Design and Analysis of Occupancy Studies Part 2

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Single-Species Multi-Season Occupancy Studies

Analysis of Northern Spotted Owl study using *unmarked*

Single Species; Multi-Season - Example

Northern Spotted Owl (*Strix occidentalis caurina*) in California.

$s = 55$ sites visited up to $K = 8$ times per season between 1997 and 2001 ($Y = 5$).

Detection probabilities relatively constant within years, but likely different among years.

1. Read in history data.
This is a $n_{sites} \times n_{years} n_{visits}$ matrix or data.frame.
All years must have the same number of visits, but just pad on the right with missing values.

```
input.history <- read.csv("NSO_pg209.csv",
      header=FALSE, skip=2, na.strings="-")
input.history$V1 <- NULL # drop the site number

Nsites = nrow(input.history)
Nyears = 5
Nvisits= ncol(input.history)/Nyears
```

2. Create site level covariates (if any).
These are used for initial occupancy.
This is a $n_{sites} \times n_{site.covariates}$ data.frame.

```
site.covar <- data.frame(SiteNum=1:Nsites)
head(site.covar)
```

Single Species; Multi-Season - NSO - *unmarked*

3. Create site - year level covariates (if any).
These are used for colonization and extinction.
This is a $n_{sites} n_{yearr} \times n_{year.site.covariates}$ data.frame.
These should be in site major order as shown below.

```
yearsite.covar <- data.frame(
        SiteNum=rep(1:Nsites,  each=Nyears),
        Year   =as.factor(rep(1:Nyears,Nsites)))
head(yearsite.covar)
```

```
  SiteNum Year
1       1    1
2       1    2
3       1    3
4       1    4
5       1    5
6       2    1
```

4. Create visit level covariates (if any).
   These are used for detection probabilities
   This is a $n_{sites} n_{yearr} n_{visits} \times n_{visit.covariates}$ data.frame.
   These should be in site, year, visit major order as shown below.

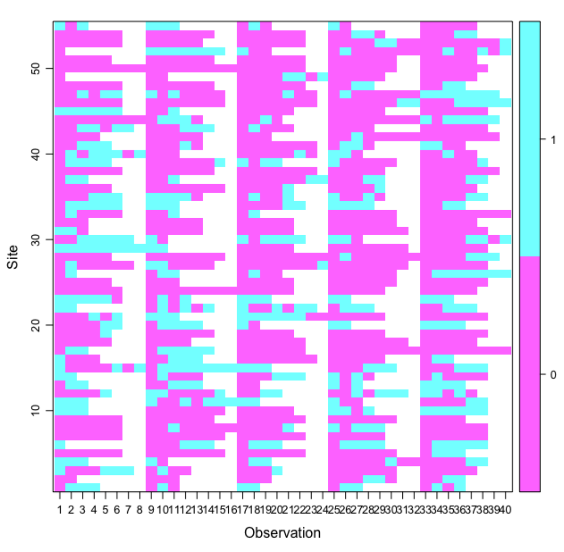
```
obs.covar <- data.frame(
      SiteNum = rep(1:Nsites, each=Nyears * Nvisits),
      Year    =  as.factor(rep( rep(1:Nyears, each=Nvisits),
      Visit   =  as.factor(rep(1:Nvisits, Nyears*Nsites)))
```

```
> obs.covar[1:30,]
   SiteNum Year Visit
1        1    1     1
2        1    1     2
...
8        1    1     8
9        1    2     1
10       1    2     2
...
16       1    2     8
```

4. The UMF object

```
nso.UMF <- unmarked::unmarkedMultFrame(
        input.history,
        siteCovs=site.covar,
        yearlySiteCovs=yearsite.covar,
        obsCovs = obs.covar,
         numPrimary=Nyears)
nso.UMF
```

Map of detections.



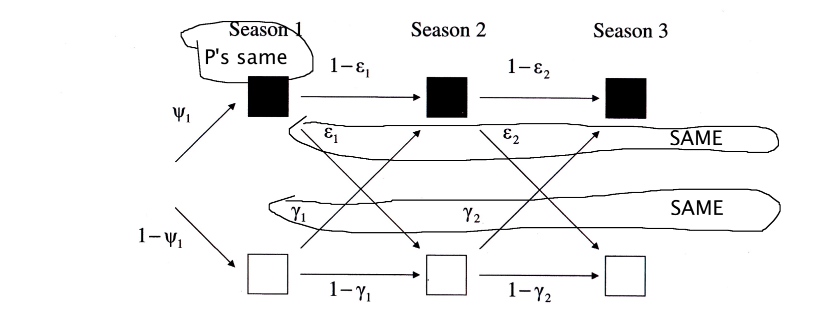
Single Species; Multi-Season - NSO - *unmarked*

Model with colonization and extinction rates parameterization.
Fit the $\psi(1997), \gamma(*), \epsilon(*), p(*)$ model in the usual way.

```
mod.psiDot.gDot.eDot.pDot <- unmarked::colext(
      psiformula= ~1,
      gammaformula = ~ 1,
      epsilonformula = ~ 1,
      pformula = ~ 1,
      data=nso.UMF,
      se=TRUE)
summary(mod.psiDot.gDot.eDot.pDot)
```

Single Species; Multi-Season - NSO - *unmarked*

Helpful to draw a diagram of the process model:



Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ Results of model fit.

```
Call:
unmarked::colext(psiformula = ~1, gammaformula = ~1, epsilo
    pformula = ~1, data = nso.UMF, se = TRUE)

AIC: 1363.32
Number of sites: 55
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ parameter estimates.
We use *predict* with a (new) data frame with nothing in it.

```
predict(mod.psiDot.gDot.eDot.pDot, type='psi')

newdata <- data.frame(dummy=1)
predict(mod.psiDot.gDot.eDot.pDot, type='psi', newdata=newd
```

gives:

```
> predict(mod.psiDot.gDot.eDot.pDot, type='psi')
   Predicted         SE     lower     upper
1  0.6311598 0.06726424 0.4927218 0.7509165
2  0.6311598 0.06726424 0.4927218 0.7509165
....
> newdata <- data.frame(dummy=1)
> predict(mod.psiDot.gDot.eDot.pDot, type='psi', newdata=ne
  Predicted         SE     lower     upper
1 0.6311598 0.06726424 0.4927218 0.7509165
```

Single Species; Multi-Season - NSO - *unmarked*

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ parameter estimates.
We use *predict* with a (new) data frame with nothing in it.

```
predict(mod.psiDot.gDot.eDot.pDot, type='col', newdata=newd

predict(mod.psiDot.gDot.eDot.pDot, type='ext', newdata=newd
```

gives:

```
> predict(mod.psiDot.gDot.eDot.pDot, type='psi', newdata=ne
  Predicted         SE     lower     upper
1 0.6311598 0.06726424 0.4927218 0.7509165

> predict(mod.psiDot.gDot.eDot.pDot, type='col', newdata=ne
  Predicted        SE     lower     upper
1 0.1841754 0.0427179 0.1145044 0.2827042
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ parameter estimates.
We use *predict* with a (new) data frame with nothing in it.

```
predict(mod.psiDot.gDot.eDot.pDot, type='det', newdata=newd
```

gives:

```
  Predicted          SE     lower     upper
1 0.4947425 0.01858223 0.4584141 0.5311265
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ derived parameter estimates of occupancy in later years

There are two type of estimates

- projected - for the population of ALL sites
- smoothed for the actual sites

-

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ derived parameter estimates of occupancy in later years
Projected - for POPULATION of ALL sites.

```
# What is the occupancy for the population of ALL potentia
# first index = not occupied/occupied, second index=year,
mod.psiDot.gDot.eDot.pDot@projected[,,1]
mod.psiDot.gDot.eDot.pDot@projected[2,,1]
projected(mod.psiDot.gDot.eDot.pDot)  # this gives the mea
```

```
> mod.psiDot.gDot.eDot.pDot@projected[,,1]
          [,1]      [,2]      [,3]      [,4]      [,5]
[1,] 0.3688402 0.3960537 0.4141528 0.4261901 0.4341959
[2,] 0.6311598 0.6039463 0.5858472 0.5738099 0.5658041
> mod.psiDot.gDot.eDot.pDot@projected[2,,1]
[1] 0.6311598 0.6039463 0.5858472 0.5738099 0.5658041
> projected(mod.psiDot.gDot.eDot.pDot)  # this gives the me
                   1         2         3         4
unoccupied 0.3688402 0.3960537 0.4141528 0.4261901 0.434195
occupied   0.6311598 0.6039463 0.5858472 0.5738099 0.565804
```

Single Species; Multi-Season - NSO - *unmarked*

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ derived parameter estimates of occupancy in later years

Smoothed - for sample of actual sites

```
# What is the actual occupancy for these particular sites
mod.psiDot.gDot.eDot.pDot@smoothed[2,,1:2]
smoothed(mod.psiDot.gDot.eDot.pDot)[2,] # this gives the m
```

```
> mod.psiDot.gDot.eDot.pDot@smoothed[2,,1:2]
     [,1]      [,2]
[1,]    1 0.1069976
[2,]    1 0.0544300
[3,]    1 0.1538519
[4,]    1 1.0000000
[5,]    1 1.0000000
> smoothed(mod.psiDot.gDot.eDot.pDot)[2,] # this gives the
        1         2         3         4         5
0.6311617 0.6084676 0.5553642 0.5756990 0.5738898
```

No SE are provided (but see below).

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ Finding growth estimates and SE using bootstrapping.

```
# Obtain standard errors for these forecasts using paramet
psi.projected <- function(model, site) {
  psi.projected <- model@projected[2,,site]

  # compute population growth
  lambda <- exp(diff(log(psi.projected),1))
  lambda.overall <- prod(lambda) # overall growth rate ove

  lambda.prime <- exp(diff(logit(psi.projected),1))
  lambda.prime.overall <- prod(lambda.prime) # overall gro
  c(psi.projected=psi.projected,
    lambda=       lambda,
    lambda.overall=lambda.overall,
    lambda.prime  =lambda.prime,
    lambda.prime.overall=lambda.prime.overall )
}
psi.projected(mod.psiDot.gDot.eDot.pDot, site=1)
```

Single Species; Multi-Season - NSO - *unmarked*

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ Finding growth estimates and SE using bootstrapping.

```
> psi.projected(mod.psiDot.gDot.eDot.pDot, site=1)
      psi.projected1       psi.projected2       psi.project
           0.6311598            0.6039463            0.5858
      psi.projected4       psi.projected5              lamb
           0.5738099            0.5658041            0.9568
             lambda2              lambda3              lamb
           0.9700319            0.9794531            0.9860
      lambda.overall        lambda.prime1         lambda.pri
           0.8964514            0.8911343            0.9276
       lambda.prime3        lambda.prime4 lambda.prime.over
           0.9517894            0.9678671            0.7615
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$
Bootstrap to obtain standard errors.

```
mod.psiDot.gDot.eDot.pDot.boot <- parboot(mod.psiDot.gDot.e
cbind(est=mod.psiDot.gDot.eDot.pDot.boot@t0,
      se=apply(mod.psiDot.gDot.eDot.pDot.boot@t.star, 2, sd
      t(apply(mod.psiDot.gDot.eDot.pDot.boot@t.star, 2, qua
```

```
                          est         se      2.5%       97.
psi.projected1      0.6311598 0.07232729 0.4999588 0.76014
psi.projected2      0.6039463 0.05104551 0.5066507 0.68279
psi.projected3      0.5858472 0.04869471 0.4959554 0.66225
psi.projected4      0.5738099 0.05355065 0.4684403 0.66400
psi.projected5      0.5658041 0.05909911 0.4421961 0.66204
lambda1             0.9568833 0.05727312 0.8403070 1.07262
lambda2             0.9700319 0.04073060 0.8816002 1.04999
lambda3             0.9794531 0.02893533 0.9184148 1.03537
lambda4             0.9860480 0.02049825 0.9426764 1.02363
lambda.overall      0.8964514 0.13731974 0.6408903 1.19518
lambda.prime1       0.8911343 0.14721357 0.5887025 1.1805
```

Single Species; Multi-Season - NSO - *unmarked*

Fit model for p to allow for year effects, but equal within each year.

Single Species; Multi-Season - NSO - *unmarked*

Model with colonization and extinction rates parameterization.
Fit the $\psi(1997), \gamma(*), \epsilon(*), p(Year)$ model in the usual way.

```
mod.psiDot.gDot.eDot.pYear <- unmarked::colext(
  psiformula= ~1,
  gammaformula = ~ 1,
  epsilonformula = ~ 1,
  pformula = ~ Year,
  data=nso.UMF,
  se=TRUE)
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ Results of model fit.

```
AIC: 1353.528
Number of sites: 55
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ parameter estimates.

```
> predict(mod.psiDot.gDot.eDot.pYear, type='psi', newdata=r
  Predicted         SE     lower     upper
1 0.6247288 0.06689193 0.4876139 0.7443861

> predict(mod.psiDot.gDot.eDot.pYear, type='col', newdata=r
  Predicted         SE     lower     upper
1 0.1788409 0.04301406 0.1092631 0.2788544
```

Single Species; Multi-Season - NSO - *unmarked*

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ parameter estimates.

```
> predict(mod.psiDot.gDot.eDot.pYear, type='ext', newdata=r
  Predicted         SE      lower     upper
1 0.1423004 0.03280271 0.08922963 0.2193345


> newdata <- data.frame(Year=as.factor(1:5))
> predict(mod.psiDot.gDot.eDot.pYear, type='det', newdata=r
  Predicted         SE     lower     upper
1 0.5905707 0.03942752 0.5116810 0.6650582
2 0.5224669 0.04047178 0.4432440 0.6005754
3 0.4074948 0.04418033 0.3245423 0.4960781
4 0.3848536 0.04125135 0.3077810 0.4681730
5 0.5365865 0.03916093 0.4595733 0.6118931...
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ Projected estimates of occupancy for POPULATION and SAMPLE

```
> mod.psiDot.gDot.eDot.pYear@projected[2,,1]
[1] 0.6247288 0.6029434 0.5881543 0.5781145 0.5712989
```

```
> mod.psiDot.gDot.eDot.pYear@smoothed[2,,1:2]
     [,1]       [,2]
[1,]    1 0.07252568
[2,]    1 0.05016299
[3,]    1 0.21254094
[4,]    1 1.00000000
[5,]    1 1.00000000
```

Single Species; Multi-Season - NSO - *unmarked*

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$
Growth parameters and standard errors via bootstrapping

	est	se	2.5%	97.
psi.projected1	0.6247288	0.06587862	0.4894743	0.7516
psi.projected2	0.6029434	0.04868917	0.5191508	0.7028
psi.projected3	0.5881543	0.04948117	0.4887079	0.6919
psi.projected4	0.5781145	0.05623694	0.4684003	0.6898
psi.projected5	0.5712989	0.06307565	0.4525634	0.6920
lambda1	0.9651283	0.05627099	0.8765583	1.0989
lambda2	0.9754717	0.03969023	0.9061482	1.0669
lambda3	0.9829301	0.02849954	0.9276229	1.0428
lambda4	0.9882107	0.02072323	0.9395945	1.0274
lambda.overall	0.9144751	0.13799503	0.7035495	1.2690
lambda.prime1	0.9121745	0.14214467	0.6666104	1.2398
lambda.prime2	0.9404430	0.09579496	0.7879826	1.1696
lambda.prime3	0.9595389	0.06676223	0.8497704	1.1150
lambda.prime4	0.9724999	0.04760985	0.8932224	1.0785
lambda.prime.overall	0.8005023	0.33738711	0.4114786	1.7708

Fit the $\psi(1997), p(year), \epsilon(year), \gamma(year)$ model.

Model with colonization and extinction rates parameterization.
Fit the $\psi(1997), p(year), \epsilon(year), \gamma(year)$ model.

```
mod.psiDot.gYear.eYear.pYear <- unmarked::colext(
  psiformula= ~1,
  gammaformula = ~ Year,
  epsilonformula = ~ Year,
  pformula = ~ Year,
  data=nso.UMF,
  se=TRUE)
```

What model would represent NO CHANGE IN OCCUPANCY in individual sites over the multiple seasons?

Single Species; Multi-Season - NSO - *unmarked*

What model would represent NO CHANGE IN OCCUPANCY in individual sites over the multiple seasons, i.e. convert this to an ‘equivalent single season model=?

$\gamma_y = 0$ and ϵ_y=0 for all years.

Fit the model and FIX some parameters
Not possible in unmarked.

Single Species; Multi-Season - NSO - *unmarked*

Here is the current AIC table:

```
                              nPars     AIC delta  AICwt cu
mod.psiDot.gDot.eDot.pYear        8 1353.53  0.00 0.7385
mod.psiDot.gYear.eYear.pYear     14 1355.65  2.12 0.2560
mod.psiDot.gDot.eDot.pDot         4 1363.32  9.79 0.0055
```

What do you conclude?
Model averaging only works for internal parameters and not derived parameters (groan), but you could write your own model averaging routine (double groan).

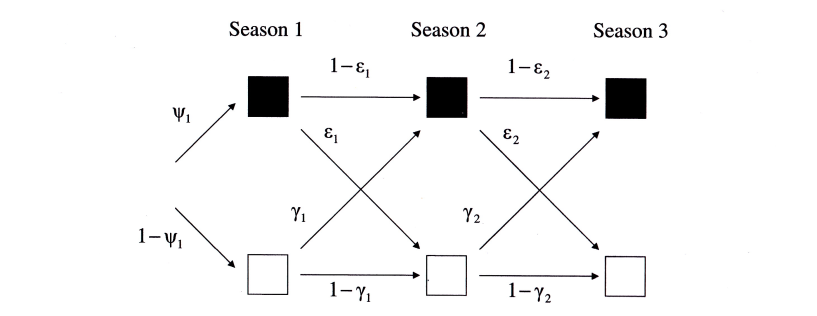
Single Species; Multi-Season - NSO - *unmarked*

What model would represent RANDOM occupancy over seasons, i.e. no site fidelity between seasons?

A RANDOM occupancy model says that occupancy in each season is a random process with no regard to sites being occupied or not occupied in previous seasons. For example, migrating birds return each year to select nesting sites but the process each year is independent of previous years. Site could be occupied for multiple years in a row, but this the result of random chance rather than any site fidelty.

A RANDOM occupancy model implies that an occupied site in season y has the same chance of being occupied in year $y+1$ (i.e. $(1-\epsilon_y)$ as does an unoccupied site in season y being occupied in year $y+1$ (i.e. γ_y).

Or ... RANDOM occupancy $\rightarrow \gamma_y = (1-\epsilon_y)$.



Model: $\psi(1997), p(year), \epsilon(year), \gamma = 1 - \epsilon$
This is equivalent to Model: $\psi(year), p(year)$ where $\gamma = 1 - \epsilon$ is enforced internally).

Currently not available in the *colext()* but you can "fake it" by analyzing each year separately using a single season occupancy model. But then you can't easily find growth rates and their standard errors. See `https://groups.google.com/forum/#!searchin/unmarked/random$20occupancy%7Csort:date/unmarked/-TINYk51EHs/Au5pyyW0BQAJ`

What model would represent a population in equilibrium in occupancy?

What model would represent a population in equilibrium in occupancy? $\psi_{y+1} = \psi_y \rightarrow \psi_{EQ} = \frac{\gamma}{\gamma+\epsilon}$

Not possible in *unmarked*.

Single Species; Multi-Season - NSO - *unmarked*

Conclusion:

- Changed in occupancy best represented by a Markov process (as expected), i.e. site fidelity at the species level (but not necessarily at the individual level).
- Random occupancy or no changes in occupancy have no support.
- Highest weight given to models in equilibrium (90% of model weights). (not possible in *unmarked*)

unmarked mostly is adequate.

- Derived estimates don't include population growth.
- Random occupancy models not directly implemented.

Single-Species Multi-Season Occupancy Studies

Analysis of Northern Spotted Owl study using *JAGS*.

Using *JAGS*:

- NOT FOR THE FAINT OF HEART!
- Order of various covariate matrices IMPORTANT - see code for details
- Use *model.matrix()* to generate the design matrices.
  - You need to understand the underlying parameterization and how to interpret
- Huge amounts of output that you must SELECTIVELY view in an efficient manner.

Northern Spotted Owl (*Strix occidentalis caurina*) in California.

$s = 55$ sites visited up to $K = 8$ times per season between 1997 and 2001 ($Y = 5$).

Detection probabilities relatively constant within years, but likely different among years.

Read in data and create the covariate matrices.

- History is $n_{sites} \times n_{years} n_{visits}$ matrix. Number of visits must be consistent among years, but just pad on the right.
- Site covariates is $n_{sites} \times n_{covariates}$ Use categorical variables when every possible rather than creating indicator variables.
- Site-Year covariates is $n_{sites} n_{years} \times n_{covariates}$ in Year major order, i.e. stack columns of yearly values. Will automatically add site covariates to the matrix.
- Visit covariates is $n_{sites} n_{years} n_{visits} \times n_{covariates}$ in Year/Visit/Site major order, i.e. stack columns of site covariates for each visit. Site-Year covariates automatically added.

Single Species; Multi-Season - NSO - *JAGS*

Create your design matrices using *model.matrix()*

```
# Create design matrix for initial occupancy covariates
covar.psi <- cbind(Site=site.covar[,"Site"],
      model.matrix( ~Browse, data=site.covar))

# Create design matrix for local extinction rate using yea
covar.epsilon <- cbind(yearsite.covar[,c("Site","Year")],
      model.matrix( ~as.factor(Year), data=yearsite.covar)

# Create design matrix for local colonization rate using y
covar.gamma <- cbind(yearsite.covar[,c("Site","Year")],
      model.matrix( ~as.factor(Year), data=yearsite.covar)

# Create design matrix for detection probabilities
covar.p <- cbind(Site, Year,
      model.matrix( ~as.factor(Year), data=obs.covar)
```

Common error is use *Year* as a continuous variable rather than a factor. Notice use of different covariate matrices. All covariate models operate on *logit()* of the parameter.

Single Species; Multi-Season - NSO - *JAGS*

No missing values allowed in site or site-year covariates. Histories (and covariate rows) with missing visit information automatically deleted.

```
# Remove rows corresponding to missing values in all input
no.visit <- is.na(History)

Site    <- Site    [ !no.visit]
Year    <- Year    [ !no.visit]
Visit   <- Visit   [ !no.visit]
History<- History[ !no.visit]
covar.p<- covar.p[ !no.visit,]
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ parameter estimates.

```
                    mean         sd
psi[1,1]       0.6323608 0.06696484

# Estimates of local extinction rate for unit 1
                    mean         sd
epsilon[1,1]   0.1497937 0.03304443
```

Single Species; Multi-Season - NSO - *JAGS*

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ parameter estimates.

```
> # Estimate of  local colonization probability for each un
                           mean           sd
gamma[1,1]          0.1833509 0.04244442

# Estimates of detection for unit 1
                      mean           sd
p.detect[1]    0.4942578 0.01854604
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ derived parameter estimates of occupancy in later years

```
                    mean         sd
psi[1,1]       0.6323608 0.06696484
psi[1,2]       0.6051648 0.05117052
psi[1,3]       0.5870344 0.05117800
psi[1,4]       0.5748694 0.05612736
psi[1,5]       0.5666558 0.06118645
```

Single Species; Multi-Season - NSO - *JAGS*

Model $\psi(1997), \gamma(*), \epsilon(*), p(*)$ derived parameter estimates of population growth.

```
                       mean         sd
lambda[1,1]       0.9604660 0.05289506
lambda[1,2]       0.9705184 0.03689389
lambda[1,3]       0.9786515 0.02604304
lambda[1,4]       0.9848033 0.01849410
lambda.prime[1,1] 0.8954618 0.13505411
lambda.prime[1,2] 0.9306257 0.08751699
lambda.prime[1,3] 0.9531346 0.05863444
lambda.prime[1,4] 0.9680748 0.04006228
```

SE are trivial to find using Bayesian methods

Single Species; Multi-Season - NSO - *JAGS*

Fit model for p to allow for year effects, but equal within each year.

Single Species; Multi-Season - NSO - *JAGS*

Model with colonization and extinction rates parameterization.
Fit the $\psi(1997), \gamma(*), \epsilon(*), p(Year)$ model in the usual way.

```
...
# Create design matrix for detection probabilities
covar.p <- cbind(Site, Year,
        model.matrix( ~as.factor(Year), data=obs.covar))
...
```

Single Species; Multi-Season - NSO - *JAGS*

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ parameter estimates.

```
> # Estimate of initial occupancy
                      mean          sd
psi[1,1]         0.6261110 0.06576700

> # Estimate of  local colonization probability for each ur
                      mean          sd
gamma[1,1]       0.1779443 0.04172938
```

Single Species; Multi-Season - NSO - *JAGS*

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ parameter estimates.

```
> # Estimate of  local extinction probability for each unit
                         mean          sd
epsilon[1,1]      0.1407420 0.03207532

> # Estimate of probability of detection at each time point
                    mean          sd
p.detect[1]    0.5916268 0.03924411
...
```

Single Species; Multi-Season - NSO - *JAGS*

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ derived parameter estimates of occupancy in later years

```
> # Derived parameters - estimated occupancy for each unit
                          mean          sd
psi[1,1]             0.6261110 0.06576700
psi[1,2]             0.6046207 0.05023741
psi[1,3]             0.5899712 0.04990449
psi[1,4]             0.5799238 0.05476636
psi[1,5]             0.5729918 0.05995964
```

Model $\psi(1997), \gamma(*), \epsilon(*), p(YEAR)$ derived parameter estimates of population growth

```
                        mean         sd
lambda[1,1]        0.9691250 0.05157563
lambda[1,2]        0.9763284 0.03630422
lambda[1,3]        0.9824216 0.02589554
lambda[1,4]        0.9871826 0.01860532
lambda.prime[1,1] 0.9175314 0.13137925
lambda.prime[1,2] 0.9441482 0.08693480
lambda.prime[1,3] 0.9615056 0.05926650
lambda.prime[1,4] 0.9732389 0.04113874
```

Fit the $\psi(1997), p(\textit{year}), \epsilon(\textit{year}), \gamma(\textit{year})$ model.

Single Species; Multi-Season - NSO - *JAGS*

What model would represent NO CHANGE IN OCCUPANCY in individual sites over the multiple seasons?

What model would represent NO CHANGE IN OCCUPANCY in individual sites over the multiple seasons, i.e. convert this to an ‘equivalent single season model=?

$\gamma_y = 0$ and ϵ_y=0 for all years.

You would specify HIGHLY informative priors that the $\beta_{epsilon} = 0$.

Single Species; Multi-Season - NSO - *JAGS*

Very complex to do model comparison and model averaging in Bayesian methods for mere mortals.
See me for details.

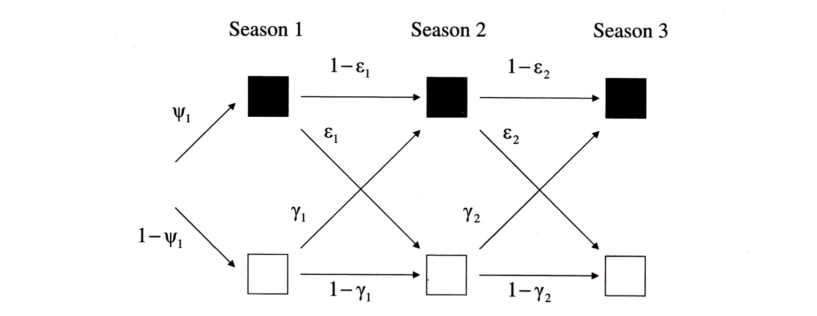
What model would represent RANDOM occupancy over seasons, i.e. no site fidelity between seasons?

A RANDOM occupancy model says that occupancy in each season is a random process with no regard to sites being occupied or not occupied in previous seasons. For example, migrating birds return each year to select nesting sites but the process each year is independent of previous years. Site could be occupied for multiple years in a row, but this the result of random chance rather than any site fidelty.

Single Species; Multi-Season - NSO - *JAGS*

A RANDOM occupancy model implies that an occupied site in season y has the same chance of being occupied in year $y+1$ (i.e. $(1-\epsilon_y)$ as does an unoccupied site in season y being occupied in year $y+1$ (i.e. γ_y).

Or ... RANDOM occupancy $\rightarrow \gamma_y = (1-\epsilon_y)$.



A RANDOM occupancy model is fit using *type=do.4*. Now the parameters are ψ (now for each season), and *p* with $\gamma = 1 - \epsilon$ enforced internally depending on estimates of ψ for each year.

Not currently implemented in *JAGS*, but see me if you are interested (not difficult).
You can always fit a SSMS model like in *unmarked*.

Single Species; Multi-Season - NSO - *JAGS*

What model would represent a population in equilibrium in occupancy?

What model would represent a population in equilibrium in occupancy? $\psi_{y+1} = \psi_{y} \rightarrow \psi_{EQ} = \frac{\gamma}{\gamma+\epsilon}$

Not currently implemented in *JAGS*.

Conclusion:

- Bayesian methods make it easy to find posterior beliefs, e.g. what is *Pr(trend ¿0)*.
- Very flexible but requires discipline to implement and debug (!)
- Model selection and averaging not for mere mortals.
- Model assessment (goodness of fit) possible but not implemented here.

Single Species; Multi-season - Covariates - *unmarked*

The second and third parameterizations of *PRESENCE* and *MARK* are not available in *unmarked*.
Random occupancy model not available directly in *unmarked*, but refer to web link in previous slides for work around.

The second and third parameterizations of *PRESENCE* and *MARK* are not available in *JAGS* but are readily implemented (see me for details).

Random occupancy model not available directly in *JAGS*, but contact me for details on work around.