III. Capture-Recapture for group-structured, "multi-session" or stratified populations

Group structure or stratified populations

- Examples
  - Sex
  - Location (e.g., trapping grid)
  - Time (year)
- Exactly like “model Mh” with finite mixture except we have information on which group captured individuals belong to
- Thus the groups have biological context

Sex specificity of model parameters

Two ways to formulate the model in BUGS:

1. As an additive covariate:

    logit(p[i]) = alpha0 + alpha1*Xsex[i]

    Xsex[i] = 1 if male, 0 if female (dummy variable)

2. Index variables:

    logit(p[i]) = alpha0[Xsex[i]]

    Xsex[i] = 1 if female
    2 if male

Key technical issues:

- Xsex is missing for M-n individuals in our augmented data set.
- Put a prior distribution on it....just like Model Mh
- Xsex can be missing for some captured individuals

SEX SPECIFICITY

Prior distribution for a 2-class variable:

Pr(Xsex = 1) = f (estimate the parameter f)

then

Pr(Xsex = 1) = 1-f

f = "prob. that an individual in the population is female"

Implies class specific population size:

$N_1 \sim \mathrm{Bin}(N, f)$ and $N_2 = N – N_1$

GENERAL CASE

- > 2 classes, could be space or time groupings
- The class membership probabilities are a prior distribution on the discrete class variable

SEX SPECIFICITY

- R work session

MULTI-YEAR DATA

- If we have data from multiple years (or "sessions") we can use the exactly same model but treat year as a class variable to allocate the augmented individuals into years.

- For this model we stack the data from each year:

A sex-structured data set is just:
Y<- rbind(Ymale, Yfemale)

```
Y <- rbind(Y1, Y2, Y3, Y4, Y5)
                  ## T=5 years Yt = nind[t] x K
```

Then apply data augmentation to the matrix Y

- This is a primitive form of an open model in which individual identity is ignored across years, N[t] are independent parameters then

MULTI-YEAR DATA

- year[i] = year to which individual i belongs. This has T possible values then
- In BUGS the model looks like this:

```
year[i] ~ dcat(probs[])

probs[t] <- 1/T
```

- We could also model the categorical probabilities directly as a function of time or explicit covariates :

```
log(mu[t]) = beta0 + beta1*x[t]
probs[t]<- mu[t]/sum(mu[])
```

Multinomial logit

OVENBIRD STUDY

The R package "secr" has the ovenbird data

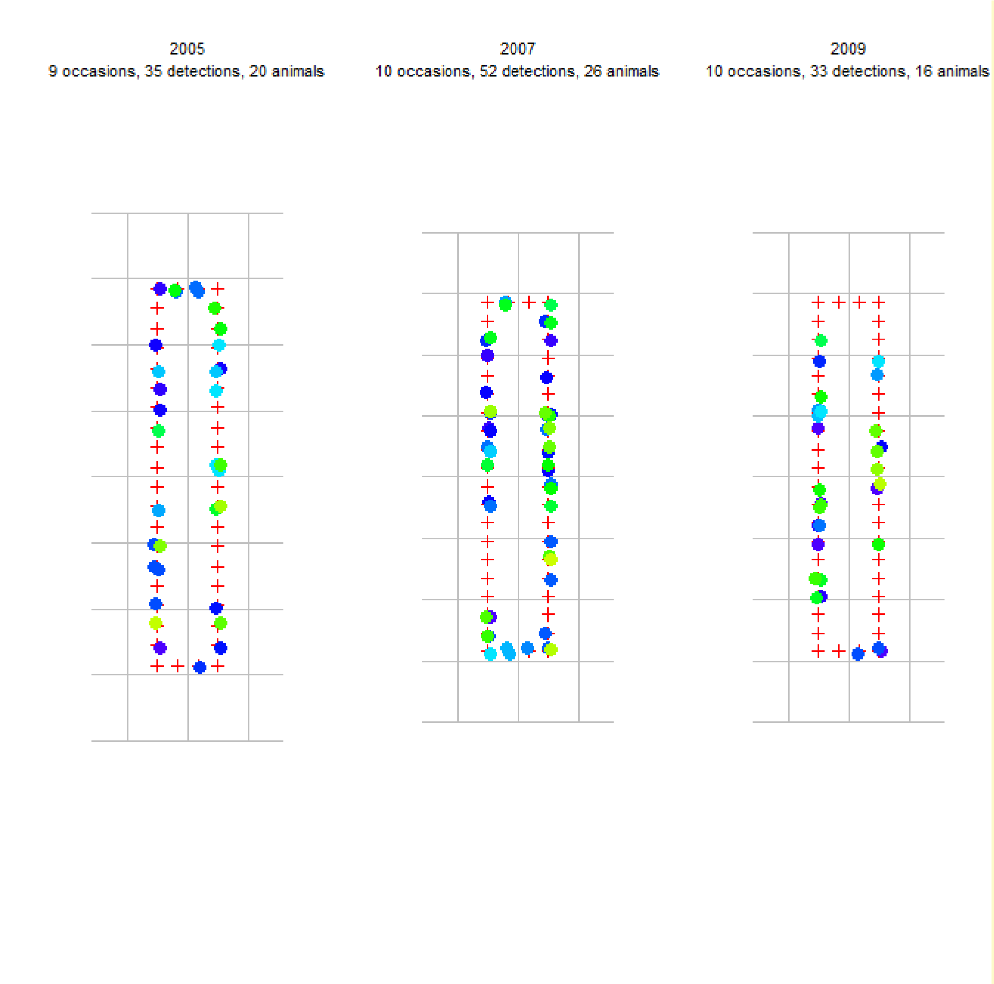
```
library(secr)
data(ovenbird)
```

This is based on 44 mist nets operated for 5 years.

Distracting problems to deal with:

- 1. One individual died on capture
- 2. Year 1 had K=9 reps, other years had K=10

OVENBIRD STUDY



- 44 nets (+ signs)
- Captures marked with circles
- Individuals marked with colors
- 5 year study, only 3 years shown here

OVENBIRD STUDY

- Data are SPATIAL encounter histories
- Mist-nets: individual can only be captured in 1 trap per occasion (unlike Fort Drum bear data)
- y[i,j] = TRAP OF CAPTURE. Ordinary CR models operate on binary data (captured or not)
- For now we will throw out the spatial information. Just change trap of capture to "1"

The "year as a class variable" model

```
psi ~ dunif(0,1)

for(t in 1:5){
   p[t] ~ dunif(0,1)
   probs[t]<- 1/5    ## uniform distribution on year membership
}
for(i in 1:M){
  year[i] ~ dcat(probs[])
  z[i] ~ dbern(psi)

  for(k in 1:K){
   mu[i,k]<- z[i]*p[year[i]]*(1-isdead[i,k])*sampled[k,year[i]]
   Ystacked[i,k] ~ dbern( mu[i,k] )
  }
 }

for(t in 1:5){
  N[t]<- sum(inyear[,t])
  for(i in 1:M){
    inyear[i,t]<- equals(year[i],t)*z[i]
  }
}
```

N[t] are derived parameters
Have to compute number of
Individuals in each year

YEAR AS A CLASS VARIABLE

By treating year as a class variable:

- We have to recover N[t] by creating a frequency distribution of the year variable.

- Also note that the joint prior distribution for N[1], …, N[t] is

  (N[1], N[2], …, N[T]) ~ Multinomial(M; probs[1:T])

  Roughly the same as saying N[t] ~ Poisson(lambda)

Reference: Royle, J. A., & Converse, S. J. (2014). Hierarchical spatial capture–recapture models: modelling population density in stratified populations. *Methods in Ecology and Evolution*, *5*(1), 37-43.

MULTI-YEAR DATA/OPEN POPULATIONS

Many ways to analyze multi-year data sets:

- Treat “year” as a class variable: year[i] ~ dcat(psi[year])

- Day 3 of the workshop “open population models”
  - T-fold data augmentation -- Input the data as a 3-d array “individual x replicate x year” with each year augmented independently
    - Still regards individuals as independent across years
  - Fully dynamic model: preserve individual identity across years.

SUMMARY PART III

- Discrete classes are common in capture-recapture studies (sex is the typical one also year as a class variable is a special type of open model)
- Technical problem is that class is unknown for uncaptured individuals
- We solve this by putting a prior distribution on class membership
- In BUGS this is easy…?
- Model follows naturally from Model Mh, the finite-mixture version, but with information about which class

SUMMARY PART III

- Year (or other temporal period) can be treated as a class variable to model variation in N (and density) across time
- This casts the model as a basic stratified population model analogous to models with sex-specificity
- “multi-session” models in “secr” do a similar thing but not exactly the same thing.