuAcu
##             1           2           3           4           5
## 1 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 2             1.47869e-10 1.47869e-10 1.47869e-10 1.47869e-10
## 3                         1.47869e-10 1.47869e-10 1.47869e-10
## 4                                     1.47869e-10 1.47869e-10
## 5                                                 1.47869e-10
##
##
## Real Parameter GammaPrime
## Group:coloniesAmericano
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesCapimAcu
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
```

```
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesForteBoldro
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesLeao
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesPedreiraSueste
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesPiquinho
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesPraiaBoldro
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
##
## Group:coloniesTejuAcu
##           2         3         4         5
## 1 0.4750208 0.4750208 0.4750208 0.4750208
## 2           0.4750208 0.4750208 0.4750208
## 3                     0.4750208 0.4750208
## 4                               0.4750208
```

```r
setwd(dir = directory) # Changing directory back to original
```

Interpreting the results

Now, it is important to notice that the `U` the model outputs is `NOT` the `population size`. The last, as well as other parameters can, however be derived:

Derived Parameters

$\lambda[j]$ = overall mean resighting rate for primary occasion j. This is a parameter derived as a function of $\alpha[j]$, $\sigma^2[j]$ and and E[j]. Note that when $\sigma[j] = 0$ and E[j] = 0, then the real parameter estimate for $\alpha[j]$ is identical to the derived parameter estimate for $\lambda[j]$.

N[j] = U[j] + n[j], or the total population size during primary occasion j. This is a derived parameter, because MARK actually estimates U[j] in the model. n[j] is the marked population.

8. Calculating derived parameters

RMark automatically calculates the `population size` for each group (and occasion when we do a long term study with longer interval time).

```
mabuya.model$results$derived$`N Population Size`
```

```
##     estimate        se        lcl       ucl
## 1   64.77139  7.187997  52.144489  80.45592
## 2   64.77139  7.187997  52.144489  80.45592
## 3   64.77139  7.187997  52.144489  80.45592
## 4   64.77139  7.187997  52.144489  80.45592
## 5   64.77139  7.187997  52.144489  80.45592
## 6   64.77139  7.187997  52.144489  80.45592
## 7   11.51089  2.060962   8.126509  16.30475
## 8   11.51089  2.060962   8.126509  16.30475
## 9   11.51089  2.060962   8.126509  16.30475
## 10  11.51089  2.060962   8.126509  16.30475
## 11  11.51089  2.060962   8.126509  16.30475
## 12   5.00000  0.000000   5.000000   5.00000
## 13  59.70416  6.861207  47.698351  74.73187
## 14  59.70416  6.861207  47.698351  74.73187
## 15  59.70416  6.861207  47.698351  74.73187
## 16  59.70416  6.861207  47.698351  74.73187
## 17  59.70416  6.861207  47.698351  74.73187
## 18  59.70416  6.861207  47.698351  74.73187
## 19  12.29225  2.455360   8.341844  18.11342
## 20  12.29225  2.455360   8.341844  18.11342
## 21  12.29225  2.455360   8.341844  18.11342
## 22   5.00000  0.000000   5.000000   5.00000
## 23   5.00000  0.000000   5.000000   5.00000
## 24  12.29225  2.455360   8.341844  18.11342
## 25  13.21445  2.028514   9.798083  17.82202
## 26  13.21445  2.028514   9.798083  17.82202
## 27  13.21445  2.028514   9.798083  17.82202
## 28  13.21445  2.028514   9.798083  17.82202
## 29  13.21445  2.028514   9.798083  17.82202
## 30  13.21445  2.028514   9.798083  17.82202
## 31  22.09473  3.726941  15.911504  30.68077
## 32  22.09473  3.726941  15.911504  30.68077
## 33  22.09473  3.726941  15.911504  30.68077
## 34  22.09473  3.726941  15.911504  30.68077
## 35  22.09473  3.726941  15.911504  30.68077
## 36  22.09473  3.726941  15.911504  30.68077
## 37 128.13847 13.396123 104.455551 157.19096
## 38 128.13847 13.396123 104.455551 157.19096
## 39 128.13847 13.396123 104.455551 157.19096
## 40 128.13847 13.396123 104.455551 157.19096
## 41 128.13847 13.396123 104.455551 157.19096
```

```
## 42 128.13847 13.396123 104.455551 157.19096
## 43  10.86305  2.205264   7.326413  16.10691
## 44  10.86305  2.205264   7.326413  16.10691
## 45  10.86305  2.205264   7.326413  16.10691
## 46  10.86305  2.205264   7.326413  16.10691
## 47  10.86305  2.205264   7.326413  16.10691
## 48  10.86305  2.205264   7.326413  16.10691
```

You will notice, however, that it doesn't output the location's names. We can, however retrieve it from the original data, and clean it up (repetitions):

```
populationSize <- cbind(covars$colonies, mabuya.model$results$derived$`N Population Size`) %>%
  unique()
populationSize <-  populationSize[populationSize$se > 0,]
```

Now we can also calculate the densities among the areas (and at some point compare them statistically):

```
populationSize$areaSize <- c(15, 52, 36.7,
                             48, 30, 13.5,
                             44.9, 7.7)
density <- populationSize$estimate/populationSize$areaSize
populationSize <- cbind(populationSize, density)
colnames(populationSize) <- c("location", "estimate", "standard.error",
                            "lowerCI", "upperCI", "areaSize", "density")
```

And here we see the final result of the population size:

location	estimate	standard.error	lowerCI	upperCI	areaSize	density
Americano	64.77	7.19	52.14	80.46	15.0	4.32
CapimAcu	11.51	2.06	8.13	16.30	52.0	0.22
ForteBoldro	59.70	6.86	47.70	74.73	36.7	1.63
Leao	12.29	2.46	8.34	18.11	48.0	0.26
PedreiraSueste	13.21	2.03	9.80	17.82	30.0	0.44
Piquinho	22.09	3.73	15.91	30.68	13.5	1.64
PraiaBoldro	128.14	13.40	104.46	157.19	44.9	2.85
TejuAcu	10.86	2.21	7.33	16.11	7.7	1.41