Modelos de marcação e recaptura: populações fechadas

Contents

- Arquivo em pdf
- Arquivo em markdown (para executar os comandos no R studio)

Preparação

Vamos usar o pacote *RMark*, que é um pacote do R para usar o programa MARK. Siga as instruções deste sítio para instalar o MARK para uso pelo pacote: (http://www.phidot.org/software/mark/rmark/).

Abra o R e carregue o pacote

```
library(RMark)
```

Usaremos dados de registro fotográfico de indivíduos do boto cinza (*Sotalia guianensis*) em 11 ocasiões. Aqui há mais informações sobre este caso de estudo.

Os dados estão no formato nativo do MARK (*.inp*). Use os comandos abaixo para importá-lo para o R:

```
## Link dos dados na página da disciplina
url <- "http://ecologia.ib.usp.br/bie5703/lib/exe/fetch.php?media=roteiros:botos_2002.inp"
## Importa arquivo inp
boto2002 <- convert.inp(url)
```

Ajuste dos modelos

Processamento dos dados

O primeiro passo é usar a função `process.data` para criar um objeto com as informações que o Mark usa para ajustar o modelo. Uma delas é o tipo de modelo, que é indicado no argumento `model`.

Para o modelo de populações fechada sem heterogeneidade e de verossimilhança não condicionada este argumento é `model="Closed"`:

```
boto <- process.data(data=boto2002, model="Closed")
```

E para o modelo com heterogeneidade o argumento é `model="FullHet"`

```
botoH <- process.data(data=boto2002, model="FullHet")
```

Ajuste dos modelos sem heterogeneidade

Para ajustar os modelos, crie listas que especificam a fórmula de cada termo. No modelo `Closed` os nomes parâmetros que podem variar são `p` (probabilidade da primeira captura), `c` (probabilidade de recaptura). O objeto criado na seção acima tem uma covariável de tempo chamada `time`, que então pode ser usado nas fórmulas:

```
## Fórmulas estatísticas para cada parâmetro do modelo sem heterogeneidade
## p e c constantes mas diferentes
t.dot <- list(formula=~1)
## p=c contantes (use o argumento share=TRUE)
t.dotshared=list(formula=~1,share=TRUE)
## Parametros dependem do tempo
t.time <- list(formula=~time)
## Parametro p=c dependem do tempo
t.timeshared <- list(formula=~time, share=TRUE)
```

E usamos a função `mark` para fazer os ajuste:

```
##
## Output summary for Closed model
## Name : p(~1)c()f0(~1)
##
## Npar :  2
## -2lnL:  285.7052
## AICc :  289.7349
##
## Beta
##                  estimate         se        lcl         ucl
## p:(Intercept)  -0.9507660 0.1174229 -1.180915 -0.7206172
## f0:(Intercept) -0.6778984 2.2177383 -5.024665   3.6688687
##
##
## Real Parameter p
##          1         2         3         4         5         6         7
##  0.2787308 0.2787308 0.2787308 0.2787308 0.2787308 0.2787308 0.2787308
##          8         9        10        11
##  0.2787308 0.2787308 0.2787308 0.2787308
##
##
## Real Parameter c
##          2         3         4         5         6         7         8
##  0.2787308 0.2787308 0.2787308 0.2787308 0.2787308 0.2787308 0.2787308
##          9        10        11
##  0.2787308 0.2787308 0.2787308
##
##
## Real Parameter f0
##          1
##  0.5076828
```

```
##
## Note: only 2 parameters counted of 3 specified parameters
##
## AICc and parameter count have been adjusted upward


##
## Output summary for Closed model
## Name : p(~1)c(~1)f0(~1)
##
## Npar :  3  (unadjusted=2)
## -2lnL:  284.0513
## AICc :  290.1108  (unadjusted=288.081)
##
## Beta
##                  estimate         se        lcl         ucl
## p:(Intercept)   -0.6931472 0.2013468  -1.087787  -0.2985075
## c:(Intercept)   -1.0277862 0.1319381  -1.286385  -0.7691875
## f0:(Intercept) -26.2097700 0.0000000 -26.209770 -26.2097700
##
##
## Real Parameter p
##          1         2         3         4         5         6         7
##  0.3333333 0.3333333 0.3333333 0.3333333 0.3333333 0.3333333 0.3333333
##          8         9        10        11
##  0.3333333 0.3333333 0.3333333 0.3333333
##
##
## Real Parameter c
##          2         3         4         5         6         7         8
##  0.2635135 0.2635135 0.2635135 0.2635135 0.2635135 0.2635135 0.2635135
##          9        10        11
##  0.2635135 0.2635135 0.2635135
##
##
## Real Parameter f0
##            1
##  4.142299e-12


##
## Output summary for Closed model
## Name : p(~time)c()f0(~1)
##
## Npar :  12
## -2lnL:  245.407
## AICc :  270.1989
##
## Beta
##                   estimate         se        lcl         ucl
## p:(Intercept)  -7.453964e-01 0.3527787 -1.4368426 -0.0539502
## p:time2        -1.610872e-06 0.4957385 -0.9716491  0.9716459
## p:time3        -1.708022e-06 0.4957387 -0.9716496  0.9716462
## p:time4         6.763185e-01 0.4800351 -0.2645502  1.6171873
## p:time5         5.686119e-01 0.4807174 -0.3735942  1.5108179
## p:time6        -1.257968e-01 0.5018273 -1.1093783  0.8577847
```

```
## p:time7          3.494272e-01 0.4841920 -0.5995892  1.2984435
## p:time8         -2.124981e+00 0.8070584 -3.7068155 -0.5431466
## p:time9         -1.119841e+00 0.5949152 -2.2858752  0.0461925
## p:time10        -1.119841e+00 0.5949153 -2.2858753  0.0461927
## p:time11        -9.060579e-01 0.5670665 -2.0175084  0.2053925
## f0:(Intercept)  -1.247048e+00 3.4918753 -8.0911238  5.5970276
##
##
## Real Parameter p
##          1          2          3          4          5          6          7
##  0.3218252 0.3218249 0.3218249 0.4827374 0.4559186 0.2950061 0.4022812
##          8          9         10         11
##  0.0536375 0.1340937 0.1340937 0.1609125
##
##
## Real Parameter c
##          2          3          4          5          6          7          8
##  0.3218249 0.3218249 0.4827374 0.4559186 0.2950061 0.4022812 0.0536375
##          9         10         11
##  0.1340937 0.1340937 0.1609125
##
##
## Real Parameter f0
##          1
##  0.2873518
##
##
## Note: only 18 parameters counted of 22 specified parameters
##
## AICc and parameter count have been adjusted upward
##
##
## Output summary for Closed model
## Name : p(~time)c(~time)f0(~1)
##
## Npar :  22  (unadjusted=18)
## -2lnL:  235.9902
## AICc :  282.6256  (unadjusted=273.75305)
##
## Beta
##                    estimate           se           lcl           ucl
## p:(Intercept)   -0.7339699 3.511878e-01 -1.422298e+00    -0.0456418
## p:time2         -0.0198017 5.542165e-01 -1.106066e+00     1.0664627
## p:time3          0.1278339 6.171772e-01 -1.081833e+00     1.3375014
## p:time4          0.5516487 6.999988e-01 -8.203491e-01     1.9236464
## p:time5         -0.8754666 1.150360e+00 -3.130172e+00     1.3792385
## p:time6          0.3285065 9.780925e-01 -1.588555e+00     2.2455678
## p:time7          0.0408212 1.274098e+00 -2.456411e+00     2.5380537
## p:time8        -21.4416760 7.911593e+03 -1.552816e+04 15485.2800000
## p:time9        -21.4416760 7.911593e+03 -1.552816e+04 15485.2800000
## p:time10         0.7339735 1.457161e+00 -2.122063e+00     3.5900098
## p:time11        31.3004850 1.653928e-04  3.130016e+01    31.3008090
## c:(Intercept)   -0.6931471 6.123682e-01 -1.893389e+00     0.5070946
## c:time3         -0.1541506 7.829996e-01 -1.688830e+00     1.3805287
```

4

```
## c:time4           0.6931470 7.272142e-01 -7.321928e-01    2.1184868
## c:time5           0.7576856 7.100430e-01 -6.339986e-01    2.1493699
## c:time6          -0.2451222 7.277248e-01 -1.671463e+00    1.1812184
## c:time7           0.3364719 7.045723e-01 -1.044490e+00    1.7174337
## c:time8          -2.1102135 9.514712e-01 -3.975097e+00   -0.2453300
## c:time9          -1.0986125 7.799537e-01 -2.627322e+00    0.4300968
## c:time10         -1.3545458 8.107111e-01 -2.943540e+00    0.2344481
## c:time11         -1.1314028 7.792644e-01 -2.658761e+00    0.3959554
## f0:(Intercept) -35.7165240 0.000000e+00 -3.571652e+01  -35.7165240
##
##
## Real Parameter p
##          1    2         3         4         5         6        7
##  0.3243242 0.32 0.3529411 0.4545455 0.1666669 0.4000004 0.333333
##            8         9         10 11
##  2.340126e-10 2.340126e-10 0.5000009  1
##
##
## Real Parameter c
##          2    3    4         5         6         7         8         9
##  0.3333334 0.3 0.5 0.516129 0.2812501 0.4117647 0.0571428 0.1428571
##         10        11
##  0.1142857 0.1388888
##
##
## Real Parameter f0
##            1
##  3.079715e-16
```

Ajuste dos modelos com heterogeneidade

Para os modelos com heterogeneidade acrescente o termo `mixture` nas fórmulas do parâmetro p:

```
## Fórmulas estatísticas para cada parâmetro do modelo com heterogeneidade
## p com heterogeneidade
t.mix <- list(formula=~mixture)
## p=c com heterogeneidade (use o argumento share=TRUE)
t.mixshared=list(formula=~mixture,share=TRUE)
## Parametros dependem do tempo
t.timemixshared <- list(formula=~time+mixture, share=TRUE)
t.timemix <- list(formula=~time+mixture)
```

E ajuste os modelos

```
##
## Output summary for FullHet model
## Name : pi(~1)p(~mixture)c()f0(~1)
##
## Npar :  4
## -2lnL:  267.5892
## AICc :  275.6888
##
## Beta
```

```
##                   estimate        se        lcl        ucl
## pi:(Intercept) -1.9790955 0.6998966 -3.3508928 -0.6072981
## p:(Intercept)   0.6679508 0.5013994 -0.3147922  1.6506937
## p:mixture2     -1.9666459 0.4489058 -2.8465012 -1.0867906
## f0:(Intercept)  0.6523467 1.0079167 -1.3231699  2.6278634
##
##
## Real Parameter pi
##
##
## mixture:1 0.1214153
##
##
## Real Parameter p
##
##                   1         2         3         4         5         6
## mixture:1 0.6610441 0.6610441 0.6610441 0.6610441 0.6610441 0.6610441
## mixture:2 0.2143847 0.2143847 0.2143847 0.2143847 0.2143847 0.2143847
##                   7         8         9        10        11
## mixture:1 0.6610441 0.6610441 0.6610441 0.6610441 0.6610441
## mixture:2 0.2143847 0.2143847 0.2143847 0.2143847 0.2143847
##
##
## Real Parameter c
##
##                   2         3         4         5         6         7
## mixture:1 0.6610441 0.6610441 0.6610441 0.6610441 0.6610441 0.6610441
## mixture:2 0.2143847 0.2143847 0.2143847 0.2143847 0.2143847 0.2143847
##                   8         9        10        11
## mixture:1 0.6610441 0.6610441 0.6610441 0.6610441
## mixture:2 0.2143847 0.2143847 0.2143847 0.2143847
##
##
## Real Parameter f0
##
##        1
##   1.920041


##
## Output summary for FullHet model
## Name : pi(~1)p(~mixture)c(~mixture)f0(~1)
##
## Npar :  6
## -2lnL:  263.0737
## AICc :  275.2837
##
## Beta
##                   estimate         se        lcl        ucl
## pi:(Intercept) -1.8878485  0.6887566  -3.2378115 -0.5378854
## p:(Intercept)   1.8897359  1.9074780  -1.8489212  5.6283929
## p:mixture2     -2.7227439  1.8964776  -6.4398400  0.9943523
## c:(Intercept)   0.5499068  0.4700608  -0.3714123  1.4712260
## c:mixture2     -1.9882608  0.4260234  -2.8232666 -1.1532549
## f0:(Intercept) -2.8499141 17.4771450 -37.1051190 31.4052910
```

```
##
##
## Real Parameter pi
##
##
## mixture:1 0.13149
##
##
## Real Parameter p
##
##                    1         2         3         4         5         6
## mixture:1 0.8687254 0.8687254 0.8687254 0.8687254 0.8687254 0.8687254
## mixture:2 0.3030094 0.3030094 0.3030094 0.3030094 0.3030094 0.3030094
##                    7         8         9        10        11
## mixture:1 0.8687254 0.8687254 0.8687254 0.8687254 0.8687254
## mixture:2 0.3030094 0.3030094 0.3030094 0.3030094 0.3030094
##
##
## Real Parameter c
##
##                    2         3         4         5         6         7
## mixture:1 0.6341140 0.6341140 0.6341140 0.6341140 0.6341140 0.6341140
## mixture:2 0.1918004 0.1918004 0.1918004 0.1918004 0.1918004 0.1918004
##                    8         9        10        11
## mixture:1 0.6341140 0.6341140 0.6341140 0.6341140
## mixture:2 0.1918004 0.1918004 0.1918004 0.1918004
##
##
## Real Parameter f0
##
##          1
##  0.0578493


##
## Note: only 12 parameters counted of 13 specified parameters
##
## AICc and parameter count have been adjusted upward


##
## Output summary for FullHet model
## Name : pi(~1)p(~time)c()f0(~1)
##
## Npar :  13  (unadjusted=12)
## -2lnL:  245.407
## AICc :  272.3332  (unadjusted=270.19889)
##
## Beta
##                      estimate           se          lcl          ucl
## pi:(Intercept)  1.593731e-05 1299.5784000 -2547.1736000 2547.1736000
## p:(Intercept)  -7.453957e-01    0.3527797   -1.4368439   -0.0539475
## p:time2        -2.169180e-06    0.4957395   -0.9716515    0.9716472
## p:time3        -2.348598e-06    0.4957400   -0.9716528    0.9716481
## p:time4         6.763179e-01    0.4800360   -0.2645526    1.6171885
## p:time5         5.686113e-01    0.4807181   -0.3735963    1.5108189
```

```
## p:time6        -1.257975e-01    0.5018280    -1.1093803    0.8577854
## p:time7         3.494268e-01    0.4841929    -0.5995914    1.2984450
## p:time8        -2.124982e+00    0.8070590    -3.7068173   -0.5431459
## p:time9        -1.119842e+00    0.5949161    -2.2858778    0.0461934
## p:time10       -1.119842e+00    0.5949161    -2.2858773    0.0461938
## p:time11       -9.060588e-01    0.5670675    -2.0175111    0.2053934
## f0:(Intercept) -1.247060e+00    3.4919393    -8.0912610    5.5971412
##
##
## Real Parameter pi
##
##
## mixture:1 0.500004
##
##
## Real Parameter p
##
##                 1         2         3         4         5         6
## mixture:1 0.3218254 0.3218249 0.3218249 0.4827374 0.4559187 0.2950061
## mixture:2 0.3218254 0.3218249 0.3218249 0.4827374 0.4559187 0.2950061
##                 7         8         9        10        11
## mixture:1 0.4022812 0.0536375 0.1340937 0.1340938 0.1609125
## mixture:2 0.4022812 0.0536375 0.1340937 0.1340938 0.1609125
##
##
## Real Parameter c
##
##                 2         3         4         5         6         7
## mixture:1 0.3218249 0.3218249 0.4827374 0.4559187 0.2950061 0.4022812
## mixture:2 0.3218249 0.3218249 0.4827374 0.4559187 0.2950061 0.4022812
##                 8         9        10        11
## mixture:1 0.0536375 0.1340937 0.1340938 0.1609125
## mixture:2 0.0536375 0.1340937 0.1340938 0.1609125
##
##
## Real Parameter f0
##
##          1
##   0.2873484


##
## Note: only 22 parameters counted of 25 specified parameters
##
## AICc and parameter count have been adjusted upward


##
## Output summary for FullHet model
## Name : pi(~1)p(~time + mixture)c(~time + mixture)f0(~1)
##
## Npar :  25  (unadjusted=22)
## -2lnL:  210.3795
## AICc :  263.7916  (unadjusted=257.01493)
##
## Beta
```

```
##                  estimate           se          lcl          ucl
## pi:(Intercept)  -1.8513436 6.055801e-01  -3.0382806   -0.6644066
## p:(Intercept)    1.8247546 1.598480e+00  -1.3082664    4.9577756
## p:time2          0.3147930 6.133119e-01  -0.8872983    1.5168842
## p:time3          0.5439871 6.672682e-01  -0.7638585    1.8518327
## p:time4          0.9695440 7.442000e-01  -0.4890881    2.4281761
## p:time5         -0.4569172 1.177572e+00  -2.7649589    1.8511246
## p:time6          0.7470596 1.009953e+00  -1.2324478    2.7265669
## p:time7          0.4593849 1.298719e+00  -2.0861039    3.0048737
## p:time8        -20.8643760 4.301848e-07 -20.8643770  -20.8643760
## p:time9        -20.8643760 4.302410e-07 -20.8643770  -20.8643760
## p:time10         1.1525428 1.478743e+00  -1.7457925    4.0508781
## p:time11        37.8870460 0.000000e+00  37.8870460   37.8870460
## p:mixture2      -2.9772723 1.642774e+00  -6.1971085    0.2425638
## c:(Intercept)    0.6699147 8.386237e-01  -0.9737878    2.3136172
## c:time3          0.1287734 9.198690e-01  -1.6741698    1.9317166
## c:time4          1.3449796 8.545692e-01  -0.3299761    3.0199353
## c:time5          1.4846200 8.378972e-01  -0.1576584    3.1268985
## c:time6          0.3162734 8.548021e-01  -1.3591387    1.9916855
## c:time7          1.0358254 8.328286e-01  -0.5965186    2.6681695
## c:time8         -1.8530973 1.059225e+00  -3.9291780    0.2229834
## c:time9         -0.6808814 9.019246e-01  -2.4486537    1.0868908
## c:time10        -0.9871515 9.302707e-01  -2.8104821    0.8361792
## c:time11        -0.7040671 9.007161e-01  -2.4694707    1.0613365
## c:mixture2      -2.3848035 4.685460e-01  -3.3031538   -1.4664533
## f0:(Intercept) -18.2860330 0.000000e+00 -18.2860330  -18.2860330
##
##
## Real Parameter pi
##
##
## mixture:1 0.1357152
##
##
## Real Parameter p
##
##                   1         2         3         4         5         6
## mixture:1 0.8611357 0.8946880 0.9144124 0.9423670 0.7970305 0.9290254
## mixture:2 0.2400295 0.3020142 0.3523944 0.4543838 0.1666671 0.4000017
##                   7            8            9         10 11
## mixture:1 0.9075549 5.385144e-09 5.385144e-09 0.9515379  1
## mixture:2 0.3333365 2.742738e-10 2.742738e-10 0.5000063  1
##
##
## Real Parameter c
##
##                   2         3         4         5         6         7
## mixture:1 0.6614841 0.6896938 0.882352 0.8960918 0.7283343 0.8462829
## mixture:2 0.1525307 0.1699311 0.408563 0.4426858 0.1980359 0.3364704
##                   8         9        10        11
## mixture:1 0.2344804 0.4972583 0.4213493 0.4914627
## mixture:2 0.0274385 0.0834958 0.0628531 0.0817386
##
##
```

```
## Real Parameter f0
##
##            1
##   1.144134e-08
```

Seleção de modelos

A função abaixo retorna a tabela de seleção de modelos:

```
collect.models(lx=c("boto.M0", "boto.Mb", "boto.Mt", "boto.Mtb",
                    "boto.Mh", "boto.Mbh", "boto.Mth", "boto.Mtbh"))
```

```
## Warning in model.table(x, type, pf = 2, adjust = adjust): Model list contains models of differing ty

##                                               model npar     AICc DeltaAICc
## 8 pi(~1)p(~time + mixture)c(~time + mixture)f0(~1)   25 263.7916  0.000000
## 3                               p(~time)c()f0(~1)   12 270.1989  6.407315
## 7                       pi(~1)p(~time)c()f0(~1)   13 272.3332  8.541645
## 6            pi(~1)p(~mixture)c(~mixture)f0(~1)    6 275.2837 11.492157
## 5                   pi(~1)p(~mixture)c()f0(~1)    4 275.6888 11.897169
## 4                       p(~time)c(~time)f0(~1)   22 282.6256 18.833993
## 1                             p(~1)c()f0(~1)    2 289.7349 25.943289
## 2                           p(~1)c(~1)f0(~1)    3 290.1108 26.319260
##         weight Deviance
## 8 9.429745e-01 156.7423
## 3 3.829740e-02 191.7698
## 7 1.317362e-02 191.7698
## 6 3.013074e-03 209.4365
## 5 2.460722e-03 213.9520
## 4 7.669204e-05 182.3529
## 1 2.192735e-06 232.0679
## 2 1.816960e-06 230.4140
```

Valores das estimativas

A função `coef` retorna os coeficientes na escala de ligação (logito). Para as estimativas na escala de probabilidades use a função `get.real`:

```
coef(boto.Mtbh, data=boto2002)
```

```
##                   estimate           se          lcl          ucl
## pi:(Intercept)  -1.8513436 6.055801e-01  -3.0382806  -0.6644066
## p:(Intercept)    1.8247546 1.598480e+00  -1.3082664   4.9577756
## p:time2          0.3147930 6.133119e-01  -0.8872983   1.5168842
## p:time3          0.5439871 6.672682e-01  -0.7638585   1.8518327
## p:time4          0.9695440 7.442000e-01  -0.4890881   2.4281761
## p:time5         -0.4569172 1.177572e+00  -2.7649589   1.8511246
## p:time6          0.7470596 1.009953e+00  -1.2324478   2.7265669
## p:time7          0.4593849 1.298719e+00  -2.0861039   3.0048737
## p:time8        -20.8643760 4.301848e-07 -20.8643770 -20.8643760
## p:time9        -20.8643760 4.302410e-07 -20.8643770 -20.8643760
```

```
## p:time10           1.1525428 1.478743e+00  -1.7457925    4.0508781
## p:time11          37.8870460 0.000000e+00  37.8870460   37.8870460
## p:mixture2         -2.9772723 1.642774e+00  -6.1971085    0.2425638
## c:(Intercept)       0.6699147 8.386237e-01  -0.9737878    2.3136172
## c:time3             0.1287734 9.198690e-01  -1.6741698    1.9317166
## c:time4             1.3449796 8.545692e-01  -0.3299761    3.0199353
## c:time5             1.4846200 8.378972e-01  -0.1576584    3.1268985
## c:time6             0.3162734 8.548021e-01  -1.3591387    1.9916855
## c:time7             1.0358254 8.328286e-01  -0.5965186    2.6681695
## c:time8            -1.8530973 1.059225e+00  -3.9291780    0.2229834
## c:time9            -0.6808814 9.019246e-01  -2.4486537    1.0868908
## c:time10           -0.9871515 9.302707e-01  -2.8104821    0.8361792
## c:time11           -0.7040671 9.007161e-01  -2.4694707    1.0613365
## c:mixture2         -2.3848035 4.685460e-01  -3.3031538   -1.4664533
## f0:(Intercept)    -18.2860330 0.000000e+00 -18.2860330  -18.2860330
```

```
## Na escala de probabilidades
get.real(boto.Mtbh, parameter="p")
```

```
## [[1]]
##                     1         2         3         4         5         6
## mixture:1 0.8611357 0.8946880 0.9144124 0.9423670 0.7970305 0.9290254
## mixture:2 0.2400295 0.3020142 0.3523944 0.4543838 0.1666671 0.4000017
##                     7            8            9        10 11
## mixture:1 0.9075549 5.385144e-09 5.385144e-09 0.9515379  1
## mixture:2 0.3333365 2.742738e-10 2.742738e-10 0.5000063  1
```

```
get.real(boto.Mtbh, parameter="c")
```

```
## [[1]]
##                     2         3        4         5         6         7
## mixture:1 0.6614841 0.6896938 0.882352 0.8960918 0.7283343 0.8462829
## mixture:2 0.1525307 0.1699311 0.408563 0.4426858 0.1980359 0.3364704
##                     8         9        10        11
## mixture:1 0.2344804 0.4972583 0.4213493 0.4914627
## mixture:2 0.0274385 0.0834958 0.0628531 0.0817386
```

```
get.real(boto.Mtbh, parameter="pi")
```

```
## [[1]]
##
## mixture:1 0.1357152
```