Design and Analysis of Occupancy Studies
Part 4

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Multiple-States Single-Season Occupancy Studies

Multiple States; Single-Season

Objectives:

- Estimate "gross" occupancy rates.
- Partition occupancy into a number of hierarchical states (e.g. non-breeders vs. breeders)

Multiple States; Single-Season - Sampling Protocol

Sampling Protocol:

- Landscape divided (artificially or naturally) into S patches or cells or SITES.
- Select $s << S$ sites at random (all sites have equal probability of selection).
- Visit each site K times .
- Record detection or not detection of species in site i in survey k.
- If occupancy detected, classify (with detection error) state of occupancy (e.g. adults seen, vs. adults seen with young.) [Most software can only deal with 2 states.]

Note:

- Two levels of false negatives, i.e. not detecting a species does not imply that site was unoccupied, and given that see an animal, no detection of breeding does not imply that breeding did not take place.
- States can be classified in a hierarchy.

Multiple States; Single-Season - Dynamics

Data: Detection/Encounter histories with ., 0, 1, and 2.

- 1021 Confirmed breeding status in survey 3.
- 0101 Occupied, but breeding status is unknown.
- 0000 Unsure if unoccupied or occupied.

Parameters:

- ψ_i^1 Prob(site i is occupied regardless of state).
- ψ_i^2 Prob(site i in state 2 (typically breeders) given that site is occupied.
- p_{ij}^1 Prob(detection in site i in survey j given that in state 1, non-breeder).
- p_{ij}^2 Prob(detection in site i in survey j given that in state 2, breeder).
- δ_{ij} Prob(identify as breeder (state 2) in site i in survey j given that site is occupied, in state 2, and species detected).

Then Prob(occupied in state 2) $= \psi^1\psi^2$.

Multiple States; Single-Season - Dynamics

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- ψ_i^1 Prob(site i is occupied regardless of state).
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Prob(1021) =

$$\psi_i^1 \psi_i^2 p_{i1}^2 (1 - \delta_{i1})(1 - p_{i2}^2) p_{i3}^2 \delta_{i3} p_{i4}^2 (1 - \delta_{i4})$$

Multiple States; Single-Season - Dynamics

Parameters:

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- p_{ij}^1 Prob(detection in site i in survey j given that in state 1, non-breeder).
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- δ_{ij} Prob(identify as breeder (state 2) in site i in survey j given that site is occupied, in state 2, and species detected).

Prob(0101) =

$$\psi_i^1(1-\psi_i^2)\left[(1-p_{i1}^1)p_{i2}^1(1-p_{i3}^1)p_{i4}^1\right]+$$
$$\psi_i^1\psi_i^2\left[(1-p_{i1}^2)p_{i2}^2(1-\delta_{i2})(1-p_{i3}^2)p_{i4}^2(1-\delta_{i4})\right]$$

Multiple States; Single-Season - Dynamics

Parameters:

- ψ_i^1 Prob(site i is occupied regardless of state).
- ψ_i^2 Prob(site i in state 2 (typically breeders) given that site is occupied.
- p_{ij}^1 Prob(detection in site i in survey j given that in state 1, non-breeder).
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Prob(0000) $=$ Long and messy expression!

Multiple States; Single-Season - Assumptions

1. Occupancy STATE of sites is constant during season (closure).
2. Probability of occupancy in each state (ψ^1, ψ^2) is equal across all sites (homogeneity) unless modified by covariates.
3. Probability of detection (p^1, p^2) given occupancy is equal across all sites (homogeneity) unless modified by covaraites.
4. Detection in each survey of a site is independent of those on other surveys
5. Detections at each site are independent
6. No false positives.
7. NEW Reproduction has occurred at start of "season" and evidence of reproduction continues for entire season (i.e. reproduction doesn't start in survey 5 or 10, and you must know that breeding took place even after chicks fledged).
8. NEW Evidence of states independent across surveys. Not valid to return to a new nest once chick found in subsequent surveys as no longer independent. Truncate record at confirmed reproduction and fill remainder with missing values.

Multiple States; Single-Season - Biological Hypotheses

1. Do different habitats have different occupancy in state 1 and state 2?
2. Is detection in state 1 and state 2 the same?
3. Sink and Source habitat identification.

Multiple States; Single-Season - Example

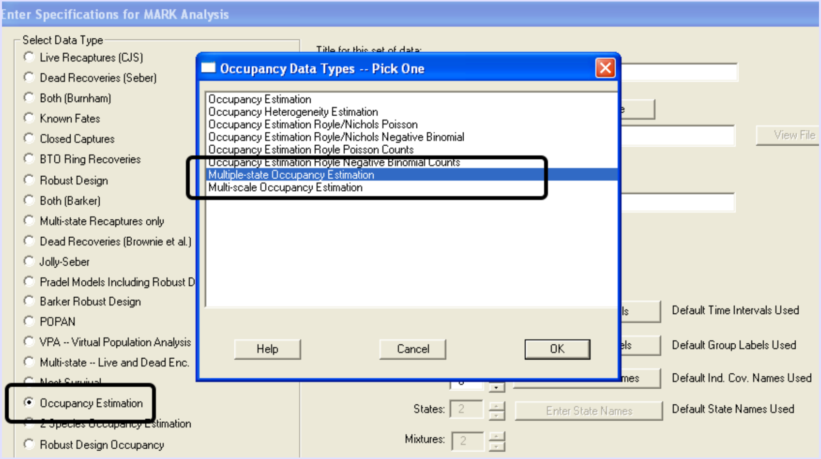
Nichols et al (2007) Ecology 88:1395-1400 looked at breeding and non-breeding California Spotted Owls in $s = 54$ sites over $k = 5$ surveys.

Hand-fed mice confirmed occupancy; breeding status only confirmed when owl took mouse to nest.

- . = site not visited.
- 0 = owl not detected.
- 1 = owl detected, but no detection of young.
- 2 = owl detected, along with evidence of young.

Using MARK

Locate the data file, and start MARK in the usual fashion:



Multiple States; Single-Season - Example

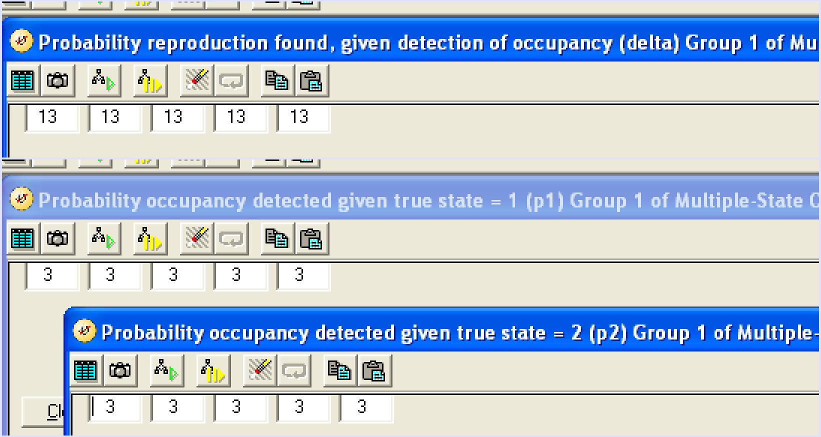
Biological models:

- $p_{it}^{s} = p$, or $p_{it}^{s} = p^{s}$ or $p_{it}^{s} = p_t$ or $p_{it}^{s} = p_{it}^{s}$
- $\delta_{it} = \delta$ or $\delta_{it} = \delta_{it}$ or $\delta_{it} = \delta^{12}$ *or* δ^{345} based on it being "hard" to detect reproduction early and "easier" to detect reproduction later in season.

Start by fitting the the model $\psi^1, \psi^2, p(*, *), \delta(*)$

Multiple States; Single-Season - Example

Model $\psi^1, \psi^2, p(*, *), \delta(*)$



Multiple States; Single-Season - Example

Model $\psi^1, \psi^2, p(*,*), \delta(*)$ results. Interpret these.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{psi1 psi2 p(*,*) delta(*)}	336.1948	0.0000	1.00000	1.0000	4	0.0000	327.3785

California Spotted Owl - Multistate Model

Real Function Parameters of {psi1 psi2 p(*,*) delta(*)}

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:Psi1	0.9752276	0.0377781	0.6474845	0.9988162
2:Psi2	0.5542889	0.1124421	0.3375910	0.7521436
3:p1	0.7448009	0.0363100	0.6674445	0.8093044
4:Delta	0.4229782	0.0843411	0.2713339	0.5906726

California Spotted Owl - Multistate Model

Estimates of Derived Parameters

Estimates of Psi1*Psi2 {psi1 psi2 p(*,*) delta(*)}

Group	Psi1*Psi2-hat	Standard Error	95% Confidence Interval Lower	Upper
1	0.5405578	0.1116381	0.3277341	0.7395495

Multiple States; Single-Season - Example

Other models to fit:

- $\psi^1, \psi^2, p(*, t), \delta(*)$
- $\psi^1, \psi^2, p(s, *), \delta(*)$
- $\psi^1, \psi^2, p(s, t), \delta(*)$
- $\psi^1, \psi^2, p(*, *), \delta(12, 345)$
- $\psi^1, \psi^2, p(*, t), \delta(12, 345)$

Results:

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{psi1 psi2 p(*,t) delta(12,345)}	283.4459	0.0000	0.95457	1.0000	9	0.0000	261.3550
{psi1 psi2 p(*,*) delta(12,345)}	289.5992	6.1533	0.04402	0.0461	5	0.0000	278.3492
{psi1 psi2 p(s,t) delta(12,345)}	296.4865	13.0406	0.00141	0.0015	14	0.0000	257.7172
{psi1 psi2 p(*,t) delta(*)}	329.5843	46.1384	0.00000	0.0000	8	0.0000	310.3843
{psi1 psi2 p(*,*) delta(*)}	336.1948	52.7489	0.00000	0.0000	4	0.0000	327.3785
{psi1 psi2 p(s,*) delta(*)}	338.6127	55.1668	0.00000	0.0000	5	0.0000	327.3627
{psi1 psi2 p(*,t) delta(*)}	341.3668	57.9209	0.00000	0.0000	13	0.0000	306.2668

Multiple States; Single-Season - Example

Results:

California Spotted Owl - MultiState Model

Real Function Parameters of {psi1 psi2 p(*,t) delta(12,345)}

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:Psi1	0.9789489	0.0323620	0.6817037	0.9990106
2:Psi2	0.4495324	0.0801697	0.3020490	0.6064560
3:p1	0.5790117	0.0821281	0.4154070	0.7269281
4:p1	0.8237920	0.0677819	0.6518159	0.9211063
5:p1	0.9223752	0.0429091	0.7859100	0.9746595
6:p1	0.6970106	0.0771335	0.5292754	0.8247649
7:p1	0.6196330	0.1122511	0.3904316	0.8055704
8:Delta	0.2935477E-016	0.1555513E-008	-0.3048805E-008	0.3048805E-008
9:Delta	0.8683310	0.0729096	0.6539372	0.9583604

California Spotted Owl - MultiState Model

Estimates of Derived Parameters

Estimates of Psi1*Psi2 {psi1 psi2 p(*,t) delta(12,345)}

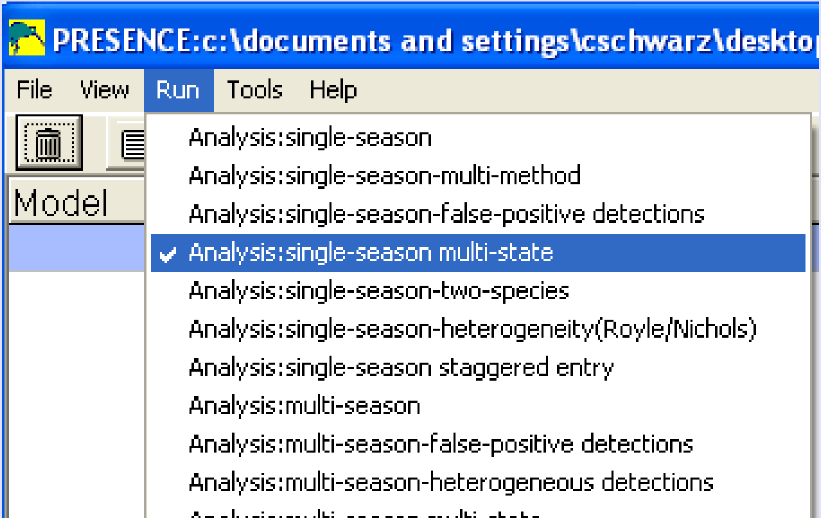
Group	Psi1*Psi2-hat	Standard Error	95% Confidence Interval Lower	Upper
1	0.4400692	0.0798189	0.2940524	0.5972503

Unfortunately, GOF and $\widehat{c}$ not yet implemented in MARK.

Multiple States; Single-Season - Example

Using PRESENCE

Locate the data file, start PRESENCE, and enter the data in the usual fashion:



Multiple States; Single-Season - Example

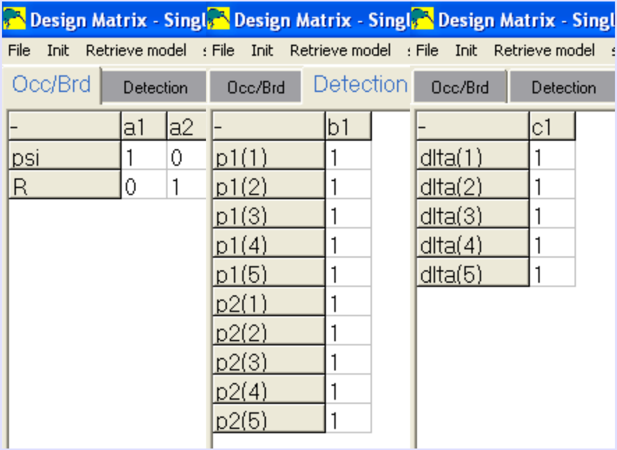
Biological models:

- $p^s_{it} = p$, or $p^s_{it} = p^s$ or $p^s_{it} = p_t$ or $p^s_{it} = p^s_{it}$
- $\delta_{it} = \delta$ or $\delta_{it} = \delta_{it}$ or $\delta_{it} = \delta^{12}$ *or* δ^{345} based on it being "hard" to detect reproduction early and "easier" to detect reproduction later in season.

Start by fiting the the model $\psi^1, \psi^2, p(*, *), \delta(*)$.
Note: PRESENCE uses R for ψ^2.

Multiple States; Single-Season - Example

Model $\psi^1, \psi^2, p(*, *), \delta(*)$



-	a1	a2
psi	1	0
R	0	1

-	b1
p1(1)	1
p1(2)	1
p1(3)	1
p1(4)	1
p1(5)	1
p2(1)	1
p2(2)	1
p2(3)	1
p2(4)	1
p2(5)	1

-	c1
dlta(1)	1
dlta(2)	1
dlta(3)	1
dlta(4)	1
dlta(5)	1

Multiple States; Single-Season - Example

Model $\psi^1, \psi^2, p(*,*), \delta(*)$ results. Interpret these.

```
=============================================================

   Individual Site estimates of <psi>
                    Site                   estimate  Std.err    95% conf. interval
psi                 1 site 1             :  0.9752   0.0378     0.6475 - 0.9988

   Individual Site estimates of <R>
                    Site                   estimate  Std.err    95% conf. interval
R                   1 site 1             :  0.5543   0.1124     0.3376 - 0.7521

   Individual Site estimates of <p1(1)>
                    Site                   estimate  Std.err    95% conf. interval
p1(1)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p1(2)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p1(3)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093 |
p1(4)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p1(5)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093

   Individual Site estimates of <p2(1)>
                    Site                   estimate  Std.err    95% conf. interval
p2(1)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p2(2)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p2(3)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p2(4)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093
p2(5)               1 site 1             :  0.7448   0.0363     0.6674 - 0.8093

   Individual Site estimates of <dlta(1)>
                    Site                   estimate  Std.err    95% conf. interval
dlta(1)             1 site 1             :  0.4230   0.0843     0.2713 - 0.5907
dlta(2)             1 site 1             :  0.4230   0.0843     0.2713 - 0.5907
dlta(3)             1 site 1             :  0.4230   0.0843     0.2713 - 0.5907
dlta(4)             1 site 1             :  0.4230   0.0843     0.2713 - 0.5907
dlta(5)             1 site 1             :  0.4230   0.0843     0.2713 - 0.5907
```

Multiple States; Single-Season - Example

Other models to fit:

- $\psi^1, \psi^2, p(*, t), \delta(*)$
- $\psi^1, \psi^2, p(s, *), \delta(*)$
- $\psi^1, \psi^2, p(s, t), \delta(*)$
- $\psi^1, \psi^2, p(*, *), \delta(12, 345)$
- $\psi^1, \psi^2, p(*, t), \delta(12, 345)$

Results:

Model	AIC	deltaAIC	AIC wgt	Model Likel	no.Par.	-2*LogLike
psi,R, p(*,t) delta(12,345)	279.36	0.00	0.9890	1.0000	9	261.36
psi,R, p(*,*) delta(12,345)	288.35	8.99	0.0110	0.0112	5	278.35
psi,R, p(*,t) delta(*)	326.38	47.02	0.0000	0.0000	8	310.38
psi,R, p(s,t) delta(*)	332.27	52.91	0.0000	0.0000	13	306.27
psi,R, p(*,*) delta(*)	335.38	56.02	0.0000	0.0000	4	327.38
psi,R, p(s,*) delta(*)	337.36	58.00	0.0000	0.0000	5	327.36

Multiple States; Single-Season - Example

Results:

```
=============================================================

   Individual Site estimates of <psi>
                 Site                  estimate  Std.err    95% conf. interval
psi              1 site 1           :  0.9789    0.0324     0.6817 - 0.9990

   Individual Site estimates of <R>
                 Site                  estimate  Std.err    95% conf. interval
R                1 site 1           :  0.4495    0.0802     0.3020 - 0.6065

   Individual Site estimates of <p1(1)>
                 Site                  estimate  Std.err    95% conf. interval
p1(1)            1 site 1           :  0.5790    0.0821     0.4154 - 0.7269
p1(2)            1 site 1           :  0.8238    0.0678     0.6518 - 0.9211
p1(3)            1 site 1           :  0.9224    0.0429     0.7859 - 0.9747
p1(4)            1 site 1           :  0.6970    0.0771     0.5293 - 0.8248
p1(5)            1 site 1           :  0.6196    0.1123     0.3904 - 0.8056

   Individual Site estimates of <p2(1)>
                 Site                  estimate  Std.err    95% conf. interval
p2(1)            1 site 1           :  0.5790    0.0821     0.4154 - 0.7269
p2(2)            1 site 1           :  0.8238    0.0678     0.6518 - 0.9211
p2(3)            1 site 1           :  0.9224    0.0429     0.7859 - 0.9747
p2(4)            1 site 1           :  0.6970    0.0771     0.5293 - 0.8248
p2(5)            1 site 1           :  0.6196    0.1123     0.3904 - 0.8056

   Individual Site estimates of <dlta(1)>
                 Site                  estimate  Std.err    95% conf. interval
dlta(1)          1 site 1           :  0.0000    0.0000     0.0000 - 1.0000
dlta(2)          1 site 1           :  0.0000    0.0000     0.0000 - 1.0000
dlta(3)          1 site 1           :  0.8683    0.0729     0.6539 - 0.9584
dlta(4)          1 site 1           :  0.8683    0.0729     0.6539 - 0.9584
dlta(5)          1 site 1           :  0.8683    0.0729     0.6539 - 0.9584
```

Multiple-States Single-Season Occupancy Studies

Using *RPresence* software.

Multiple States; Single-Season

Objectives:

- Estimate "gross" occupancy rates.
- Partition occupancy into a number of hierarchical states (e.g. non-breeders vs. breeders)

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- Landscape divided (artificially or naturally) into S patches or cells or SITES.
- Select $s << S$ sites at random (all sites have equal probability of selection).
- Visit each site K times .
- Record detection or not detection of species in site i in survey k.
- If occupancy detected, classify (with detection error) state of occupancy (e.g. adults seen, vs. adults seen with young.) [Most software can only deal with 2 states.]

Note:

- Two levels of false negatives, i.e. not detecting a species does not imply that site was unoccupied, and given that see an animal, no detection of breeding does not imply that breeding did not take place.
- States can be classified in a hierarchy.

Multiple States; Single-Season - Dynamics

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- 1021 Confirmed breeding status in survey 3.
- 0101 Occupied, but breeding status is unknown.
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- δ_{ij} Prob(identify as breeder (state 2) in site i in survey j given that site is occupied, in state 2, and species detected).

Then Prob(occupied in state 2) $= \psi r$.

Multiple States; Single-Season - Dynamics

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- δ_{ij} Prob(identify as breeder (state 2) in site i in survey j given that site is occupied, in state 2, and species detected).

Prob(1021) $=$

$$\psi_i r_i p_{i1}^2(1-\delta_{i1})(1-p_{i2}^2)p_{i3}^2\delta_{i3}p_{i4}^2(1-\delta_{i4})$$

Multiple States; Single-Season - Dynamics

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- δ_{ij} Prob(identify as breeder (state 2) in site i in survey j given that site is occupied, in state 2, and species detected).

Prob(0101) =

$$\psi_i(1-r_i)\left[(1-p_{i1}^1)p_{i2}^1(1-p_{i3}^1)p_{i4}^1\right]+$$

$$\psi_i r_i\left[(1-p_{i1}^2)p_{i2}^2(1-\delta_{i2})(1-p_{i3}^2)p_{i4}^2(1-\delta_{i4})\right]$$

Multiple States; Single-Season - Dynamics

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Prob(0000) $=$ Long and messy expression!

Multiple States; Single-Season - Assumptions

1. Occupancy STATE of sites is constant during season (closure).
2. Probability of occupancy in each state (ψ, r) is equal across all sites (homogeneity) unless modified by covariates.
3. Probability of detection (p^1, p^2) given occupancy is equal across all sites (homogeneity) unless modified by covaraites.
4. Detection in each survey of a site is independent of those on other surveys
5. Detections at each site are independent
6. No false positives.
7. NEW Reproduction has occurred at start of "season" and evidence of reproduction continues for entire season (i.e. reproduction doesn't start in survey 5 or 10, and you must know that breeding took place even after chicks fledged).
8. NEW Evidence of states independent across surveys. Not valid to return to a new nest once chick found in subsequent surveys as no longer independent. Truncate record at confirmed reproduction and fill remainder with missing values.

Multiple States; Single-Season - Biological Hypotheses

1. Do different habitats have different occupancy in state 1 and state 2?
2. Is detection in state 1 and state 2 the same?
3. Sink and Source habitat identification.

Multiple States; Single-Season - Example - *RPresence*

Nichols et al (2007) Ecology 88:1395-1400 looked at breeding and non-breeding California Spotted Owls in $s = 54$ sites over $k = 5$ surveys.

Hand-fed mice confirmed occupancy; breeding status only confirmed when owl took mouse to nest.

- . = site not visited.
- 0 = owl not detected.
- 1 = owl detected, but no detection of young.
- 2 = owl detected, along with evidence of young.

Sites selected based on assumed occupancy so ψ is not relevant. Visits divided in two periods (early (visits 1,2), and late (visits 3,4,5).

Using *RPresence*

Read in the history data

```
occ.data <- readxl::read_excel("CalSpottedOwl.xls",
                                sheet="RawData",
                                skip=10, na='.')
head(occ.data)

input.history <- occ.data[,-1] #drop first column

Nsites <- nrow(input.history)
Nvisits<- ncol(input.history)
```

Multiple States; Single-Season - Example - *RPresence*

Define the site-time covariates. These are in visit major order.

```
period <- data.frame(
      Site=rep(1:Nsites, Nvisits),
      Visit=rep(1:Nvisits, each=Nsites),
      Per  =rep(c("E","E","L","L","L"), each=Nsites))
```

Create the **.pao* object

```
owl.pao <- createPao(input.history,
                     survcov=period,
                      title="owl multi state single season'
summary(owl.pao)
```

```
Naive occ=0.8703704
naiveR   =0.3518519
      nunits      nsurveys      nseasons
        "54"           "5"           "1"
nsurveyseason      nmethods      nunitcov
         "5"           "1"           "1"
    nsurvcov
         "4"
unit covariates  : TEMP
survey covariates: SURVEY Site Visit Per
```

Notice naive estimates of occupancy.
Notice strange number of unit covariates?

Multiple States; Single-Season - Example - *RPresence*

Biological models:

- $p^s_{it} = p$, or $p^s_{it} = p^s$ or $p^s_{it} = p_t$ or $p^s_{it} = p^s_{it}$
- $\delta_{it} = \delta$ or $\delta_{it} = \delta_{it}$ or $\delta_{it} = \delta^{12}$ *or* δ^{345} based on it being "hard" to detect reproduction early and "easier" to detect reproduction later in season.

Start by fitting the the model $\psi, r, p1(*), p2(*), \delta(*)$

Multiple States; Single-Season - Example - *RPresence*

Model $\psi, r, p1(*) = p2(*), \delta(*)$

```
mod1 <- occMod(model=list(
    psi~1, # occupancy regardless of state
    r~1,   # occupancy in state 2 | occupied
    p~1,   # detection in state i
    delta~1),# identified as state 2 if detected (and in s
    data=owl.pao,
    type="do.ms.2")
summary(mod1)
```

```
Model name=psi()r()p()delta()
AIC=335.3784
-2*log-likelihood=327.3784
num. par=4
```

What are the parameters?

Multiple States; Single-Season - Example - *RPresence*

Model $\psi, r, p1(*) = p2(*), \delta(*)$

```
> mod1$real$psi[1,] # prob site is occupied
         est     se  lower  upper
unit1 0.9752 0.0378 0.6475 0.9988

> mod1$real$r[1,]  # prob in state 2 | occupied
         est     se  lower  upper
unit1 0.5543 0.1124 0.3376 0.7521
```

ψ is not of interest (see previous) but compare to naive estimate.
r estimates proportion of breeders - compared to naive estimate.

Multiple States; Single-Season - Example - *RPresence*

Model $\psi, r, p1(*) = p2(*), \delta(*)$

```
                est      se   lower   upper
unit1_1-1 0.7448 0.0363 0.6674 0.8093
unit1_1-2 0.7448 0.0363 0.6674 0.8093
...
> mod1$real$p2[seq(1,by=Nsites, length.out=Nvisits),]  # pr
                est      se   lower   upper
unit1_1-1 0.7448 0.0363 0.6674 0.8093
unit1_1-2 0.7448 0.0363 0.6674 0.8093
...
> mod1$real$delta[seq(1,by=Nsites, length.out=Nvisits),] #
               est      se   lower   upper
unit1_1-1 0.423 0.0843 0.2713 0.5907
unit1_1-2 0.423 0.0843 0.2713 0.5907
...
```

Less than 50% chance of identifying a breeding pair if actually a breeding pair!

Multiple States; Single-Season - Example - *RPresence*

Other models to fit:

- $\psi, r, p1(t) = p2(t), \delta(*)$
- $\psi, r, p1(*), p2(*), \delta(*)$
- $\psi, r, p1(*) = p2(*), \delta(Per)$
- $\psi, r, p1(t) = p2(t), \delta(Per)$
- $\psi, r, p1(*), p2(*), \delta(Per)$

What do these models mean. Check the output to confirm.
Caution with model that involve $\delta(Per)$ as the detection probability in period 1 is 0 which causes numerical problems.

Multiple States; Single-Season - Example - *RPresence*

AICc table:

	Model	DAIC	wgt	npar	neg2ll	war
1	psi()r()p(SURVEY)delta(Per)	0.00	0.9848	9	261.36	
2	psi()r()p()delta(Per)	8.99	0.0110	5	278.35	
3	psi()r()p(STATE)delta(Per)	10.88	0.0043	6	278.24	
4	psi()r()p(SURVEY)delta()	47.03	0.0000	8	310.38	
5	psi()r()p()delta()	56.02	0.0000	4	327.38	
6	psi()r()p(STATE)delta()	58.01	0.0000	5	327.36	

Multiple States; Single-Season - Example - *RPresence*

Model averaged estimates

```
> RPresence::modAvg(results, param="psi")[1,]
            est         se lower_0.95 upper_0.95
unit1 0.9788445 0.03249207   0.681173   0.999003

> RPresence::modAvg(results, param="r")  [1,]
            est         se lower_0.95 upper_0.95
```

ψ not useful (why?).
Interpret estimate of r.

Multiple States; Single-Season - Example - *RPresence*

Model averaged estimates

```
> RPresence::modAvg(results, param="p1")[seq(1,by=Nsites, l
                est          se lower_0.95 upper_0.95
unit1_1-1 0.5814721 0.08402199  0.4138997  0.7321398
...
> RPresence::modAvg(results, param="p2")[seq(1,by=Nsites, l
                est          se lower_0.95 upper_0.95
unit1_1-1 0.5815911 0.08426813  0.4135243  0.7326347
...
> RPresence::modAvg(results, param="delta")[seq(1,by=Nsites
                   est         se lower_0.95 upper_0.95
unit1_1-1 2.593953e-11        NaN        NaN        NaN
unit1_1-2 2.593953e-11        NaN        NaN        NaN
unit1_1-3 8.683107e-01 0.07269637  0.6547659  0.9581997
unit1_1-4 8.683107e-01 0.07269637  0.6547659  0.9581997
unit1_1-5 8.683107e-01 0.07269637  0.6547659  0.9581997
```

Interpret estimate of δ.

Multiple States; Single-Season - Example - *RPresence*

Unfortunately, GOF and $\widehat{c}$ not yet implemented in *RPresence* but you could do a bootstrap after defining your appropriate statistic.

Multiple States; Single-Season - Exercise

Coosa bass collected via electrofishing from four 50-80 m sections in streams at 54 sites in the Upper Coosa River basin. The objective was to evaluate the effect of streamflow variability on Coosa bass reproduction. States are:

- species not detected (state = 0),
- adult detected (state = 1),
- YOY present (state = 2).

There are 2 covariates stream link magnitude (standardized), and CV of stream flow during summer.

Multiple States; Single-Season - Exercise

Models to fit:

- $\psi^1, \psi^2, p(*,*), \delta(*)$
- $\psi^1(L), \psi^2(L), p(*,*)(L), \delta(*)(L)$, i.e. as a function of length.
- $\psi^1(CV), \psi^2(CV), p(*,*)(CV), \delta(*)(CV)$, i.e. as a function of variation in flow

Hints:

- Does "time" have a meaning here?
- Don't forget that a logistic regressions has an intercept and a slope.

Multiple States; Single-Season - Exercise

PRESENCE results:

Model	AIC	deltaAIC	AIC wgt	Model Likel	no.Par.	-2*LogLike
psi,R, p1(*)=p2(*)(L) ,deta(*)(L)	360.74	0.00	0.9999	1.0000	8	344.74
psi,R, p1(*)=p2(*)(CV) ,deta(*)(CV)	380.02	19.28	0.0001	0.0001	8	364.02
psi,R, p1(*)=,p2(*), delta(*)	389.20	28.46	0.0000	0.0000	4	381.20

Multiple States; Single-Season - Exercise

MARK results:

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{psi1(L), psi2(L) p(*,*)(L) delta(*)(L)}	363.9405	0.0000	0.99993	1.0000	8	344.7405	344.7405
{psi1(CV), psi2(CV) p(*,*)(CV) delta(*)(CV)}	383.2208	19.2803	0.00007	0.0001	8	364.0208	364.0208
{psi1, psi2 p(*,*) delta(*)}	390.0119	26.0714	0.00000	0.0000	4	381.1956	381.1956

Multiple States; Single-Season - Exercise

MARK results:

Coose Bass

LOGIT Link Function Parameters of {psi1(L), psi2(L) p(*,*)(L) delta(*)(L)}

Parameter	Beta	Standard Error	95% Confidence Interval Lower	Upper
1:	3.7267939	1.4143066	0.9547530	6.4988349
2:	3.5339919	1.2414517	1.1007466	5.9672372
3:	1.4197249	0.9709173	-0.4832731	3.3227228
4:	-0.5373002	0.7437811	-1.9951112	0.9205108
5:	1.5582874	0.2434488	1.0811277	2.0354470
6:	-0.2513000	0.2129819	-0.6687446	0.1661446
7:	-0.5722787	0.3185632	-1.1966626	0.0521052
8:	0.1457854	0.2874052	-0.4175289	0.7090997

Coose Bass

Real Function Parameters of {psi1(L), psi2(L) p(*,*)(L) delta(*)(L)}

Following estimates based on unstandardized individual covariate values:

Variable	Value
STDLINK	0.1146296
CVFLOW	1.4740741

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:Psi1	0.9842012	0.0240583	0.7501328	0.9992270
2:Psi2	0.7954563	0.1476977	0.3962592	0.9584072
3:p1	0.8219304	0.0336287	0.7463313	0.8786621
4:Delta	0.3645737	0.0711546	0.2391065	0.5116103

Multiple-State Single-season Summary

Multiple States; Single-Season - Summary

Similar to previous methods + :

- Key parameters are
  - $\psi^1 =$ prob of occupancy regardless of state 1 (non-breeder) or state 2 (breeder)
  - $\psi^2 =$ prob of state 2 (breeder) given that species present on site.
  - Must adjust for two types of false negative – non-detect of occupancy; non-detect of breeding if occupancy confirmed.
  - Planning studies will require much thought. Use GENPRES in a similar fashion as in previous examples.

EXTENSIONS:

  - Multiple seasons – colonization and extinction could depend on occupancy and breeding success.