Design and Analysis of Occupancy Studies
Part 3

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Multiple-Species Single-Season Occupancy Studies

Multiple Species; Single-Season

Objectives:

- Does occupancy of site by 1 species depend on presence/absence of other species?
- Does colonization and local extinction depend on presence/absence of other species
- Does detection of 1 species depend on presence/absence/detection of other species?
- Estimated # species on sites - species richness.
- Community similarity among sites.
- Species turn over rates.

Multiple Species; 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_y times in each of Y (years) seasons.
- Record detection or not detection of **two species** in site i in year y in visit k. [Most software can only deal with 2 species.]
- PRESENCE: Create a **Detection/Encounter History** for each **SPECIES** in each visited site
  e.g. 011 00 0110. [No blanks between season when input into programs.]. For s sites, you will have $2s$ detection/encounter histories.
- MARK: Create a detection/encounter history using 2 'digits' for each survey, with the first digit being ./0/1 not searched/ not detected/ detected for species A, and the second digits similarly for species B.

Multiple Species; Single-Season - Dynamics

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

- If two species occupancy are INDEPENDENT, then $\psi^{AB} = \psi^{A}\psi^{B}$ and table simplifies.
- If two species "like" / "dislike" each other, then $\psi^{AB} > / < \psi^{A}\psi^{B}$.
- Look at margins of tables.

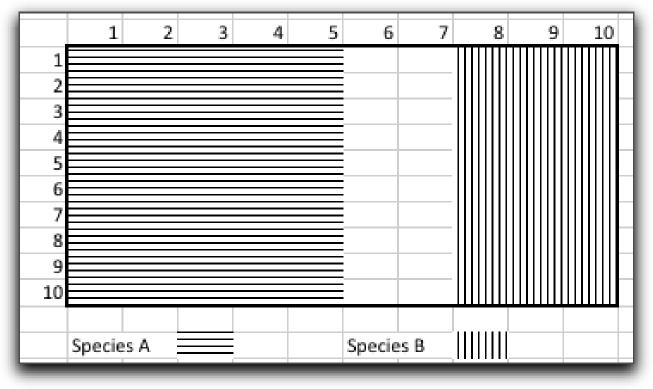
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0}{0.3 \times 0.5} = 0.$

Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

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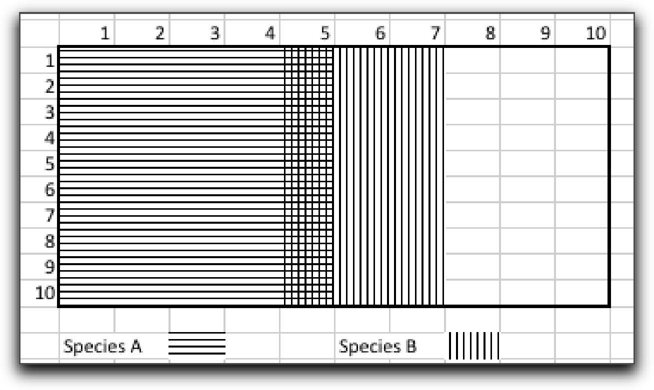


$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.1, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.1}{0.3 \times 0.5} =$ 0.67.

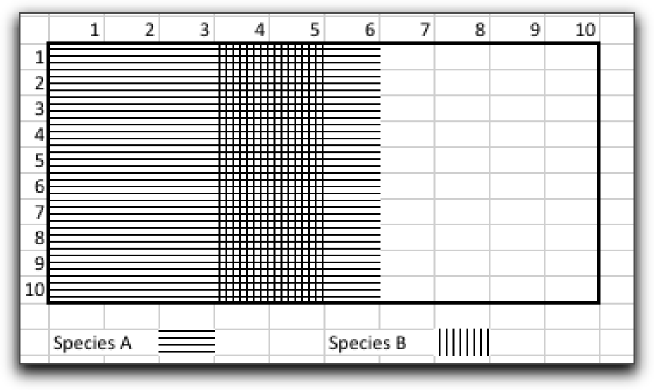
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.2, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.2}{0.3 \times 0.5} = 1.33.$

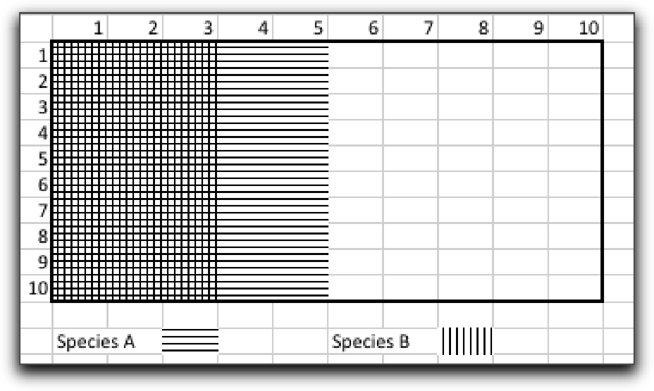
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.3, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.3}{0.3 \times 0.5} =$ 2.0.

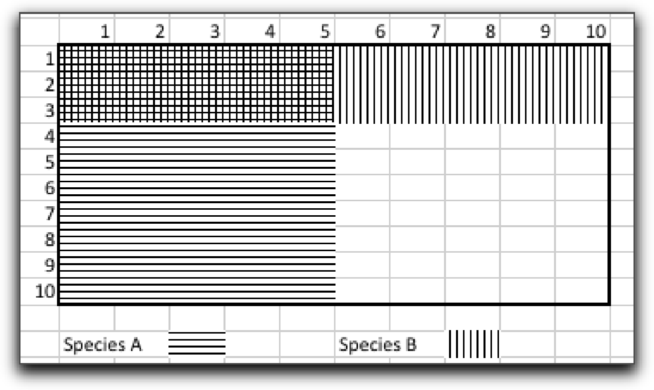
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.15, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.15}{0.3 \times 0.5} =$ 1.0.

Multiple Species; Single-Season - Dynamics

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^A
	Absent	p_s^B	0

r_s^{AB} = prob of detecting BOTH species when both are present.
r_s^{Ab} = prob of detecting A, but not B when both species are present.
r_s^{aB} = prob of not detecting A. detecting B, when both species are present.
$r_s^{ab} = 1 - r_s^{AB} - r_s^{Ab} - r_s^{aB}$ = prob of detecting neither species when both are present.

Multiple Species; Single-Season - Assumptions

1. Occupancy state of sites is constant during all single-season surveys FOR EACH SPECIES (closure).
2. Probability of occupancy (ψ) is equal across all sites (homogeneity).
3. Probability of detection (p) given occupancy is equal across all sites (homogeneity).
4. Detection of species in each survey of a site is independent of those on other surveys
5. Detection histories at each location are independent
6. No false positives.

Multiple Species; Single-Season - History Probabilities

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^{A}= 110; History^{B} = 000

$$\psi^{AB} r_1^{Ab} r_2^{Ab} r_3^{ab} + (\psi^{A} - \psi^{AB}) p_1^{A} p_2^{A} (1 - p_3^{A})$$

Multiple Species; Single-Season - History Probabilities

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A}-\psi^{AB}$
	Absent	$\psi^{B}-\psi^{AB}$	$1-\psi^{A}-\psi^{B}+\psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^{A}= 011; History^{B} = 010

$$\psi^{AB}(1-r_1^{AB}-r_1^{Ab}-r_1^{aB})r_2^{AB}r_3^{AB}$$

Multiple Species; Single-Season - History Probabilities

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A}-\psi^{AB}$
	Absent	$\psi^{B}-\psi^{AB}$	$1-\psi^{A}-\psi^{B}+\psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^{A}= 000; History^{B} =101

$\psi^{AB} r_1^{AB}(1-r_2^{AB}-r_2^{Ab}-r_2^{aB})r_3^{AB}+(\psi^{B}-\psi^{AB})p_1^{B}(1-p_2^{B})p_3^{B}$

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^{A}= 000; History^{B} =000

You don't want to write this out without using matrices!

Multiple Species; Single-Season - Alternate Parameterization

Problem: Previous parameterization in ψ leads to numerical difficulties when maximizing the likelihood.

Alternate parameterization starts by defining a *Species Interaction Factor (SIF)*

$$SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent
$SIF > 1 \rightarrow$ co-occur more frequently than if independent.

$$\psi^{AB} = \psi^{A}\psi^{B} SIF$$

Note that:

$$max(\psi^{A} + \psi^{B} - 1, 0 \leq \psi^{AB} \leq min(\psi^{A}, \psi^{B})$$

which leads to restrictions of *SIF*

Multiple Species; Single-Season - Alternate Parameterization

Problem: Previous parameterization in p leads to numerical difficulties.

Alternate parameterization starts by defining a *Species Interaction Factor* (SIF^r)

$$r^{AB} = r^A r^B SIF^r$$

where r^A = marginal prob of detection of Species A regardless of detection of Species B given that both are present.
$SIF^r = \delta$ in some papers.
$SIF < 1 \rightarrow$ detected less frequently than if independent .
$SIF > 1 \rightarrow$ detected more frequently than if independent.

There are similar restrictions on the range of the SIF^r.

Multiple Species; Single-Season - Biological Hypotheses

1. Level of co-occurance of species:
   - H: SIF^{ψ}=1. E.g. do spotted owls and barred owls use sites independently?
2. Detection of species when both are present.
   - H: SIF^{r}=1. E.g. does detection of a predator affect detection of a prey (given that both occupy site)?
3. Detection of species if other is present/absent?
   - H: $r^A = p^A$? H:$r^B = p^B$? E.g. Does detection of a spotted owl depend if barred owl occupies site?

Multiple Species; Single-Season - Example

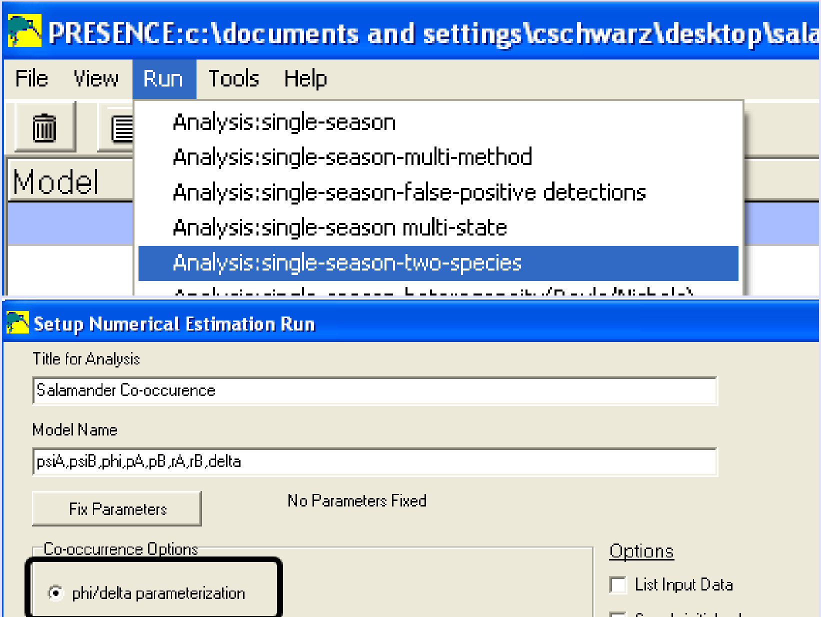
Co-occurence of Jordan's salamander (*Plethodon jordani*) (PJ) and members of *Plethodon glutinosus* (PG) in Great Smokey Mountains National Park (MacKenzie et al. 2004).

$s = 88$ sites; $K = 5$

Open the dataset in OccupancySampleData. Paste data into Presence.
You need to STACK the two species, i.e. "number of sites is set to $2 \times 88 = 176$.
Enter the covariate (elevation) twice and standardize it.

Multiple Species; Single-Season - Example

Select the single-season two-species model:



Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ - what does this mean?

File Init Retrieve model special

Occupancy | Detection

	a1	a2	a3
psiA	1	0	0
psiB	0	1	0
phi	0	0	1

Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ - what does this mean?
Notice the structure in the Design Matrix below:

File Init Retrieve model special

Occupancy | Detection

	b1	b2	b3	b4	b5
pA[1]	1	0	0	0	0
pA[2]	1	0	0	0	0
pA[3]	1	0	0	0	0
pA[4]	1	0	0	0	0
pA[5]	1	0	0	0	0
pB[1]	0	1	0	0	0
pB[2]	0	1	0	0	0
pB[3]	0	1	0	0	0
pB[4]	0	1	0	0	0
pB[5]	0	1	0	0	0

Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ Estimates of Occupancy

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

   Individual Site estimates of <psiA>
                  Site                  estimate  Std.err   95% conf. interval
psiA              1 site 1            :  0.5719    0.0572    0.4580 - 0.6787

   Individual Site estimates of <psiB>
                  Site                  estimate  Std.err   95% conf. interval
psiB              1 site 1            :  0.4815    0.0538    0.3784 - 0.5862

   Individual Site estimates of <phi>
                  Site                  estimate  Std.err   95% conf. interval
phi               1 site 1            :  0.6597    0.1135    0.4709 - 0.9243
```

Conclusion? Avoidance (why?)

Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ Estimates of Detection of PG/PJ when other species absent

PG

```
   Individual Site estimates of <pA[1]>
                Site                  estimate   Std.err    95% conf. interval
pA[1]           1 site 1            :  0.5396    0.0416     0.4576 - 0.6194
pA[2]           1 site 1            :  0.5396    0.0416     0.4576 - 0.6194
pA[3]           1 site 1            :  0.5396    0.0416     0.4576 - 0.6194
pA[4]           1 site 1            :  0.5396    0.0416     0.4576 - 0.6194
pA[5]           1 site 1            :  0.5396    0.0416     0.4576 - 0.6194
```

PJ

```
   Individual Site estimates of <pB[1]>
                Site                  estimate   Std.err    95% conf. interval
pB[1]           1 site 1            :  0.9027    0.0391     0.7949 - 0.9569
pB[2]           1 site 1            :  0.9027    0.0391     0.7949 - 0.9569
pB[3]           1 site 1            :  0.9027    0.0391     0.7949 - 0.9569
pB[4]           1 site 1            :  0.9027    0.0391     0.7949 - 0.9569
pB[5]           1 site 1            :  0.9027    0.0391     0.7949 - 0.9569
```

Conclusion? Different detection if the only species present.

Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ Estimates of Detection of PG/PJ when other species present

```
   Individual Site estimates of <rA[1]>
                    Site                     estimate   Std.err     95% conf. interval
rA[1]               1 site 1             :   0.4882     0.0766      0.3433 - 0.6350
rA[2]               1 site 1     PG      :   0.4882     0.0766      0.3433 - 0.6350
rA[3]               1 site 1             :   0.4882     0.0766      0.3433 - 0.6350
rA[4]               1 site 1             :   0.4882     0.0766      0.3433 - 0.6350
rA[5]               1 site 1             :   0.4882     0.0766      0.3433 - 0.6350

   Individual Site estimates of <rB[1]>
                    Site                     estimate   Std.err     95% conf. interval
rB[1]               1 site 1             :   0.5553     0.0632      0.4306 - 0.6734
rB[2]               1 site 1     PJ      :   0.5553     0.0632      0.4306 - 0.6734
rB[3]               1 site 1             :   0.5553     0.0632      0.4306 - 0.6734
rB[4]               1 site 1             :   0.5553     0.0632      0.4306 - 0.6734
rB[5]               1 site 1             :   0.5553     0.0632      0.4306 - 0.6734
```

Conclusion? Appear to have similar detection given both are present at a site.

Multiple Species; Single-Season - Example

Fit the $\psi(S), \phi(.), p(S), r(s), \delta(.)$ Estimates of Detection SIF

Individual Site estimates of <delta[1]>

	Site		estimate	Std.err	95% conf. interval
delta[1]	1 site 1	:	0.9029	0.1105	0.7104 - 1.1477
delta[2]	1 site 1	:	0.9029	0.1105	0.7104 - 1.1477
delta[3]	1 site 1	:	0.9029	0.1105	0.7104 - 1.1477
delta[4]	1 site 1	:	0.9029	0.1105	0.7104 - 1.1477
delta[5]	1 site 1	:	0.9029	0.1105	0.7104 - 1.1477

Conclusion? As before as $\delta \approx 1$.

Multiple Species; Single-Season - Example

Fit

- $\psi(S), \phi(.), p(S), r(A) = r(B), \delta(.)$.
- $\psi(S), \phi = 1, p(S), r(A) = r(B), \delta(.)$.
- $\psi(S), \phi(.), p(S), r(A) = r(B), \delta = 1$.

Fix the parameter in the Run box and delete relevant column from design matrix.

Model	AIC	deltaAIC	AIC wgt	Model Likel	no.Par.	-2*LogLike
psiA,psiB,phi,pA,pB,rA=rB,delta=1	749.25	0.00	0.4236	1.0000	6	737.25
psiA,psiB,phi,pA,pB,rA=rB,delta	750.33	1.08	0.2469	0.5827	7	736.33
psiA,psiB,phi,pA,pB,rA,rB,delta=1	750.62	1.37	0.2135	0.5041	7	736.62
psiA,psiB,phi,pA,pB,rA,rB,delta	751.87	2.62	0.1143	0.2698	8	735.87
psiA,psiB,phi=1,,pA,pB,rA,rB,delta	760.33	11.08	0.0017	0.0039	7	746.33
psiA,psiB,phi,pA=pB,rA,rB,delta	791.65	42.40	0.0000	0.0000	7	777.65

Overall conclusion? [Ignores effect of elevation.]

Multiple Species; Single-Season - Example

Fit

- $\psi(S), \phi(.), p(S), r(A) = r(B), \delta(.)$.
- $\psi(S), \phi = 1, p(S), r(A) = r(B), \delta(.)$.
- $\psi(S), \phi(.), p(S), r(A) = r(B), \delta = 1$.

Fix the parameter in the Run box and delete relevant column from design matrix.

Model	AIC	deltaAIC	AIC wgt	Model Likel	no.Par.	-2*LogLike
psiA,psiB,phi,pA,pB,rA=rB,delta=1	749.25	0.00	0.4236	1.0000	6	737.25
psiA,psiB,phi,pA,pB,rA=rB,delta	750.33	1.08	0.2469	0.5827	7	736.33
psiA,psiB,phi,pA,pB,rA,rB,delta=1	750.62	1.37	0.2135	0.5041	7	736.62
psiA,psiB,phi,pA,pB,rA,rB,delta	751.87	2.62	0.1143	0.2698	8	735.87
psiA,psiB,phi=1,,pA,pB,rA,rB,delta	760.33	11.08	0.0017	0.0039	7	746.33
psiA,psiB,phi,pA=pB,rA,rB,delta	791.65	42.40	0.0000	0.0000	7	777.65

Overall conclusion? [Ignores effect of elevation but see MacKenzie et al. 2006.]

Using MARK
yet another (but more natural IMHO)
parameterization

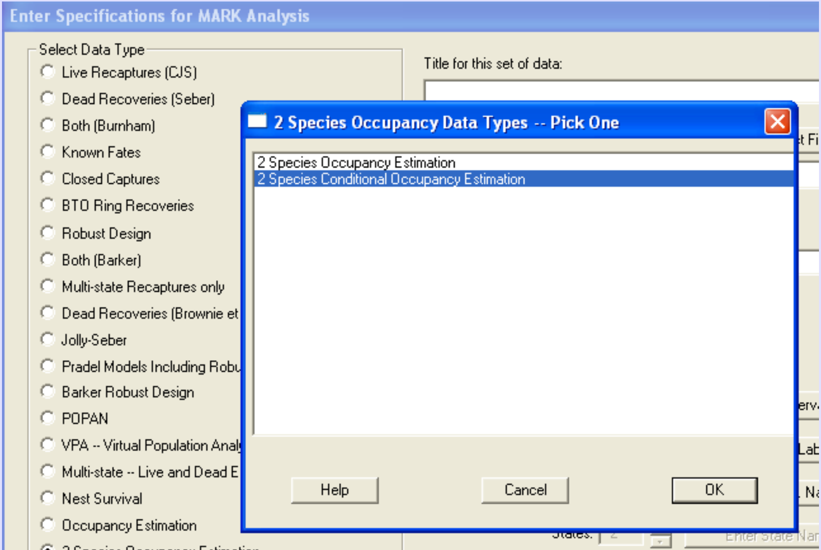
Format for data entry is different than PRESENCE:

$$h_1^A h_1^B h_2^A h_2^B h_3^A h_3^B h_4^A h_4^B \ldots$$

where the detection of each species occurs in two-digit pairs.

Multiple Species; Single-Season - Example

Launch MARK, import the data in the usual way. Choose the second parameterization. Don't forget to enter the 3 covariate and their names.



Multiple Species; Single-Season - Example

MARK parameterization - Occupancy dynamics.

- ψ^{A} occupancy of species A.
- $\psi^{B|A}$ occupancy of species B IF species A is present.
- $\psi^{B|a}$ occupancy of species B IF species A is absent.

If occupancy is independent ($SIF^{\psi} = 1$), then $\psi^{B|A} = \psi^{B|a}$.

Advantage of this parameterization is that all three parameters are free to vary between 0 and 1 without any odd restrictions.

$\psi^{B} = \psi^{B|A}\psi^{A} + \psi^{B|a}(1 - \psi^{A})$, $\psi^{A \text{ and } B} = \psi^{B|A}\psi^{A}$

A SIF^{ψ} can be derived.

Multiple Species; Single-Season - Example

MARK parameterization - Detection Dynamics - Species alone.

- p^A detection of species A if alone in the site.
- p^B detection of species B if alone in the site.

These parameters have no information about joint species dynamics.

Multiple Species; Single-Season - Example

MARK parameterization - Detection Dynamics - Both species present.

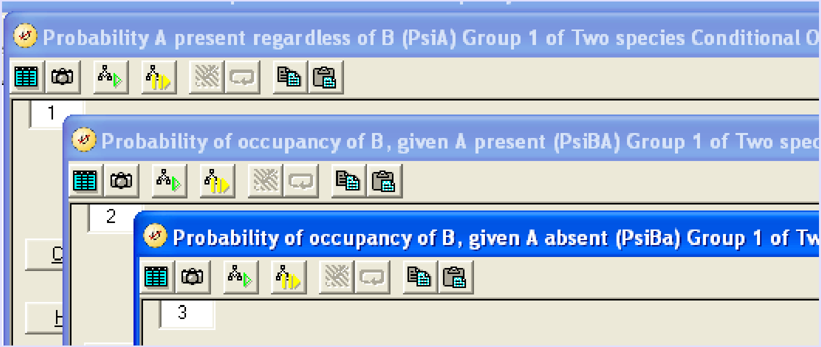
- r^A detection of species A if both species on site.
- $r^{B|A}$ detection of species B if species A detected when both species on site.
- $r^{B|a}$ detection of species B if species A not detected when both species on site.

If detection of species is independent ($SIF^r = 1$) then $r^{B|A} = r^{B|a}$.

Advantage of this parameterization is that all three parameters are free to vary between 0 and 1 without any odd restrictions.

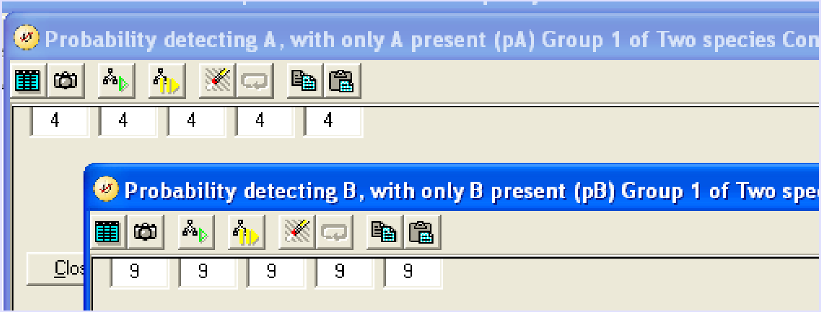
Multiple Species; Single-Season - Example

Fit the full model $\psi(A,B|A,B|a), p(A,B), r(A,B|A,B|a)$ - Occupancy



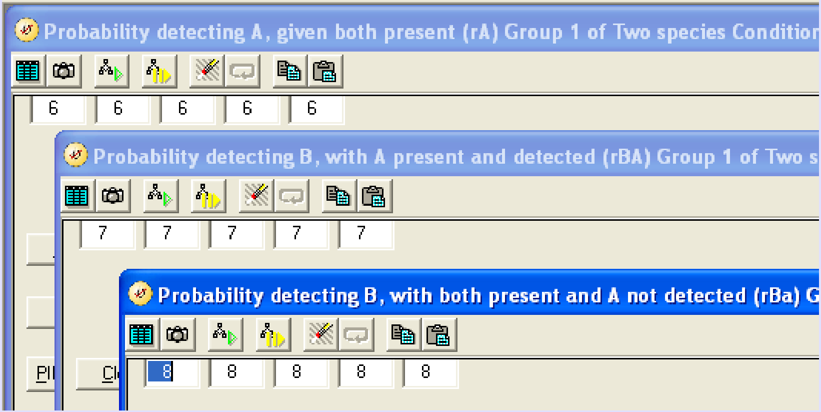
Multiple Species; Single-Season - Example

Fit the full model $\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$ - Detection when only one species present



Multiple Species; Single-Season - Example

Fit the full model $\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$ - Detection when both species present



Multiple Species; Single-Season - Example

$\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$ - Results - Occupancy

Salamander Co-occurrence

Real Function Parameters of {psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1:PsiA	0.5719191	0.0572320	0.4579761	0.6787130
2:PsiBA	0.3176853	0.0716540	0.1958653	0.4709030
3:PsiBa	0.7004620	0.0777920	0.5306616	0.8286653
4:pA	0.5395742	0.0416405	0.4576290	0.6194344
5:pB	0.9026760	0.0391113	0.7949028	0.9568886
6:rA	0.4881555	0.0766451	0.3433001	0.6350279
7:rBA	0.5013677	0.0847369	0.3409932	0.6614613
8:rBa	0.6066572	0.0919680	0.4201592	0.7665057

Salamander Co-occurrence

Estimates of Derived Parameters

Species Interaction Factors of {psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}

Group	SIF-hat	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1	0.6597213	0.1135058	0.4372499	0.8821927

Species B Occupancy of {psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}

Group	PsiB-hat	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1	0.4815447	0.0537889	0.3784493	0.5862358

Both Species Occupancy of {psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}

Group	PsiAB-hat	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1	0.1816903	0.0465427	0.1073117	0.2908262

$SIF^{\psi} = \frac{\psi^{A \text{ and } B}}{\psi^A \psi^B} = \frac{0.18}{0.57 \times 0.48}$ Conclusions?

Avoidance (look at PsiBA vs. PsiBa)

Multiple Species; Single-Season - Example

$\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$ - Results - Detection

Salamander Co-occurrence

Real Function Parameters of {psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:PsiA	0.5719191	0.0572320	0.4579761	0.6787130
2:PsiBA	0.3176853	0.0716540	0.1958653	0.4709030
3:PsiBa	0.7004620	0.0777920	0.5306616	0.8286653
4:pA	0.5395742	0.0416405	0.4576290	0.6194344
5:pB	0.9026760	0.0391113	0.7949028	0.9568886
6:rA	0.4881555	0.0766451	0.3433001	0.6350279
7:rBA	0.5013677	0.0847369	0.3409932	0.6614613
8:rBa	0.6066572	0.0919680	0.4201592	0.7665057

Conclusions?

- No interference in detection of A when other species present. Compare pA vs. rA.
- Interference in detection of B when other species present. Compare pB vs. (rBA and rBa).
- No influence in detection of B by detection of A when both species present. Compare rBA vs. rBa.

Multiple Species; Single-Season - Example

Fit

- $\psi(A, B|A, B|a), p(A, B), r(A, B|A = B|a)$.
- $\psi(A, B|A = B|a), p(A, B), r(A, B|A = B|a)$.
- $\psi(A, B|A, B|a), p(A, B), r(A = B|A = B|b)$.

Results Browser: Two species Conditional Occupancy Estimation

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{psi(A,Ba,BA) p(A,B) r(A,BA=Ba)}	752.0240	0.0000	0.67374	1.0000	7	736.6240	736.6240
{psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}	753.6893	1.6653	0.29301	0.4349	8	735.8665	735.8665
{psi(A,Ba=BA) p(A,B) r(A=BA=Ba)}	758.9769	6.9529	0.02083	0.0309	5	748.2452	748.2452
{psi(A,Ba=BA) p(A,B) r(A,BA=Ba)}	760.0107	7.9867	0.01242	0.0184	6	746.9737	746.9737

Overall conclusion? [Ignores effect of elevation but see MacKenzie et al. 2006.]

Multiple Species; Single-Season - Example

Add the (standardized) elevation covariate to the ψ, p, r terms using the design matrix. [Try first the ψ terms and then the other terms], [No need to check the standardized covariate term in the Run box]

Design Matrix Specification: Two species Conditional Occupancy Estimation

B1:	B2:	B3:	B4:	B5:	B6:	Parm	B7:	B8:	B9:	B10:
1	Elev	0	0	0	0	1:PsiA	0	0	0	0
0	0	1	Elev	0	0	2:PsiBA	0	0	0	0
0	0	0	0	1	Elev	3:PsiBa	0	0	0	0
0	0	0	0	0	0	4:pA	1	0	0	0
0	0	0	0	0	0	5:pB	0	1	0	0
0	0	0	0	0	0	6:rA	0	0	1	0
0	0	0	0	0	0	7:rBA	0	0	0	1

Multiple Species; Single-Season - Example

Design Matrix Specification: Two species Conditional Occupancy Estimation

B1:	B2:	B3:	B4:	B5:	B6:	B7:	Parm	B8:	B9:	B10:	B11:	B12:	B13:	B14:
1	Elev	0	0	0	0	0	1:PsiA	0	0	0	0	0	0	0
0	0	1	Elev	0	0	0	2:PsiBA	0	0	0	0	0	0	0
0	0	0	0	1	Elev	0	3:PsiBa	0	0	0	0	0	0	0
0	0	0	0	0	0	1	4:pA	Elev	0	0	0	0	0	0
0	0	0	0	0	0	0	5:pB	0	1	Elev	0	0	0	0
0	0	0	0	0	0	0	6:rA	0	0	0	1	Elev	0	0
0	0	0	0	0	0	0	7:rBA	0	0	0	0	0	1	Elev

Multiple Species; Single-Season - Example

Adding (standardized) elevation covariate results.

Results Browser: Two species Conditional Occupancy Estimation

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{psi(A(E),Ba(E),BA(E)) p(A(E),B(E)) r(A(E),BA(E)=Ba(E))}	644.6277	0.0000	1.00000	1.0000	14	610.8743	610.8743
{psi(A(E),Ba(E),BA(E)) p(A,B) r(A,BA=Ba)}	690.3285	45.7008	0.00000	0.0000	10	667.4714	667.4714
{psi(A,Ba,BA) p(A,B) r(A,BA=Ba)}	752.0240	107.3963	0.00000	0.0000	7	736.6240	736.6240
{psi(A,Ba,BA) p(A,B) r(A,BA,Ba)}	753.6893	109.0616	0.00000	0.0000	8	735.8665	735.8665
{psi(A,Ba=BA) p(A,B) r(A=BA=Ba)}	758.9769	114.3492	0.00000	0.0000	5	748.2452	748.2452
{psi(A,Ba=BA) p(A,B) r(A,BA=Ba)}	760.0107	115.3830	0.00000	0.0000	6	746.9737	746.9737

Adding (standardized) elevation covariate results - what is happening?

Salamander Co-occurrence

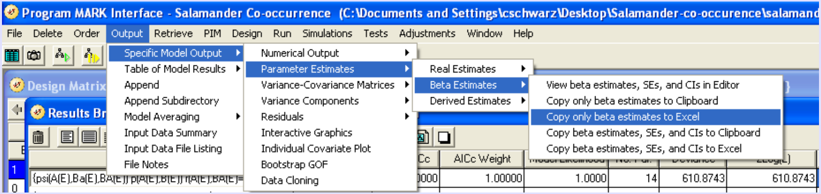
LOGIT Link Function Parameters of {psi(A(E),Ba(E),BA(E)) p(A(E),B(E)) r(A(E),BA(E)=Ba(E))}

Parameter		Beta	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1:	PSI A	0.7353874	0.3092140	0.1293279	1.3414470
2:		-3.5331199	3.6953651	-10.776036	3.7097959
3:	PSI BA	-0.1567177	0.4775495	-1.0927148	0.7792794
4:		15.164286	4.4846935	6.3742861	23.954285
5:	PSI Ba	3.9690554	3.6272168	-3.1402897	11.078401
6:		89.940177	68.233490	-43.797466	223.67782
7:		0.3309093	0.3203107	-0.2968997	0.9587183
8:		4.7862847	1.8422197	1.1755340	8.3970355
9:		1.6833185	0.5304986	0.6435412	2.7230958
10:		3.4736623	4.1863096	-4.7315046	11.678829
11:		1.2043112	0.4514325	0.3195034	2.0891190
12:		-19.745903	4.4428211	-28.453832	-11.037973
13:		-0.8320577	0.4181954	-1.6517207	-0.0123948
14:		15.291967	4.0352834	7.3828110	23.201122

Multiple Species; Single-Season - Example

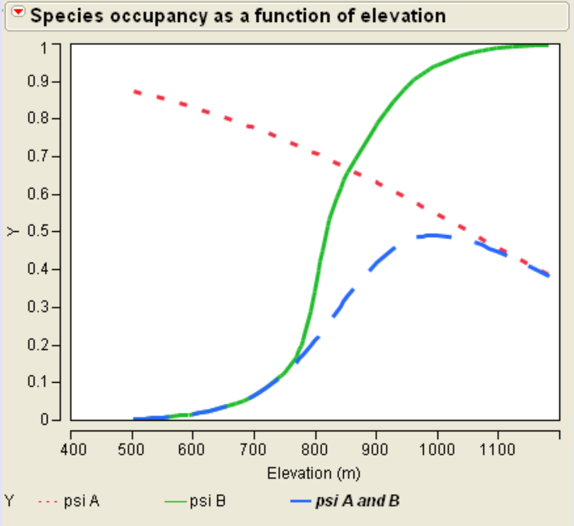
Adding (standardized) elevation covariate results - what is happening?

Export the regression functions (on the logit scale)



Generate a plot of the occupancy as a function of elevation (see original spreadsheet)

Multiple Species; Single-Season - Example



Conclusion? Species interaction may solely be a function of elevation.

Multiple Species; Single-Season - Study Design Issues

- VERY data hungry!
- Similar design issues as seen previously.
- NEW Length of Season
  - Sites must be closed over season.
  - "Co-occurrence" influenced by how "season" is defined.
- Similar concerns about "co-occurrence" at SITE level and size of size influences this.

Multiple Species; Single-Season - Exercise

Spotted owl vs. barred owl. Based on:

> *Bailey, L.L, Reid, J.A., Forsman, E.D., Nichols, J.D. 2009.*
> *Modeling co-occurrence of northern spotted and barred owls: Accounting for detection probability differences.*
> *Biological Conservation, 142, 2983–2989*

$s = 151$ sites, surveyed $K = 10$ times, and recorded detection/not detection of spotted and barred owls. Use one covariate = Nite = if survey was done at night.

Multiple Species; Single-Season - Exercise

PRESENCE models (interpret)

- $\psi(S), \phi, p(S), r(S), \delta$
- $\psi(S), \phi = 1, p(S), r(S), \delta$
- $\psi(S), \phi = 1, p(S), r(S), \delta = 1$
- $\psi(S), \phi, p(S \times Nite), r(S \times Nite), \delta$
- $\psi(S), \phi = 1, p(S \times Nite), r(S \times Nite), \delta$
- $\psi(S), \phi = 1, p(S \times Nite), r(S \times Nite), \delta = 1$

Hints:

- Why isn't *Nite* used as covariate for ψ?
- Remember to stack the spotted owl and barred owl data and to stack the covariate TWICE.
- The initial design matrix for detection has only 1 column of 1's and needs to be changed.
- Don't forget to delete columns in the design matrix when setting $\phi = 1$ or $\delta = 1$.
- $S \times Nite$ means TWO logistic regressions, each having an intercept and a slope.

Multiple Species; Single-Season - Exercise

PRESENCE results:

Model	AIC	deltaAIC	AIC wgt	Model Likelih	no.Par.	-2*LogLike
psiA,psiB,phi=1 ,pAxN,pBxN, rAxN ,rBxN,delta=	1214.50	0.00	0.7186	1.0000	10	1194.50
psiA,psiB,phi ,pAxN,pBxN, rAxN ,rBxN,delta=1	1216.48	1.98	0.2670	0.3716	11	1194.48
psiA,psiB,phi=1 ,pAxN,pBxN, rA,rB,delta=1	1222.33	7.83	0.0143	0.0199	8	1206.33
psiA,psiB,phi=1 ,pA,pB, rA,rB,delta=1	1270.95	56.45	0.0000	0.0000	6	1258.95
psiA,psiB,phi=1 ,pA,pB,rA,rB,delta	1272.85	58.35	0.0000	0.0000	7	1258.85
psiA,psiB,phi,pA,pB,rA,rB,delta	1273.98	59.48	0.0000	0.0000	8	1257.98

Multiple Species; Single-Season - Exercise

Part of PRESENCE Design matrix to make p^A same over all surveys:

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	Parm	B4: pB Int	B5: rA Int	B6: rBA Int	B7: rBa Int
1	0	0	1:PsiA	0	0	0	0
0	1	0	2:PsiBA	0	0	0	0
0	1	0	3:PsiBa	0	0	0	0
0	0	1	4:pA	0	0	0	0
0	0	1	5:pA	0	0	0	0
0	0	1	6:pA	0	0	0	0
0	0	1	7:pA	0	0	0	0
0	0	1	8:pA	0	0	0	0
0	0	1	9:pA	0	0	0	0
0	0	1	10:pA	0	0	0	0
0	0	1	11:pA	0	0	0	0
0	0	1	12:pA	0	0	0	0
0	0	1	13:pA	0	0	0	0
0	0	0	14:pB	1	0	0	0
0	0	0	15:pB	1	0	0	0

Multiple Species; Single-Season - Exercise

Part of PRESENCE Design matrix to model $p^A \times Nite$

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	B4:	Parm	B5: pB Int	B6:	B7: rA Int	B8 rBA I
1	0	0	0	1:PsiA	0	0	0	0
0	1	0	0	2:PsiBA	0	0	0	0
0	1	0	0	3:PsiBa	0	0	0	0
0	0	1	n1	4:pA	0	0	0	0
0	0	1	n2	5:pA	0	0	0	0
0	0	1	n3	6:pA	0	0	0	0
0	0	1	n4	7:pA	0	0	0	0
0	0	1	n5	8:pA	0	0	0	0
0	0	1	n6	9:pA	0	0	0	0
0	0	1	n7	10:pA	0	0	0	0
0	0	1	n9	11:pA	0	0	0	0
0	0	1	n9	12:pA	0	0	0	0
0	0	1	n10	13:pA	0	0	0	0
0	0	0	0	14:pB	1	n1	0	0
0	0	0	0	15:pB	1	n2	0	0
0	0	0	0	16:pB	1	n3	0	0

Multiple Species; Single-Season - Exercise

MARK models (interpret)

- $\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$
- $\psi(A, B|A = B|a), p(A, B), r(A, B|A, B|a)$
- $\psi(A, B|A = B|a), p(A, B), r(A, B|A = B|a)$
- $\psi(A, B|A, B|a), p(A, B \times N), r(A, B|A, B|a \times N)$
- $\psi(A, B|A = B|a), p(A, B \times N), r(A, B|A, B|a \times N)$
- $\psi(A, B|A = B|a), p(A, B \times N), r(A, B|A = B|a \times N)$

Hints:

- Why isn't *Nite* used as covariate for ψ?
- Use the second parameterization.
- Use the DESIGN matrix (rather than PIMS) to enforce equal rates across surveys as it is easier to modify when including Nite covariate. (see next slides).
- Don't forget to use all 10 (temporal) covariates rather the same (temporal) covariate for all 10 surveys.

Multiple Species; Single-Season - Exercise

MARK results:

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{PsiA PsiB|A=PsiB|a pAxN pBxN rAxN rB|A=rB|axN Design}	1204.8241	0.0000	0.99022	1.0000	10	1192.6330	1192.6330
{PsiA PsiB|A, PsiB|a pAxN pBxN rAxN rB|A=rB|axN Design}	1214.1166	9.2925	0.00950	0.0096	11	1192.5452	1192.5452
{PsiA PsiB|A=PsiB|a pAxN pBxN rA rB|A=rB|a Design}	1221.1844	16.3603	0.00028	0.0003	8	1204.1703	1204.1703
{PsiA PsiB|A=PsiB|a pA pB rA rB|A=rB|a Design}	1271.5351	66.7110	0.00000	0.0000	6	1258.9518	1258.9518
{PsiA PsiB|A=PsiB|a pA pB rA rB|A rB|a Design}	1273.6300	68.8059	0.00000	0.0000	7	1258.8468	1258.8468
{PsiA PsiB|A PsiB|a pA pB rA rB|A rB|a Design}	1274.9945	70.1704	0.00000	0.0000	8	1257.9804	1257.9804
{PsiA PsiB|A PsiB|a pA=pB rA rB|A rB|a Design}	1283.4987	78.6746	0.00000	0.0000	7	1268.7155	1268.7155
{PsiA PsiB|A=PsiB|a pA pB rA rB|A rB|a Design}	1313.2342	108.4101	0.00000	0.0000	7	1298.4510	1298.4510

Multiple Species; Single-Season - Exercise

Part of MARK Design matrix to make p^A same over all surveys:

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	Parm	B4: pB Int	B5: rA Int	B6: rBA Int	B7: rBa Int
1	0	0	1:PsiA	0	0	0	0
0	1	0	2:PsiBA	0	0	0	0
0	1	0	3:PsiBa	0	0	0	0
0	0	1	4:pA	0	0	0	0
0	0	1	5:pA	0	0	0	0
0	0	1	6:pA	0	0	0	0
0	0	1	7:pA	0	0	0	0
0	0	1	8:pA	0	0	0	0
0	0	1	9:pA	0	0	0	0
0	0	1	10:pA	0	0	0	0
0	0	1	11:pA	0	0	0	0
0	0	1	12:pA	0	0	0	0
0	0	1	13:pA	0	0	0	0
0	0	0	14:pB	1	0	0	0
0	0	0	15:pB	1	0	0	0
0	0	0	16:pB	1	0	0	0

Multiple Species; Single-Season - Exercise

Part of MARK Design matrix to model $p^A \times Nite$

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	B4:	Parm	B5: pB Int	B6:	B7: rA Int	B8 rBA I
1	0	0	0	1:PsiA	0	0	0	0
0	1	0	0	2:PsiBA	0	0	0	0
0	1	0	0	3:PsiBa	0	0	0	0
0	0	1	n1	4:pA	0	0	0	0
0	0	1	n2	5:pA	0	0	0	0
0	0	1	n3	6:pA	0	0	0	0
0	0	1	n4	7:pA	0	0	0	0
0	0	1	n5	8:pA	0	0	0	0
0	0	1	n6	9:pA	0	0	0	0
0	0	1	n7	10:pA	0	0	0	0
0	0	1	n9	11:pA	0	0	0	0
0	0	1	n9	12:pA	0	0	0	0
0	0	1	n10	13:pA	0	0	0	0
0	0	0	0	14:pB	1	n1	0	0
0	0	0	0	15:pB	1	n2	0	0
0	0	0	0	16:pB	1	n3	0	0

Multiple-Species Single-Season Occupancy Studies

Using *RPresence* software.

Multiple Species; Single-Season

Objectives:

- Does occupancy of site by 1 species depend on presence/absence of other species?
- Does colonization and local extinction depend on presence/absence of other species
- Does detection of 1 species depend on presence/absence/detection of other species?
- Estimated # species on sites - species richness.
- Community similarity among sites.
- Species turn over rates.

Multiple Species; 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_y times in each of Y (years) seasons.
- Record detection or not detection of **two species** in site i in year y in visit k. [Most software can only deal with 2 species.]
- Capture history consists of:
    - 0 - Neither species detected
    - 1 - Species A detected
    - 2 - Species B detected
    - 3 - Species A and B both detected

  The 0, 1, 2, 3 code can be found as
  $1 \times (A\ detected) + 2 \times (B\ detected)$

Multiple Species; Single-Season - Dynamics

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

- If two species occupancy are INDEPENDENT, then $\psi^{AB} = \psi^{A}\psi^{B}$ and table simplifies.
- If two species "like" / "dislike" each other, then $\psi^{AB} > / < \psi^{A}\psi^{B}$.
- Look at margins of tables.

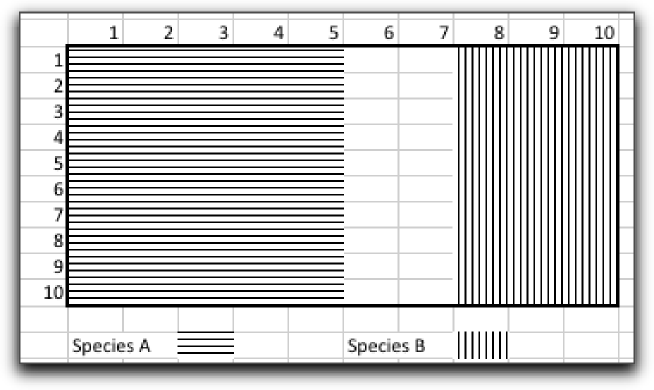
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0}{0.3 \times 0.5} = 0.$

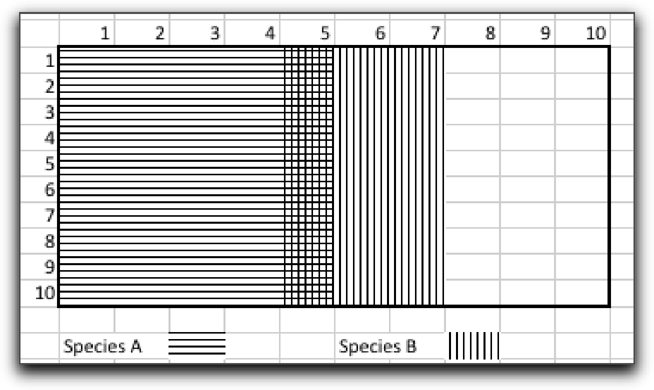
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.1, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.1}{0.3 \times 0.5} =$ 0.67.

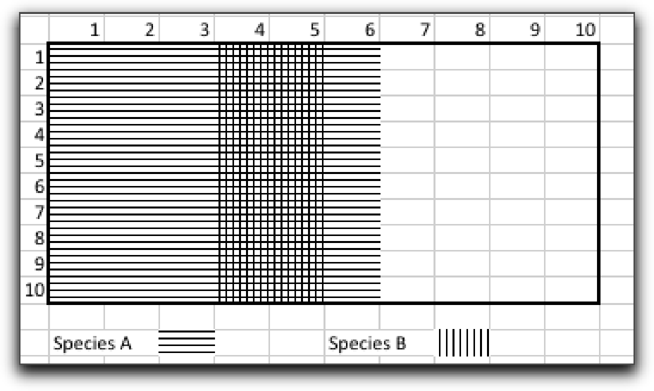
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.2, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.2}{0.3 \times 0.5} =$ 1.33.

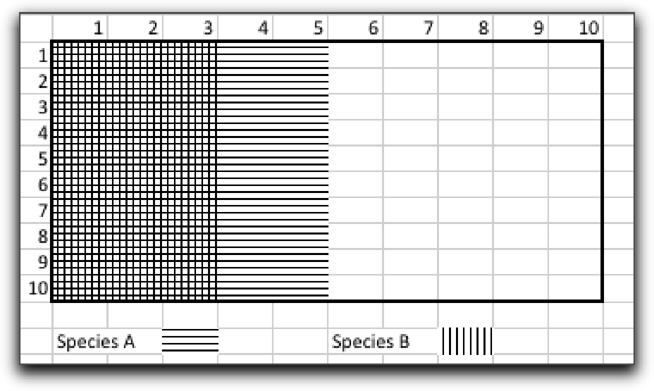
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.3, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.3}{0.3 \times 0.5} = 2.0.$

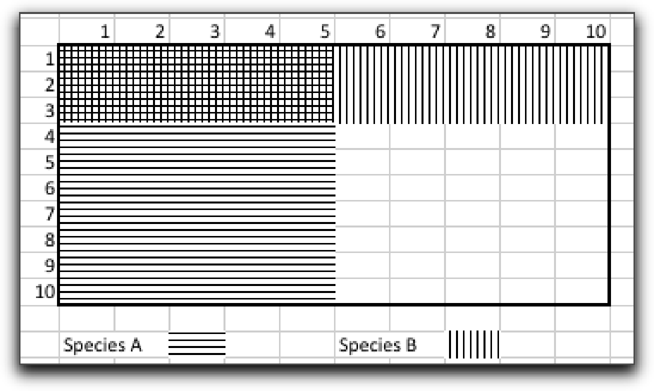
Multiple Species; Single-Season - Dynamics

Occupancy:

Species Interaction Factor $SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent

$SIF > 1 \rightarrow$ co-occur more frequently than if independent.



$\psi^{A} = 0.5, \psi^{B} = 0.3, \psi^{AB} = 0.15, SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}} = \frac{0.15}{0.3 \times 0.5} = 1.0.$

Multiple Species; Single-Season - Dynamics

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^A
	Absent	p_s^B	0

r_s^{AB} = prob of detecting BOTH species when both are present.
r_s^{Ab} = prob of detecting A, but not B when both species are present.
r_s^{aB} = prob of not detecting A. detecting B, when both species are present.
$r_s^{ab} = 1 - r_s^{AB} - r_s^{Ab} - r_s^{aB}$ = prob of detecting neither species when both are present.

Multiple Species; Single-Season - Assumptions

1. Occupancy state of sites is constant during all single-season surveys FOR EACH SPECIES (closure).
2. Probability of occupancy (ψ) is equal across all sites (homogeneity).
3. Probability of detection (p) given occupancy is equal across all sites (homogeneity).
4. Detection of species in each survey of a site is independent of those on other surveys
5. Detection histories at each location are independent
6. No false positives.

Multiple Species; Single-Season - History Probabilities

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^A= 110; History^B = 000

$$\psi^{AB} r_1^{Ab} r_2^{Ab} r_3^{ab} + (\psi^{A} - \psi^{AB}) p_1^{A} p_2^{A} (1 - p_3^{A})$$

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^{A}= 011; History^{B} = 010

$$\psi^{AB}(1 - r_1^{AB} - r_1^{Ab} - r_1^{aB})r_2^{AB}r_3^{AB}$$

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^A= 000; History^B =101

$$\psi^{AB} r_1^{AB}(1 - r_2^{AB} - r_2^{Ab} - r_2^{aB}) r_3^{AB} + (\psi^{B} - \psi^{AB}) p_1^{B}(1 - p_2^{B}) p_3^{B}$$

Occupancy:

		Species B	
		Present	Absent
Species A	Present	ψ^{AB}	$\psi^{A} - \psi^{AB}$
	Absent	$\psi^{B} - \psi^{AB}$	$1 - \psi^{A} - \psi^{B} + \psi^{AB}$

Detection:

		Species B	
		Present	Absent
Species A	Present	$r_s^{AB}, r_s^{Ab}, r_s^{aB}$	p_s^{A}
	Absent	p_s^{B}	0

History^A= 000; History^B =000

You don't want to write this out without using matrices!

Multiple Species; Single-Season - Alternate Parameterization - I

Problem: Previous parameterization in ψ leads to numerical difficulties when maximizing the likelihood.

Alternate parameterization starts by defining a *Species Interaction Factor (SIF)*

$$SIF^{\psi} = \phi = \frac{\psi^{AB}}{\psi^{A}\psi^{B}}$$

$SIF < 1 \rightarrow$ co-occur less frequently than if independent
$SIF > 1 \rightarrow$ co-occur more frequently than if independent.

$$\psi^{AB} = \psi^{A}\psi^{B} SIF$$

Note that:

$$max(\psi^{A} + \psi^{B} - 1, 0 \leq \psi^{AB} \leq min(\psi^{A}, \psi^{B})$$

which leads to restrictions of *SIF*

Multiple Species; Single-Season - Alternate Parameterization - I

Problem: Previous parameterization in p leads to numerical difficulties.

Alternate parameterization starts by defining a *Species Interaction Factor (SIF^r)*

$$r^{AB} = r^A r^B SIF^r$$

where r^A = marginal prob of detection of Species A regardless of detection of Species B given that both are present.
$SIF^r = \delta$ in some papers.
$SIF < 1 \rightarrow$ detected less frequently than if independent .
$SIF > 1 \rightarrow$ detected more frequently than if independent.

There are similar restrictions on the range of the SIF^r.

Multiple Species; Single-Season - Biological Hypotheses

1. Level of co-occurance of species:
   - H: SIF^{ψ}=1. E.g. do spotted owls and barred owls use sites independently?
2. Detection of species when both are present.
   - H: SIF^{r}=1. E.g. does detection of a predator affect detection of a prey (given that both occupy site)?
3. Detection of species if other is present/absent?
   - H: $r^A = p^A$? H:$r^B = p^B$? E.g. Does detection of a spotted owl depend if barred owl occupies site?

Multiple Species; Single-Season - Alternate Parameterization - II

IMHO this is the easiest to understand.
Occupancy dynamics.

- ψ^{A} occupancy of species A.
- $\psi^{B|A}$ occupancy of species B IF species A is present.
- $\psi^{B|a}$ occupancy of species B IF species A is absent.

If occupancy is independent ($SIF^{\psi} = 1$), then $\psi^{B|A} = \psi^{B|a}$.

Advantage of this parameterization is that all three parameters are free to vary between 0 and 1 and it is easy to impose covariates.

$\psi^{B} = \psi^{B|A}\psi^{A} + \psi^{B|a}(1 - \psi^{A})$, $\psi^{A \text{ and } B} = \psi^{B|A}\psi^{A}$

A SIF^{ψ} can be derived.

Multiple Species; Single-Season - Alternate Parameterization - II

Detection Dynamics - Species alone.

- p^A detection of species A if alone in the site.
- p^B detection of species B if alone in the site.

These parameters have no information about joint species dynamics.

Multiple Species; Single-Season - Alternate Parameterization - II

Detection Dynamics - Both species present.

- r^A detection of species A if both species on site.
- $r^{B|A}$ detection of species B if species A detected when both species on site.
- $r^{B|a}$ detection of species B if species A not detected when both species on site.

If detection of species is independent ($SIF^r = 1$) then $r^{B|A} = r^{B|a}$.

Advantage of this parameterization is that all three parameters are free to vary between 0 and 1 and covariates are easy to apply.

Multiple Species; Single-Season - Example

Co-occurence of Jordan's salamander (*Plethodon jordani*) (PJ) and members of *Plethodon glutinosus* (PG) in Great Smokey Mountains National Park (MacKenzie et al. 2004).

$s = 88$ sites; $K = 5$

Multiple Species; Single-Season - Example

Import the history data. We create the combined history data.

```
PG.data <- readxl::read_excel("Salamander co-occurrence.xls
                              sheet="RawData", na='-',
                              col_names=FALSE,
                              range = "B3:F90")

PJ.data <- readxl::read_excel("Salamander co-occurrence.xls
                              sheet="RawData", na='-',
                              col_names=FALSE,
                              range = "H3:L90")

input.history <- PG.data + 2*PJ.data
input.history
```

Multiple Species; Single-Season - Example

Import the unit covariates and standardize. (Elevation)

```
site.covar <- readxl::read_excel("Salamander co-occurrence.
                              sheet="RawData",
                              col_names=TRUE,
                              range = "N2:O90")
...
# Standardize Elevation covariates
elevation.mean <- mean(site.covar$Elevation..m.)
elevation.std  <- sd  (site.covar$Elevation..m.)
site.covar$Std..Elevation <-
     (site.covar$Elevation..m. - elevation.mean)/
          elevation.std
```

Create the **.pao* object.

```
ssalamander.pao <- createPao(input.history,
                             unitcov=site.covar,
                             title="Salamander multi species - co
summary(salamander.pao)
```

```
paoname=pres.pao
title=Salamander multi species - co-occurance
Naive occ=0.8636364
naiveR   =0.4204545
       nunits      nsurveys      nseasons nsurveyseason
         "88"           "5"           "1"           "5"
unit covariates  : Elevation..m. Std..Elevation
survey covariates: SURVEY
```

There are two types of MSSS models (parameterization) available in *RPresence*:

- type="so.2sp.1" - the $\psi^A, \psi^{B|A}, \psi_{B|a}$ parameterization.
- type="so.2sp.2" - an alternate parameterization (not discussed here).

Multiple Species; Single-Season - Example

Model are specified using 2 formula (for occupancy and detection)

```
occMod(model=list(psi~....,
                  p~....),
                data=salamander.pao,
                type="so.2sp.1")
```

Multiple Species; Single-Season - Example

Three common models for the ψ portion of the model

- $psi \sim 1$ implies $\psi^{A} = \psi^{B|A} = \psi^{B|a}$
  - Occupancy probability of B does not depend on A ($\psi^{B|A} = \psi^{B|a}$), i.e. independent occupancy
  - Occupancy probability of A and B are the same $\psi^{A} = \psi^{B|A} = \psi^{B|a}$
- $psi \sim SP$ implies ψ^{A} differs from $\psi^{B|A} = \psi^{B|a}$
  - Occupancy probability of B does not depend on A ($\psi^{B|A} = \psi^{B|a}$), i.e. independent occupancy
  - Occupancy probability of A and B are different $\psi^{A} \neq \psi^{B|A} = \psi^{B|a}$
- $psi \sim SP + INT$ implies ψ^{A} differs from $\psi^{B|A}$ which differs from $\psi^{B|a}$
  - Occupancy probability of B depend on occupancy of A ($\psi^{B|A} \neq \psi^{B|a}$)
  - Occupancy probability of A and B are different $\psi^{A} \neq \psi^{B|A} \neq \psi^{B|a}$

Multiple Species; Single-Season - Example

Similarly for detection portion of the model there are several common models specified using reserved terms

- SP - species effect on detection, but same if occupied by each species individually or when both are present
- INT_o - occupancy effects on detection but same for both species
- $SP : INT_o$ - occupancy effect on detection and differ between speciie
- INT_d - detection effects of species A on detection of species B

The most general model has $p \sim SP + INT_o + SP : INT_o + INT_d$ and is commonly the starting point.

Multiple Species; Single-Season - Example

Fit the full model
$\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$

```
mod1 <- occMod(model=list(
          psi~SP+INT,
          p~SP+INT_o+SP:INT_o + INT_d),
          data=salamander.pao,
          type="so.2sp.1")# param="PsiBA")
```

This gives:

```
Model name=psi(SP P INT)p(SP P INT_o P SP T INT_o P INT_d)
AIC=751.8665
-2*log-likelihood=735.8665
num. par=8
```

What are the 8 parameters?

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of occupancy.

```
> mod1$real$psiA  [1,]
         est      se lower  upper
unit1 0.5719 0.0572 0.458 0.6787

> # Pr(Occupancy of B | A absence)
> mod1$real$psiBA [1,]
         est      se  lower  upper
unit1 0.3177 0.0716 0.1959 0.4709
>
> # Pr(Occupancy of B | a absence)
> mod1$real$psiBa[1,]
         est      se  lower  upper
unit1 0.7005 0.0778 0.5307 0.8287
```

If species occupied sites independently then $\psi(BA) = \psi(Ba)$ - does not appear to be the case.

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
We define ν as the odds ratio of $\psi(B|A)/\psi(B|a)$

```
> # If there is no interaction between species then this is
> # If less than 1, then occur less often than expected if
> # If greater than 1, then occur more often than expected
> mod1$real$nu[1,]
              est        se      lower     upper
unit1 0.1991038 0.1027362 0.07241979 0.5473963
>
> c(mod1$real$psiA[1,1],psiB[1,1], mod1$real$psiA[1,1]*psiB
[1] 0.5719000 0.4815767 0.2754137
> # Actual estimation of occupancy of both species
> mod1$real$psiBA [1,1]*mod1$real$psiA[1,1]
[1] 0.1816926
```

So B occupies the site less often than expected if there were no interaction.

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of occupancy.

```
> # We can compute the marginal estimate of occupancy of B
> psiB <-   mod1$real$psiA  * mod1$real$psiBA+
+         (1-mod1$real$psiA) * mod1$real$psiBa
> psiB[1,]
            est         se     lower     upper
unit1 0.4815767 0.07744536 0.3773616 0.5858611
```

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of detection.

```
> # Probability of detection of species A if alone
> mod1$real$pA[1,]
             est     se  lower  upper
unit1_1-1 0.5396 0.0416 0.4576 0.6194
>
> # Probability of detection of species B if alone
> mod1$real$pB[1,]
             est     se lower  upper
unit1_1-1 0.9027 0.0391 0.795 0.9569
```

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of detection.

```
> mod1$real$rA[1,]
              est     se  lower upper
unit1_1-1 0.4882 0.0766 0.3433 0.635
> mod1$real$rBA[1,]
              est     se lower  upper
unit1_1-1 0.5014 0.0847 0.341 0.6614
> mod1$real$rBa[1,]
              est    se  lower  upper
unit1_1-1 0.6067 0.092 0.4202 0.7665
```

There may be opportunity to fit simpler models for detection here (why)?

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Conclusions - about detection

- No interference in detection of A when other species present. Compare pA vs. rA.
- Interference in detection of B when other species present. Compare pB vs. (rBA and rBa).
- No influence in detection of B by detection of A when both species present. Compare rBA vs. rBa.

Multiple Species; Single-Season - Example

Is there any support for independence of occupancy?
Model $\psi(A), \psi(B|A) = \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$

```
# mod1.occind is same as model 1, but we assume that specie
# independent. This implies that a psiBA=psiBa and is found
# fitting the interaction term in the occupancy mode

mod1.occind <- occMod(model=list(psi~SP,  p~SP+INT_o+INT_d-
                      data=salamander.pao,
                      type="so.2sp.1",  param="PsiBA")
```

```
Model name=psi(SP)p(SP P INT_o P INT_d P SP T INT_o),psiBA
AIC=760.3286
-2*log-likelihood=746.3286
num. par=7
```

What are the 7 parameters?

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A) = \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of occupancy.

```
> # Probability of occupancy of A
> mod1.occind$real$psiA  [1,]
         est    se  lower  upper
unit1 0.5949 0.057 0.4801 0.7002

> # Pr(Occupancy of B | A present)
> mod1.occind$real$psiBA [1,]
         est     se  lower  upper
unit1 0.4867 0.0546 0.3819 0.5926
>
> # Pr(Occupancy of B | A absent)
> mod1.occind$real$psiBa[1,]
         est     se  lower  upper
unit1 0.4867 0.0546 0.3819 0.5926
```

If species occupied sites independently then $\psi(BA) = \psi(Ba)$ (as forced by our model)

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A) = \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
We define ν as the odds ratio of $\psi(B|A)/\psi(B|a)$

```
> # If there is no interaction between species then this is
> # If less than 1, then occur less often than expected if
> # If greater than 1, then occur more often than expected
> mod1.occind$real$nu[1,]
      est se lower upper
unit1   1  0     1     1
>
> # For example, the marginal estimates are and prob if ind
> c(mod1.occind$real$psiA[1,1],psiB[1,1], mod1.occind$real$
[1] 0.5949000 0.4815767 0.2864900
> # Actual estimation of occupancy of both species
> mod1.occind$real$psiBA [1,1]*mod1.occind$real$psiA[1,1]
[1] 0.2895378
```

This is consistent with the forced model

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A) = \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Estimates of occupancy.

```
> # We can compute the marginal estimate of occupancy of B
> psiB <-   mod1.occind$real$psiA  * mod1.occind$real$psiBA
+         (1-mod1.occind$real$psiA) * mod1.occind$real$psiBa
> psiB[1,]
         est     se  lower  upper
unit1 0.4867 0.0546 0.3819 0.5926
>
```

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A) = \psi(B|a), p(A), p(B), r(A), r(B|A), r(B|a)$
Is there any support?

```
models<-list(mod1,
             mod1.occind)
results<-RPresence::createAicTable(models)
summary(results)
```

```
> summary(results)
                                                   Model
1 psi(SP P INT)p(SP P INT_o P SP T INT_o P INT_d),psiBA
2       psi(SP)p(SP P INT_o P INT_d P SP T INT_o),psiBA
  DAIC   wgt npar neg2ll warn.conv warn.VC
1 0.00 0.986    8 735.87         0       0
2 8.46 0.014    7 746.33         0       0
>
```

Neglible support for the independent occupancy model

Multiple Species; Single-Season - Example

Try and fit a simpler detection model? Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A) = r(B|a)$.

```
mod1.detind <- occModd(model=list(psi~SP+INT,  p~SP+INT_o+S
                     data=salamander.pao,
                     type="so.2sp.1")
summary(mod1.detind)
```

```
Model name=psi(SP P INT)p(SP P INT_o P SP T INT_o),psiBA
AIC=750.624
-2*log-likelihood=736.624
num. par=7
```

What are the 7 parameters?

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A) = r(B|a)$
Estimates of detection.

```
> mod1.detind$real$pA[1,]
             est     se  lower  upper
unit1_1-1 0.5406 0.0416 0.4587 0.6204
>
> # Probability of detection of species B if alone
> mod1.detind$real$pB[1,]
             est     se  lower  upper
unit1_1-1 0.9092 0.0372 0.8053 0.9604
>
```

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A) = r(B|a)$
Estimates of detection.

```
> mod1.detind$real$rA[1,]
             est    se  lower  upper
unit1_1-1 0.4776 0.073 0.3401 0.6186
> mod1.detind$real$rBA[1,]
             est    se  lower  upper
unit1_1-1 0.5504 0.062 0.4283 0.6666
> mod1.detind$real$rBa[1,]
             est    se  lower  upper
unit1_1-1 0.5504 0.062 0.4283 0.6666
```

The last two estimates are equal (why?)

Multiple Species; Single-Season - Example

Model $\psi(A), \psi(B|A), \psi(B|a), p(A), p(B), r(A), r(B|A) = r(B|a)$ Support.

```
> summary(results)
                                                         Model DAI
1         psi(SP P INT)p(SP P INT_o P SP T INT_o),psiBA 0.0
2 psi(SP P INT)p(SP P INT_o P SP T INT_o P INT_d),psiBA 1.2
3       psi(SP)p(SP P INT_o P INT_d P SP T INT_o),psiBA 9.7
  npar neg2ll warn.conv warn.VC
1    7 736.62         0       0
2    8 735.87         0       0
3    7 746.33         0       0
```

Multiple Species; Single-Season - Example

Adding the effect of elevation.
Model
$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$

```
mod.psi.elevation <- occMod(model=list(
       psi~Std..Elevation+SP+SP:Std..Elevation+INT+INT:Std..
       p  ~SP+INT_o+SP:INT_o),
       data=salamander.pao,
       type="so.2sp.1")
summary(mod.psi.elevation)
```

Notice we used the standardized elevation covariates for numerical stability.

```
Model name=psi(Std..Elevation P SP P SP T Std..Elevation P
AIC=687.4714
-2*log-likelihood=667.4714
num. par=10
```

What are the 10 parameters?

Multiple Species; Single-Season - Example

Model

$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$

This implies:

- $logit(\psi(A)) = \beta_0^A + beta_1^A(Elevation)$
- $logit(\psi(B|A)) = \beta_0^{BA} + beta_1^{BA}(Elevation)$
- $logit(\psi(B|a)) = \beta_0^{Ba} + beta_1^{Ba}(Elevation)$

We need to get the beta terms and figure out which beta fits with which equation!

```
> mod.psi.elevation$beta$psi
  psi.coeff
1  0.372485  -0.686944 -0.984296  4.503822  3.142486  16.04
```

Argh!

Model
$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$

```
>mod.psi.elevation$dmat$psi
      a1          a2                      a3           a4
psiA  "Int_psiA"  "Std..Elevation_psiA"  "SP2_psiA"   "INT2_
psiBA "Int_psiBA" "Std..Elevation_psiBA" "SP2_psiBA"  "INT2_
psiBa "Int_psiBa" "Std..Elevation_psiBa" "SP2_psiBa"  "INT2_
      a5                         a6
psiA  "Std..Elevation:SP2_psiA"  "Std..Elevation:INT2_psiA"
psiBA "Std..Elevation:SP2_psiBA" "Std..Elevation:INT2_psiBA
psiBa "Std..Elevation:SP2_psiBa" "Std..Elevation:INT2_psiBa
```

Argh!

Multiple Species; Single-Season - Example

Model

$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$

We compute the logit(occupancy) from the beta variables as a function of elevation:

```
range(site.covar$Elevation..m.)
predictPSI <- data.frame(Elevation..m.=seq(400,1200,10))
predictPSI$Std..Elevation <- (predictPSI$Elevation..m. - el

predictPSI$psiA.logit  <- mod.psi.elevation$beta$psi[1,] +
        mod.psi.elevation$beta$psi[2,]*predictPSI$Std..Elev
predictPSI$psiBA.logit <- mod.psi.elevation$beta$psi[3,] +
       mod.psi.elevation$beta$psi[5,]*predictPSI$Std..Eleva
predictPSI$psiBa.logit <- mod.psi.elevation$beta$psi[4,] +
       mod.psi.elevation$beta$psi[6,]*predictPSI$Std..Eleva
```

Multiple Species; Single-Season - Example

Model

$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$

We convert from logit(occupancy) to p(occupancy) as a function of elevation.

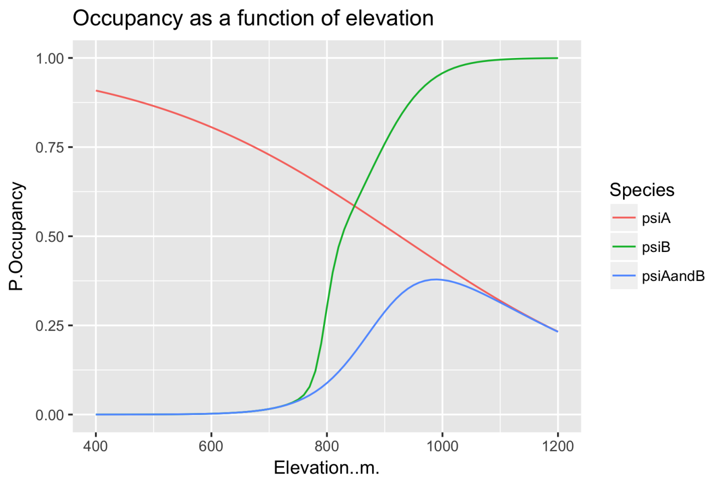
```
expit <- function (x) {1/(1+exp(-x))}
predictPSI$psiA  <- expit(predictPSI$psiA.logit)
predictPSI$psiBA <- expit(predictPSI$psiBA.logit)
predictPSI$psiBa <- expit(predictPSI$psiBa.logit)
```

Obtain the marginal probability of occupancy:

```
# We can compute the marginal estimate of occupancy of B
predictPSI$psiB <-   predictPSI$psiA  * predictPSI$psiBA+
                  (1-predictPSI$psiA) * predictPSI$psiBa
predictPSI$psiAandB <- predictPSI$psiA  * predictPSI$psiBA
```

Multiple Species; Single-Season - Example

$$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$$



Conclusion? Species interaction may solely be a function of elevation.

Multiple Species; Single-Season - Example

Model
$\psi(A|El), \psi(B|A, El), \psi(B|a, El), p(A), p(B), r(A), r(B|A) = r(B|a)$
Support.

```
> summary(results)
                                                     Model DAI
1         elevatio model
2         psi(SP P INT)p(SP P INT_o P SP T INT_o),psiBA 0.0
3 psi(SP P INT)p(SP P INT_o P SP T INT_o P INT_d),psiBA 1.2
4       psi(SP)p(SP P INT_o P INT_d P SP T INT_o),psiBA 9.7
   DAIC wgt npar neg2ll warn.conv warn.VC
1  0.00   1   10 667.47         0       0
2 63.15   0    7 736.62         0       0
3 64.40   0    8 735.87         0       0
4 72.86   0    7 746.33         0       0
```

Conclusion? Species interaction may solely be a function of elevation.

Multiple Species; Single-Season - Study Design Issues

- VERY data hungry!
- Similar design issues as seen previously.
- NEW Length of Season
  - Sites must be closed over season.
  - "Co-occurrence" influenced by how "season" is defined.
- Similar concerns about "co-occurrence" at SITE level and size of size influences this.

Multiple Species; Single-Season - Exercise

Spotted owl vs. barred owl. Based on:

> *Bailey, L.L, Reid, J.A., Forsman, E.D., Nichols, J.D. 2009.*
> *Modeling co-occurrence of northern spotted and barred owls: Accounting for detection probability differences. Biological Conservation, 142, 2983–2989*

$s = 151$ sites, surveyed $K = 10$ times, and recorded detection/not detection of spotted and barred owls. Use one covariate = Nite = if survey was done at night.

Multiple Species; Single-Season - Exercise

PRESENCE models (interpret)

- $\psi(S), \phi, p(S), r(S), \delta$
- $\psi(S), \phi = 1, p(S), r(S), \delta$
- $\psi(S), \phi = 1, p(S), r(S), \delta = 1$
- $\psi(S), \phi, p(S \times Nite), r(S \times Nite), \delta$
- $\psi(S), \phi = 1, p(S \times Nite), r(S \times Nite), \delta$
- $\psi(S), \phi = 1, p(S \times Nite), r(S \times Nite), \delta = 1$

Hints:

- Why isn't *Nite* used as covariate for ψ?
- Remember to stack the spotted owl and barred owl data and to stack the covariate TWICE.
- The initial design matrix for detection has only 1 column of 1's and needs to be changed.
- Don't forget to delete columns in the design matrix when setting $\phi = 1$ or $\delta = 1$.
- $S \times Nite$ means TWO logistic regressions, each having an intercept and a slope.

Multiple Species; Single-Season - Exercise

PRESENCE results:

Model	AIC	deltaAIC	AIC wgt	Model Likelih	no.Par.	-2*LogLike
psiA,psiB,phi=1 ,pAxN,pBxN, rAxN ,rBxN,delta=	1214.50	0.00	0.7186	1.0000	10	1194.50
psiA,psiB,phi ,pAxN,pBxN, rAxN ,rBxN,delta=1	1216.48	1.98	0.2670	0.3716	11	1194.48
psiA,psiB,phi=1 ,pAxN,pBxN, rA,rB,delta=1	1222.33	7.83	0.0143	0.0199	8	1206.33
psiA,psiB,phi=1 ,pA,pB, rA,rB,delta=1	1270.95	56.45	0.0000	0.0000	6	1258.95
psiA,psiB,phi=1 ,pA,pB,rA,rB,delta	1272.85	58.35	0.0000	0.0000	7	1258.85
psiA,psiB,phi,pA,pB,rA,rB,delta	1273.98	59.48	0.0000	0.0000	8	1257.98

Multiple Species; Single-Season - Exercise

Part of PRESENCE Design matrix to make p^A same over all surveys:

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	Parm	B4: pB Int	B5: rA Int	B6: rBA Int	B7: rBa Int
1	0	0	1:PsiA	0	0	0	0
0	1	0	2:PsiBA	0	0	0	0
0	1	0	3:PsiBa	0	0	0	0
0	0	1	4:pA	0	0	0	0
0	0	1	5:pA	0	0	0	0
0	0	1	6:pA	0	0	0	0
0	0	1	7:pA	0	0	0	0
0	0	1	8:pA	0	0	0	0
0	0	1	9:pA	0	0	0	0
0	0	1	10:pA	0	0	0	0
0	0	1	11:pA	0	0	0	0
0	0	1	12:pA	0	0	0	0
0	0	1	13:pA	0	0	0	0
0	0	0	14:pB	1	0	0	0
0	0	0	15:pB	1	0	0	0

Multiple Species; Single-Season - Exercise

Part of PRESENCE Design matrix to model $p^A \times Nite$

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	B4:	Parm	B5: pB Int	B6:	B7: rA Int	B8 rBA I
1	0	0	0	1:PsiA	0	0	0	0
0	1	0	0	2:PsiBA	0	0	0	0
0	1	0	0	3:PsiBa	0	0	0	0
0	0	1	n1	4:pA	0	0	0	0
0	0	1	n2	5:pA	0	0	0	0
0	0	1	n3	6:pA	0	0	0	0
0	0	1	n4	7:pA	0	0	0	0
0	0	1	n5	8:pA	0	0	0	0
0	0	1	n6	9:pA	0	0	0	0
0	0	1	n7	10:pA	0	0	0	0
0	0	1	n9	11:pA	0	0	0	0
0	0	1	n9	12:pA	0	0	0	0
0	0	1	n10	13:pA	0	0	0	0
0	0	0	0	14:pB	1	n1	0	0
0	0	0	0	15:pB	1	n2	0	0
0	0	0	0	16:pB	1	n3	0	0

Multiple Species; Single-Season - Exercise

MARK models (interpret)

- $\psi(A, B|A, B|a), p(A, B), r(A, B|A, B|a)$
- $\psi(A, B|A = B|a), p(A, B), r(A, B|A, B|a)$
- $\psi(A, B|A = B|a), p(A, B), r(A, B|A = B|a)$
- $\psi(A, B|A, B|a), p(A, B \times N), r(A, B|A, B|a \times N)$
- $\psi(A, B|A = B|a), p(A, B \times N), r(A, B|A, B|a \times N)$
- $\psi(A, B|A = B|a), p(A, B \times N), r(A, B|A = B|a \times N)$

Hints:

- Why isn't *Nite* used as covariate for ψ?
- Use the second parameterization.
- Use the DESIGN matrix (rather than PIMS) to enforce equal rates across surveys as it is easier to modify when including Nite covariate. (see next slides).
- Don't forget to use all 10 (temporal) covariates rather the same (temporal) covariate for all 10 surveys.

Multiple Species; Single-Season - Exercise

MARK results:

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)
{PsiA PsiB|A=PsiB|a pAxN pBxN rAxN rB|A=rB|axN Design}	1204.8241	0.0000	0.99022	1.0000	10	1192.6330	1192.6330
{PsiA PsiB|A, PsiB|a pAxN pBxN rAxN rB|A=rB|axN Design}	1214.1166	9.2925	0.00950	0.0096	11	1192.5452	1192.5452
{PsiA PsiB|A=PsiB|a pAxN pBxN rA rB|A=rB|a Design}	1221.1844	16.3603	0.00028	0.0003	8	1204.1703	1204.1703
{PsiA PsiB|A=PsiB|a pA pB rA rB|A=rB|a Design}	1271.5351	66.7110	0.00000	0.0000	6	1258.9518	1258.9518
{PsiA PsiB|A=PsiB|a pA pB rA rB|A rB|a Design}	1273.6300	68.8059	0.00000	0.0000	7	1258.8468	1258.8468
{PsiA PsiB|A PsiB|a pA pB rA rB|A rB|a Design}	1274.9945	70.1704	0.00000	0.0000	8	1257.9804	1257.9804
{PsiA PsiB|A PsiB|a pA=pB rA rB|A rB|a Design}	1283.4987	78.6746	0.00000	0.0000	7	1268.7155	1268.7155
{PsiA PsiB|A=PsiB|a pA pB rA rB|A rB|a Design}	1313.2342	108.4101	0.00000	0.0000	7	1298.4510	1298.4510

Multiple Species; Single-Season - Exercise

Part of MARK Design matrix to make p^A same over all surveys:

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	Parm	B4: pB Int	B5: rA Int	B6: rBA Int	B7: rBa Int
1	0	0	1:PsiA	0	0	0	0
0	1	0	2:PsiBA	0	0	0	0
0	1	0	3:PsiBa	0	0	0	0
0	0	1	4:pA	0	0	0	0
0	0	1	5:pA	0	0	0	0
0	0	1	6:pA	0	0	0	0
0	0	1	7:pA	0	0	0	0
0	0	1	8:pA	0	0	0	0
0	0	1	9:pA	0	0	0	0
0	0	1	10:pA	0	0	0	0
0	0	1	11:pA	0	0	0	0
0	0	1	12:pA	0	0	0	0
0	0	1	13:pA	0	0	0	0
0	0	0	14:pB	1	0	0	0
0	0	0	15:pB	1	0	0	0
0	0	0	16:pB	1	0	0	0

Part of MARK Design matrix to model $p^A \times Nite$

B1: PsiA Int	B2: PsiBA Int	B3: pA Int	B4:	Parm	B5: pB Int	B6:	B7: rA Int	B8 rBA I
1	0	0	0	1:PsiA	0	0	0	0
0	1	0	0	2:PsiBA	0	0	0	0
0	1	0	0	3:PsiBa	0	0	0	0
0	0	1	n1	4:pA	0	0	0	0
0	0	1	n2	5:pA	0	0	0	0
0	0	1	n3	6:pA	0	0	0	0
0	0	1	n4	7:pA	0	0	0	0
0	0	1	n5	8:pA	0	0	0	0
0	0	1	n6	9:pA	0	0	0	0
0	0	1	n7	10:pA	0	0	0	0
0	0	1	n9	11:pA	0	0	0	0
0	0	1	n9	12:pA	0	0	0	0
0	0	1	n10	13:pA	0	0	0	0
0	0	0	0	14:pB	1	n1	0	0
0	0	0	0	15:pB	1	n2	0	0
0	0	0	0	16:pB	1	n3	0	0

Multiple Species; Single-Season - Exercise

Bull and Brook trout occupancy.
Bull trout are native and require cold water; brook trout are from the east and are supposed to have warmer temperature preferences. Each site was sampled twice, represented as "rep1" and "rep2" in the database. The two predictors of occupancy of the most interest are temperature and discharge.
$s = 183$ sites, surveyed $K = 2$ times.

Multiple-Species Single-season Summary

Multiple Species; Single-Season - Summary

Similar to previous methods + :

- Key parameters are
  - $SIF^{\psi} = \phi$ and $SIF^{p} = \delta$ OR
  - $\psi^{B|A}, \psi^{B|a}$ and $r^{B|A}, r^{B|a}$ [Easier to fit, esp with covariates.]
- Spatial and temporal scales influence “co-occurrence”.
- Planning studies will require much thought. Use GENPRES in a similar fashion as in previous examples.

EXTENSIONS:

- More than two species – not much success with these models; easier to reduce to two species.
- Multiple seasons – colonization and extinction could depend on species present; EXTREMELY data hungry!