Multi-Species Occupancy Models: Implementation in MARK

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Outline

- A brief overview of MARK
- An overview of the data needs
- Fitting and interpreting simple models
- Fitting and interpreting a more complex model

What is MARK?

- Developed by Gary White
- Windows-based program for the analysis of data from marked (and now unmarked) animals
- Freely available
- Encompasses most currently used methods for analysis of marked individuals
- Constantly being updated to include new methods (like this one)
- Flexible and powerful for statistical modeling and hypothesis testing

Program MARK Interface

File Window Help

Program MARK

You can obtain context-sensitive help with the F1 key, and can investigate objects with the Shift-F1 key. See the Help menu for known problems.

Colorado State University

Colorado State University

Program MARK Interface

03:11:12 PM

Multi-Species Model Data needs

- Like other occupancy models, the multi-species model uses detection/non-detection data from a number of sites

- Some considerations for analysis in MARK:
  - How to divide up detection/nondetection data
  - Choosing and incorporating covariate data
  - How to input the data into MARK

How to divide up detection/nondetection data

- Longer occasion lengths can help increase detection probability and estimate precision for rare species

- However, shorter occasion length increases the temporal information available and is particularly helpful for modeling species interactions

- In our examples, we will use an occasion length of 3 weeks

Choosing and incorporating covariate data

- Categorical or continuous covariates representing hypotheses about ecological processes
  - How the probability of occupancy varies among sites
    - Elevation, habitat type
  - What environmental factors affect interactions?
    - Available cover, prey abundance

- Factors affecting the observation process
  - Whether the probability of detection varies among sites or survey occasions
    - Daily temperature, understory thickness
    - Habitat type/land cover, trail/not trail

The MARK input file

- MARK requires a very specific input file for each type of model
  - Built in a text editor and given a .inp extension
  - Each line ends in “;”

- Uses a binary counting system to code detection/non-detection data:

- When there are 2 species:
  - 00 = neither species were detected
  - 01 = only species 1 was detected
  - 02 = only species 2 was detected
  - 03 = both species were detected

An example input file with 3 species

Multispecies_Ex.inp - Notepad

File Edit Format View Help

```
/* Example Multispecies occupancy dataset without covaraite data */
/* 3 survey occasions, 1 group */

000000 854;
000004 21;
040404 9;
000400 14;
040000 15;
040400 10;
000404 8;
040004 7;
020000 61;
000302 3;
010000 25;
000001 31;
```

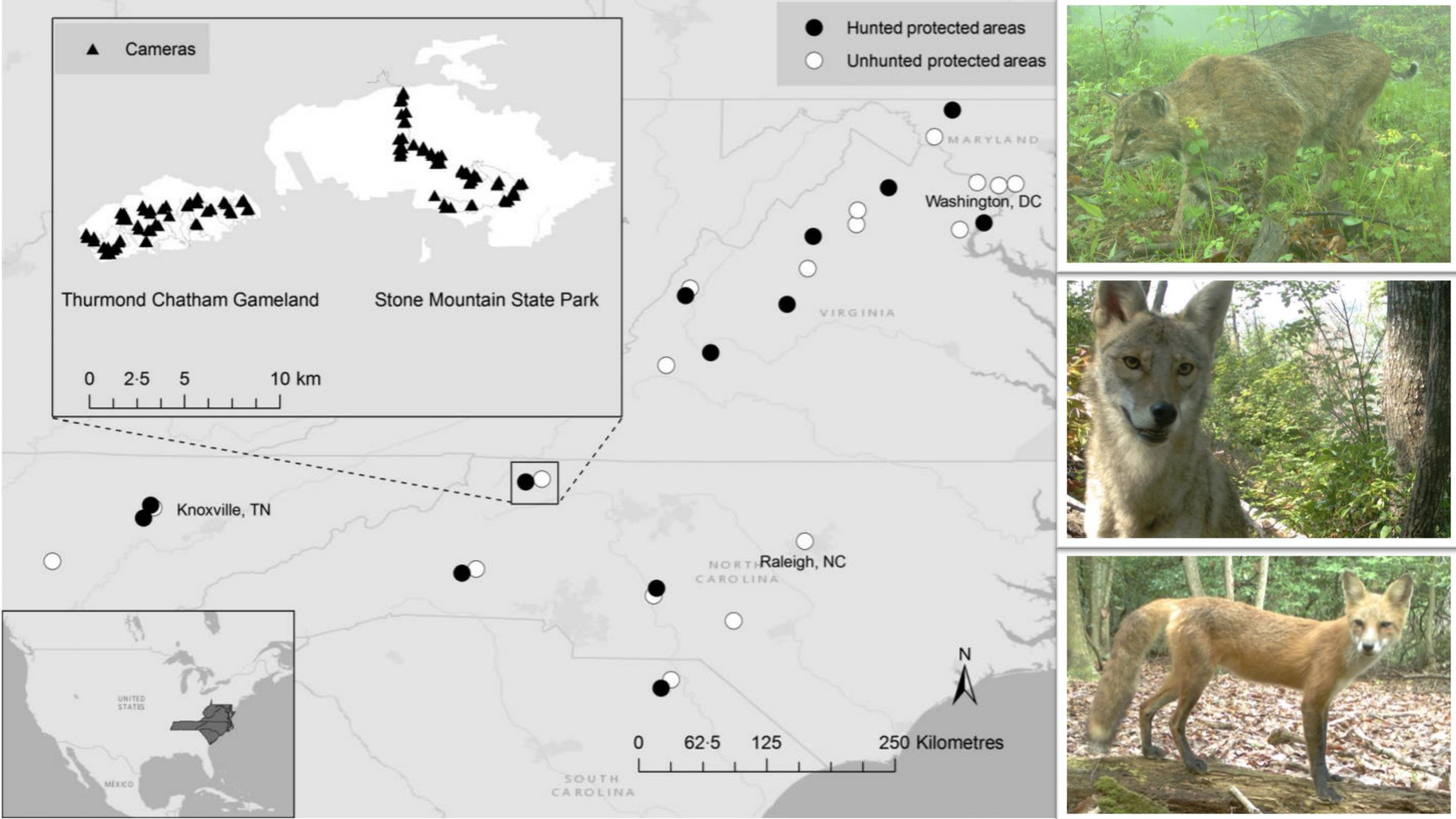
Only spp3 was detected in all 3 occasions

The number of camera sites where only spp3 was detected in all 3 occasions

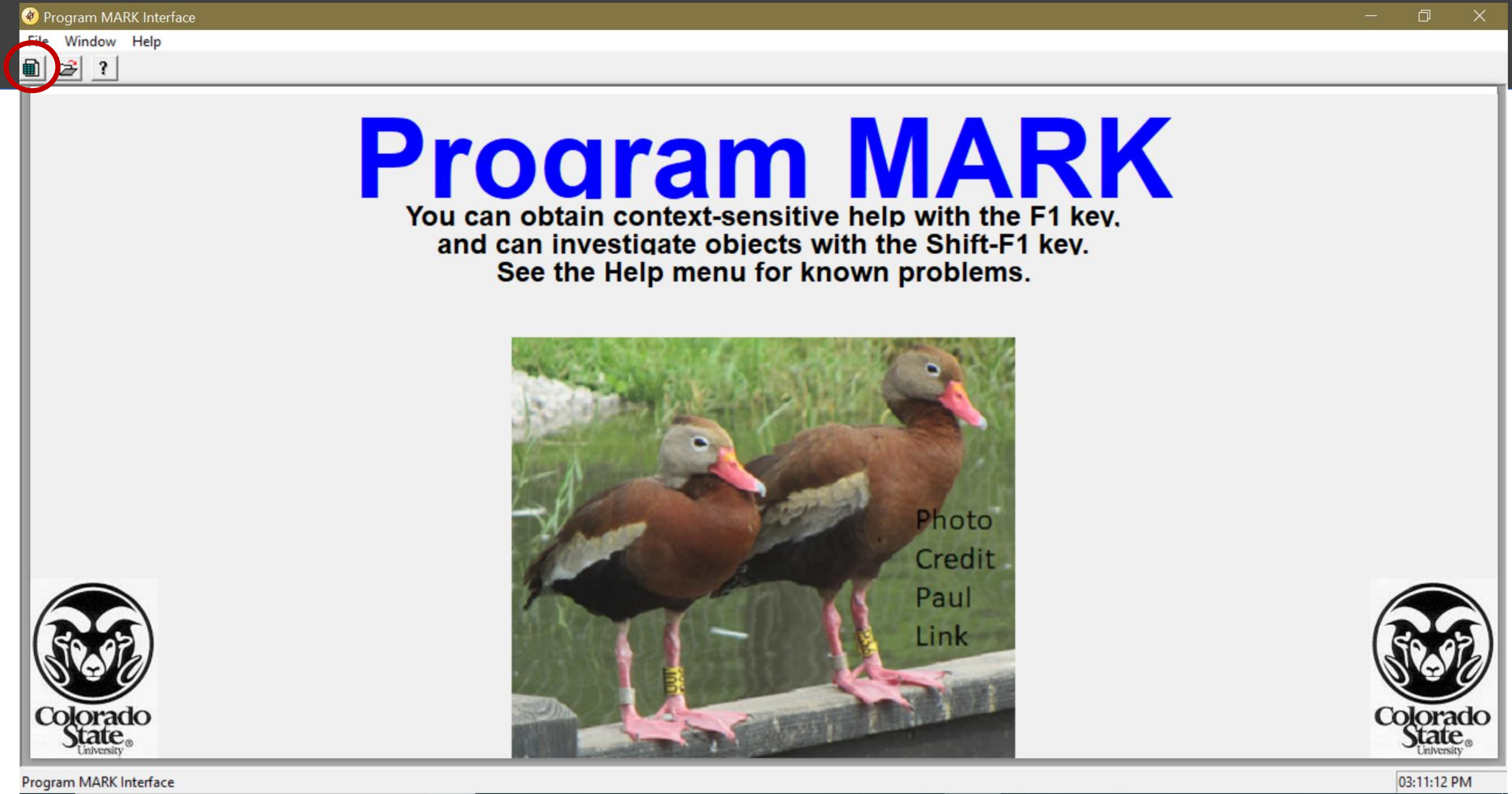
00 = None of the species detected
01 = only spp 1 detected
02 = only spp2 detected
03 = both spp 1 and spp 2 detected
04 = only spp3 detected
05 = both spp1 and spp3 detected
06 = both spp2 and spp3 detected
07 = all species detected

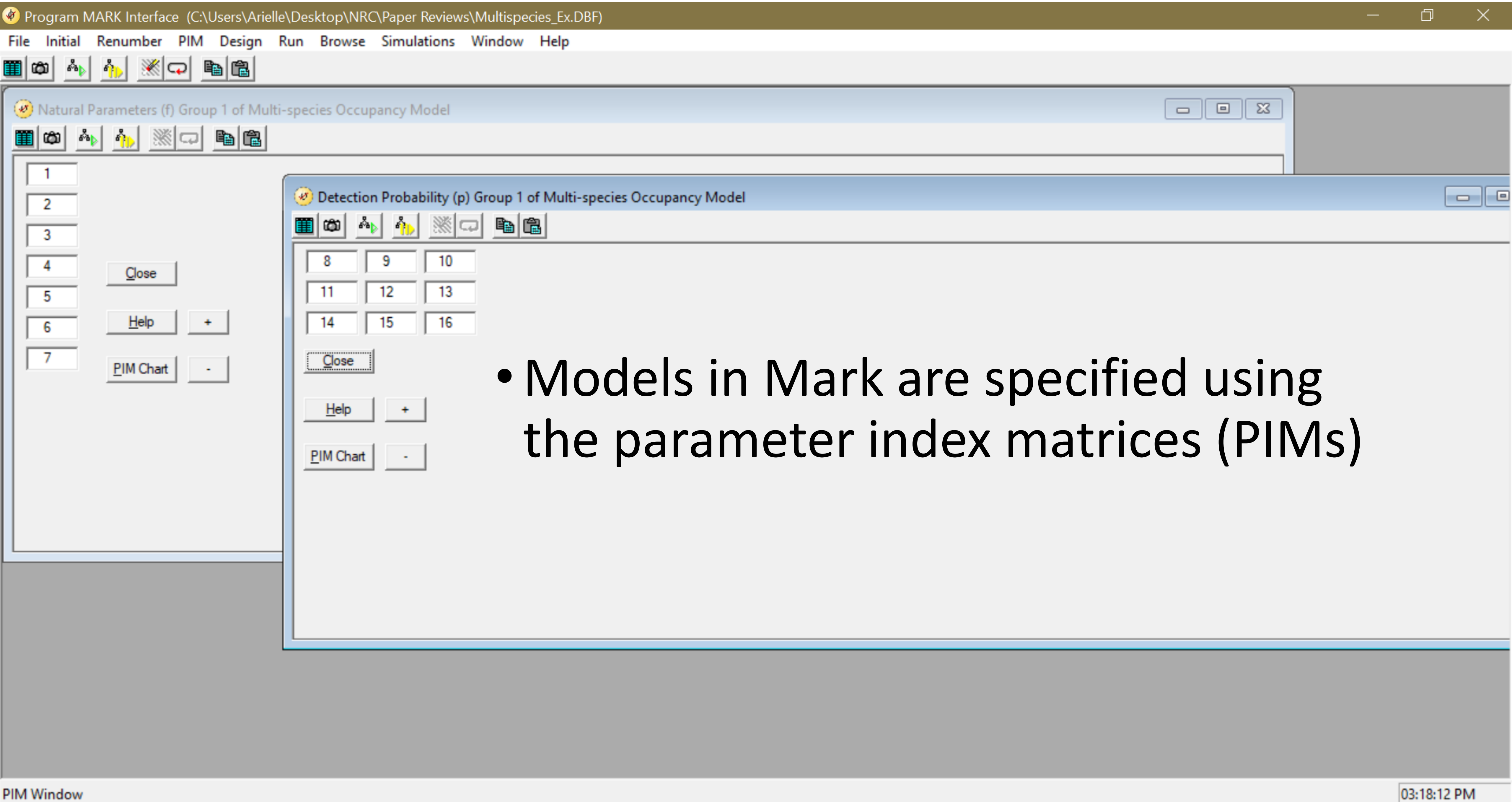
How to construct the .inp file? There's a script for that!

```r
######################################################################
######################### Make a MARK unput file #####################
################# from raw detection/nondetection data ###############
######################################################################

#Set your working directory
setwd("~/MARK")

#Read in the detection/non detection data files for each species
#In this example there are 3 species, two jackals and a genet
#The files are one row for each site, one column for each occasion
#and a 1 or 0 for whether that species was detected at that site on
#that occasion
sp1 <- read.csv('bbjackal_final.csv', header = F)
sp2 <- read.csv('ssjackal_final.csv', header = F)
sp3 <- read.csv('gen_final.csv', header = F)

#Read in the p and psi covariates
p <- read.csv('p_covariates.csv')
psi <- read.csv('psi_covariates.csv')

#Create an empty matrix to hold the capture histories
ch <- matrix(nrow = nrow(sp1), ncol = ncol(sp1))

#Loop through each site and occasion, adding ".." to the
#capture history file if the site was not
#sampled on that occassion, '00' if none of the species were detected
#at that site on that occasion, '01' if only species1, '02' if only
#species2, '03' if species1 and species2, '04' if only species3, '05'
```


Cameras
Thurmond Chatham Gameland
Stone Mountain State Park
0 2·5 5 10 km
Hunted protected areas
Unhunted protected areas
MARYLAND
Washington, DC
VIRGINIA
Knoxville, TN
NORTH CAROLINA
Raleigh, NC
SOUTH CAROLINA
0 62·5 125 250 Kilometres
N
UNITED STATES
MÉXICO

Feeding the data into Mark





- Models in Mark are specified using the parameter index matrices (PIMs)

Let’s review the parameters of the model

We will assume 3 interacting species such that:

f_1 The log odds species 1 occupies the site

f_2 The log odds species 2 occupies the site

f_{12} The log odds species 1 AND species 2 occupy the site

f_3 The log odds species 3 occupies the site

f_{13} The log odds species 1 AND species 3 occupy the site

f_{23} The log odds species 2 AND species 3 occupy the site

f_{123} The log odds species 1, 2 AND 3 occupy the site

p_{1it} Detection probability for species 1 during occasion *t* if present at site *i*

p_{2it} Detection probability for species 2 during occasion *t* if present at site *i*

p_{3it} Detection probability for species 3 during occasion *t* if present at site *i*

What is a PIM?

- Parameter Index Matrices
- Establish the set of real parameters that will be estimated
- The numbering can be used to place constraints on the real parameter estimates.
- The values in the PIMs establish how many rows there are in the Design Matrix: there will be 1 row for each unique value

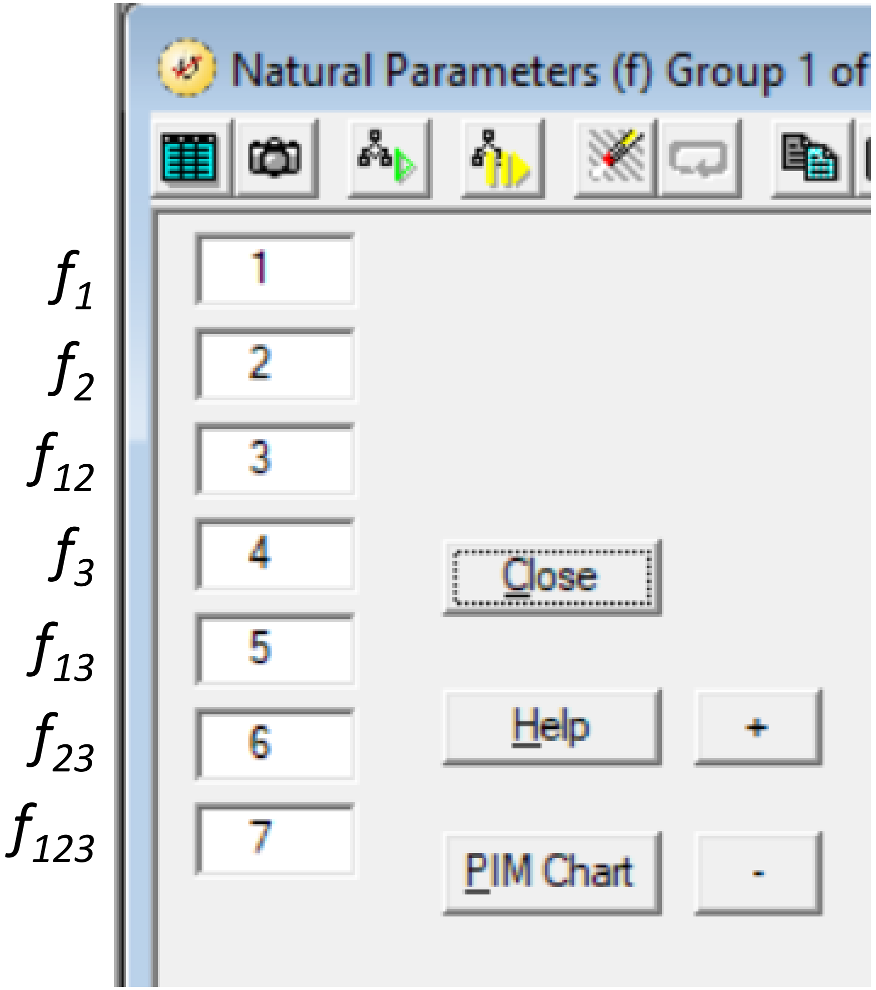
What is the design matrix?

PIM ⟶ Design Matrix ⟶ Link Function ⟶ Real Parameter Estimates

- The number of parameters (from PIMS) determines the number of rows in the design matrix.
- The number of columns in the design matrix specifies the number of actual parameters that are estimated (i.e. the betas).
- The link function converts the betas of the design matrix into the real parameter estimates.

PIMs for the Multi-Species Model

- This model has 3 species
- There are 2 PIMs for this model, one for the natural parameters (the *f'*s) and one for the detection parameters
- The *f* parameters are ordered within the PIM from top to bottom



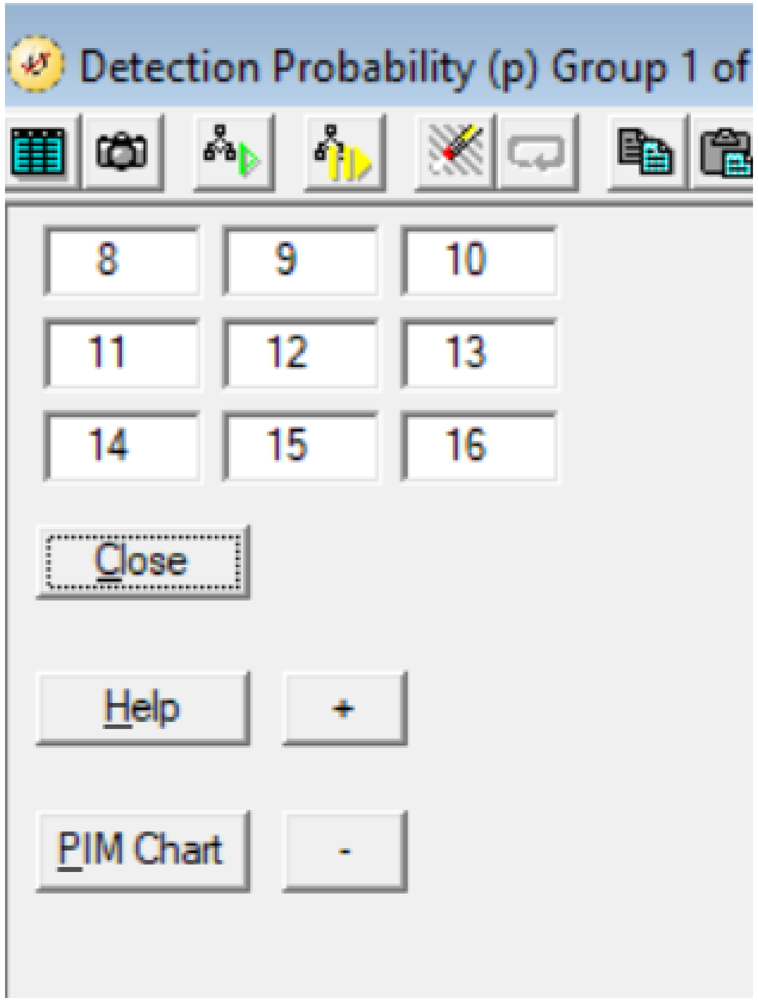
PIMs for the Multi-Species Model

- The *p* parameters are ordered with each row being a species and column being an occasion

p_{11}, p_{12}, p_{13}

p_{21}, p_{22}, p_{23}

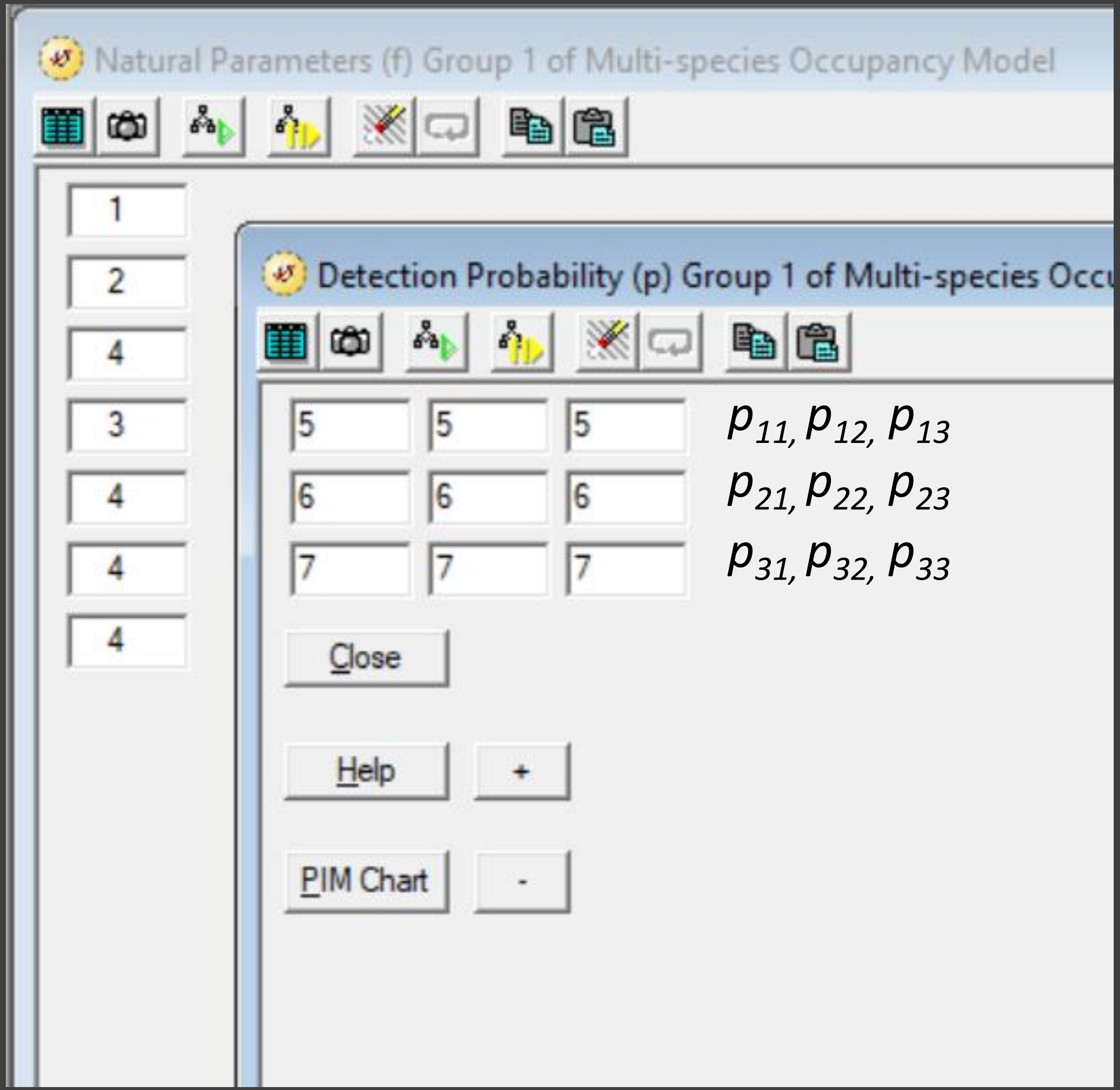
p_{31}, p_{32}, p_{33}



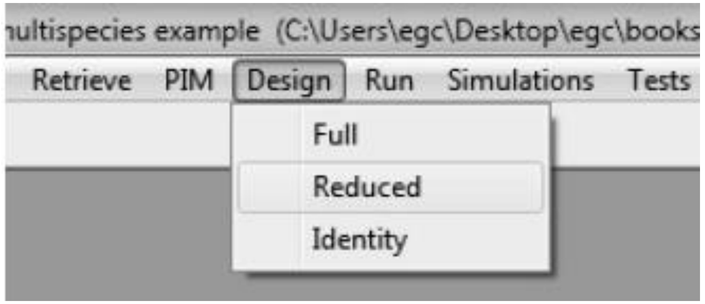
Fitting the model – let's start simple!

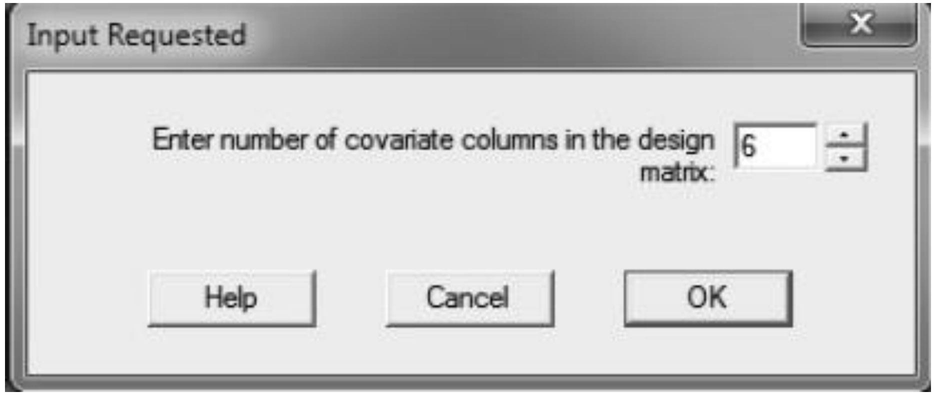
- Intercept only model
- No 2-way interactions
- Detection probability constant over time

f_1
f_2
f_{12}
f_3
f_{13}
f_{23}
f_{123}



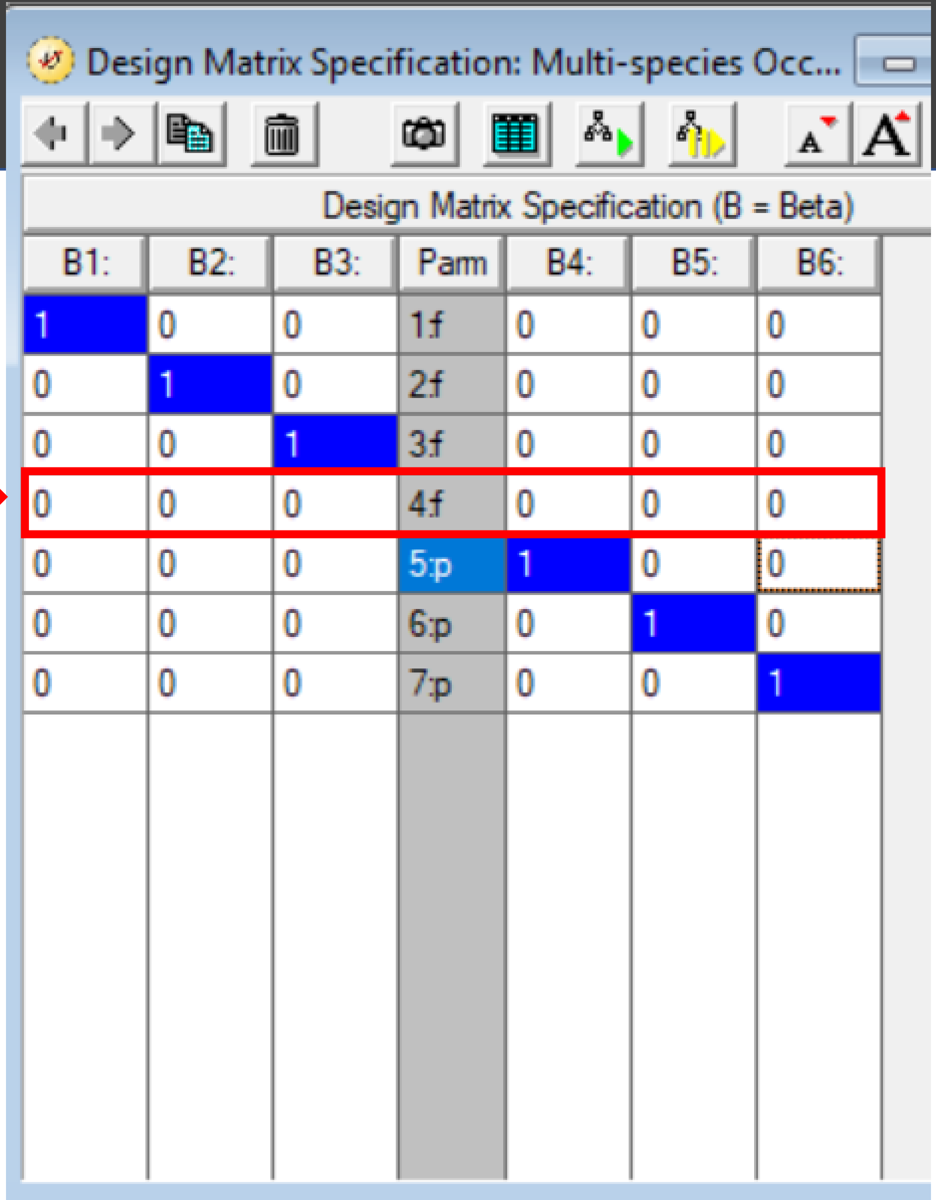
Fill in the design matrix





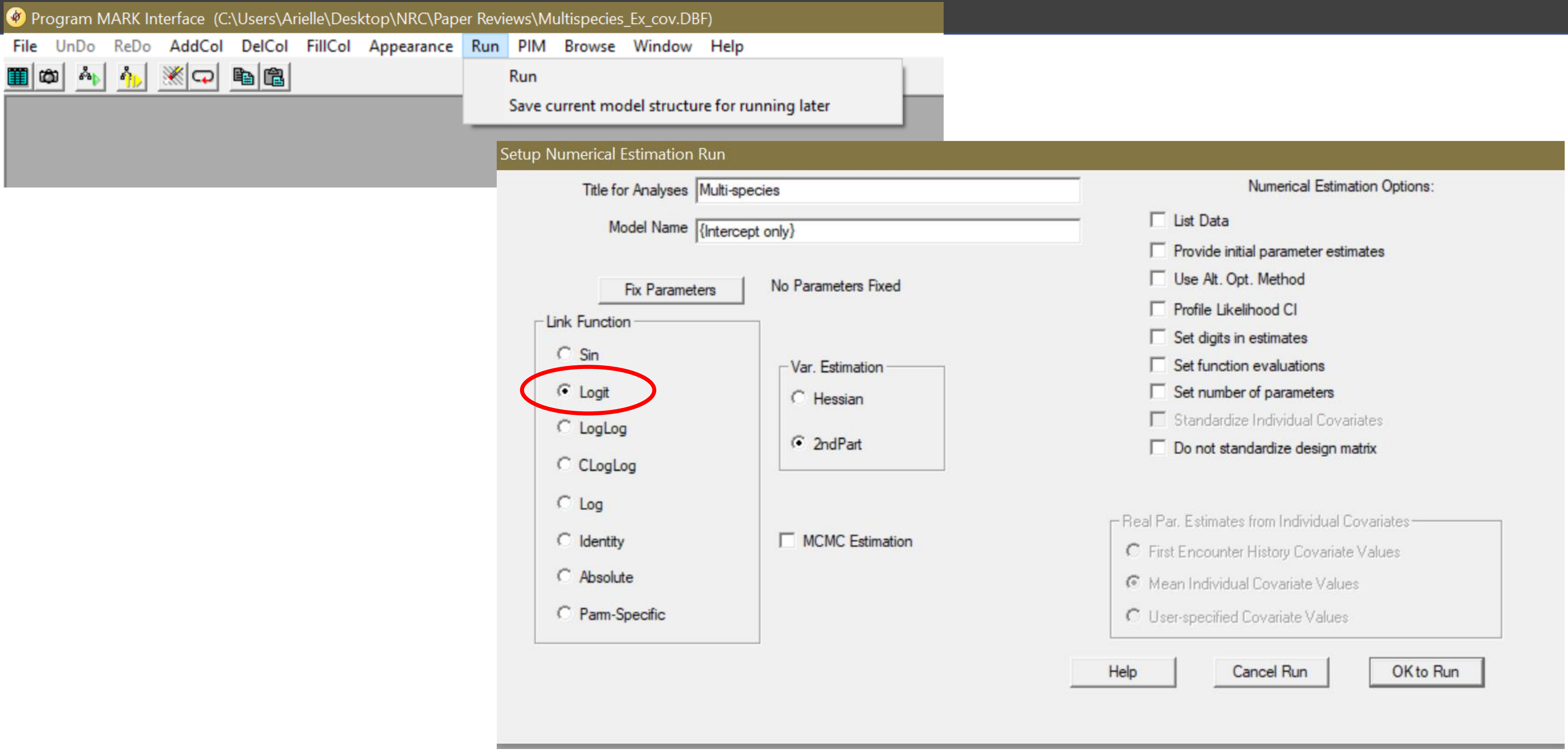
We leave 4 as 0, thus removing all 2-way parameters

$$f_1 = \beta_1$$
$$f_2 = \beta_2$$
$$f_3 = \beta_3$$
$$f_{12} = f_{13} = f_{23} = f_{123} = 0.$$



B1:	B2:	B3:	Parm	B4:	B5:	B6:
1	0	0	1:f	0	0	0
0	1	0	2:f	0	0	0
0	0	1	3:f	0	0	0
0	0	0	4:f	0	0	0
0	0	0	5:p	1	0	0
0	0	0	6:p	0	1	0
0	0	0	7:p	0	0	1

Run the model



Interpreting the model: Betas

Results Browser: Multi-species Occupancy Model

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)	Time Stamp
{Intercept only}	6710.7166	0.0000	1.00000	1.0000	6	6698.6579	6698.6579	18:09:12:12:55:08

mrk5002z.tmp - Notepad

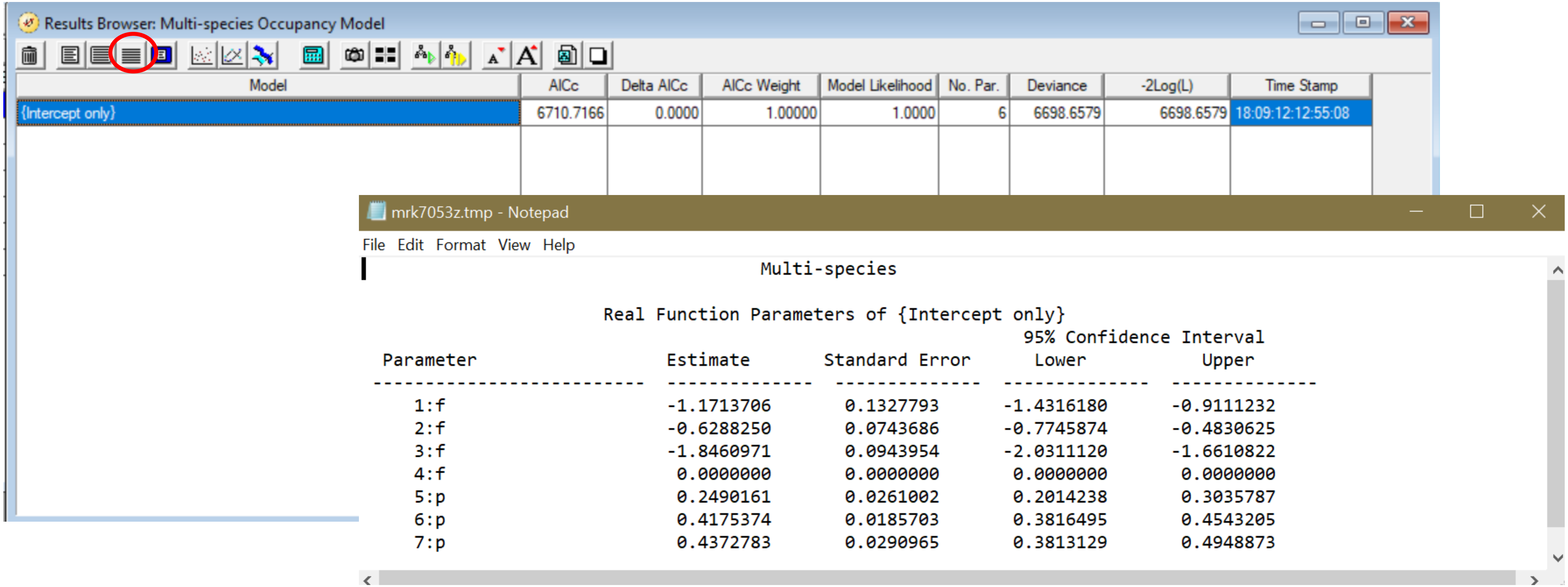
File Edit Format View Help

Multi-species

LOGIT Link Function Parameters of {Intercept only}

Parameter	Beta	Standard Error	95% Confidence Interval Lower	Upper
1: f_1	-1.1713706	0.1327793	-1.4316180	-0.9111232
2: f_2	-0.6288250	0.0743686	-0.7745874	-0.4830625
3: f_3	-1.8460971	0.0943954	-2.0311120	-1.6610822
4: p_1	-1.1038665	0.1395677	-1.3774193	-0.8303137
5: p_2	-0.3328907	0.0763581	-0.4825527	-0.1832288
6: p_3	-0.2522155	0.1182469	-0.4839795	-0.0204515

Interpreting the model: Real parameters



Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)	Time Stamp
{Intercept only}	6710.7166	0.0000	1.00000	1.0000	6	6698.6579	6698.6579	18:09:12:12:55:08

Multi-species

Real Function Parameters of {Intercept only}

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:f	-1.1713706	0.1327793	-1.4316180	-0.9111232
2:f	-0.6288250	0.0743686	-0.7745874	-0.4830625
3:f	-1.8460971	0.0943954	-2.0311120	-1.6610822
4:f	0.0000000	0.0000000	0.0000000	0.0000000
5:p	0.2490161	0.0261002	0.2014238	0.3035787
6:p	0.4175374	0.0185703	0.3816495	0.4543205
7:p	0.4372783	0.0290965	0.3813129	0.4948873

Interpreting the model: Derived estimates

Results Browser: Multi-species Occupancy Model

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Par.	Deviance	-2Log(L)	Time Stamp
{Intercept only}	6710.7166	0.0000	1.00000	1.0000	6	6698.6579	6698.6579	18:09:12:12:55:08

mrk5751z.tmp - Notepad

File Edit Format View Help

Multi-species

Estimates of Derived Parameters

Occupancy Estimates (psi) of {Intercept only}

Grp.	Parm.	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1	Psi000	0.4300223	0.0183532	0.3944790	0.4663020
1	Psi001	0.1332819	0.0140478	0.1080711	0.1632971
1	Psi010	0.2292956	0.0135757	0.2037757	0.2569800
1	Psi011	0.0710683	0.0080382	0.0568376	0.0885275
1	Psi100	0.0678799	0.0061851	0.0567156	0.0810530
1	Psi101	0.0210388	0.0027903	0.0162120	0.0272629
1	Psi110	0.0361948	0.0036170	0.0297364	0.0439922
1	Psi111	0.0112183	0.0015574	0.0085425	0.0147198

Derived from *f* parameters, for example:

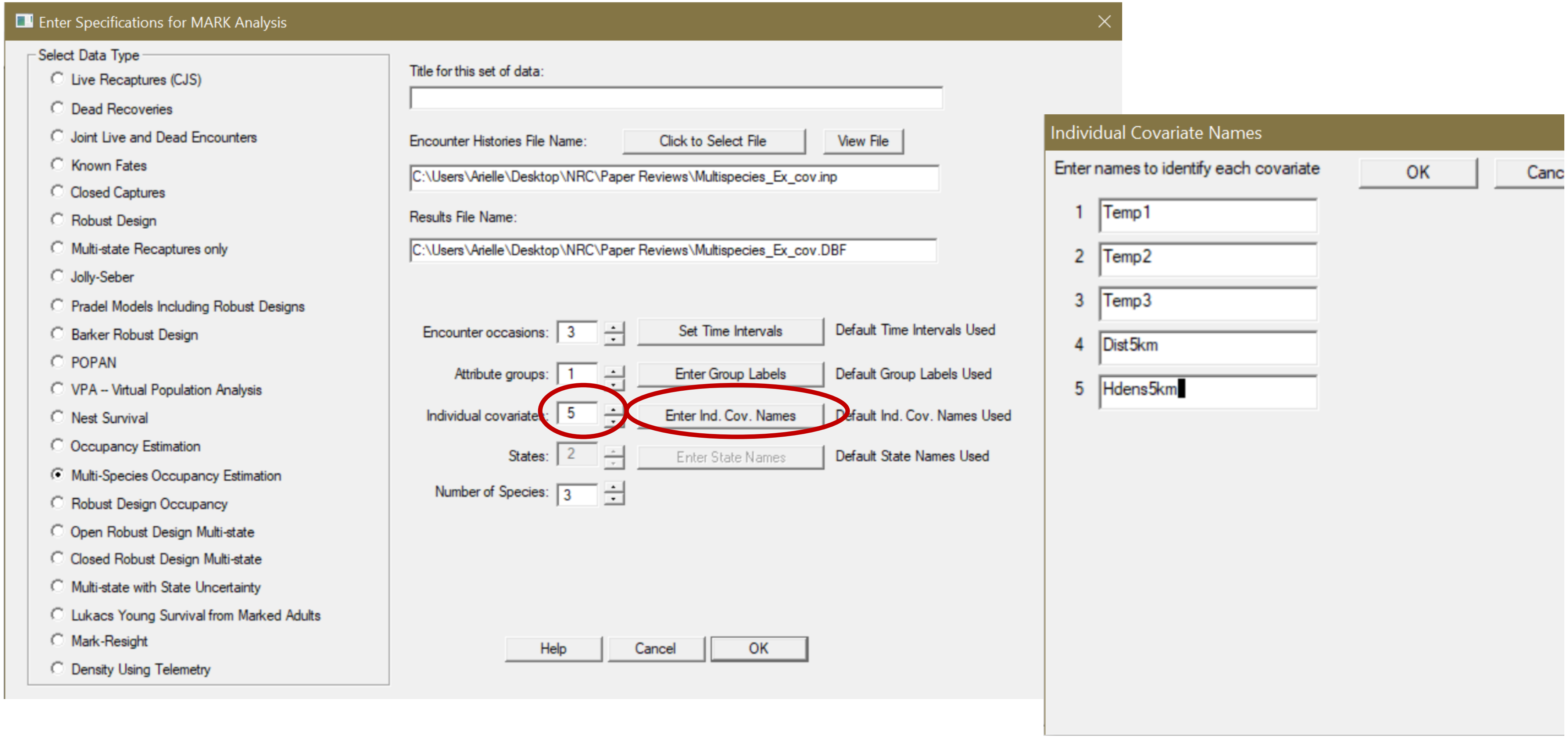
$$\psi_{111} = \frac{\exp(f_1 + f_2 + f_3 + f_{12} + f_{13} + f_{23} + f_{123})}{1 + \exp(f_1) + \exp(f_2) + \exp(f_3) + \exp(f_1 + f_2 + f_{12}) + \exp(f_1 + f_3 + f_{13}) + \exp(f_2 + f_3 + f_{23}) + \exp(f_1 + f_2 + f_3 + f_{12} + f_{13} + f_{23} + f_{123})},$$

A Model with Covariates

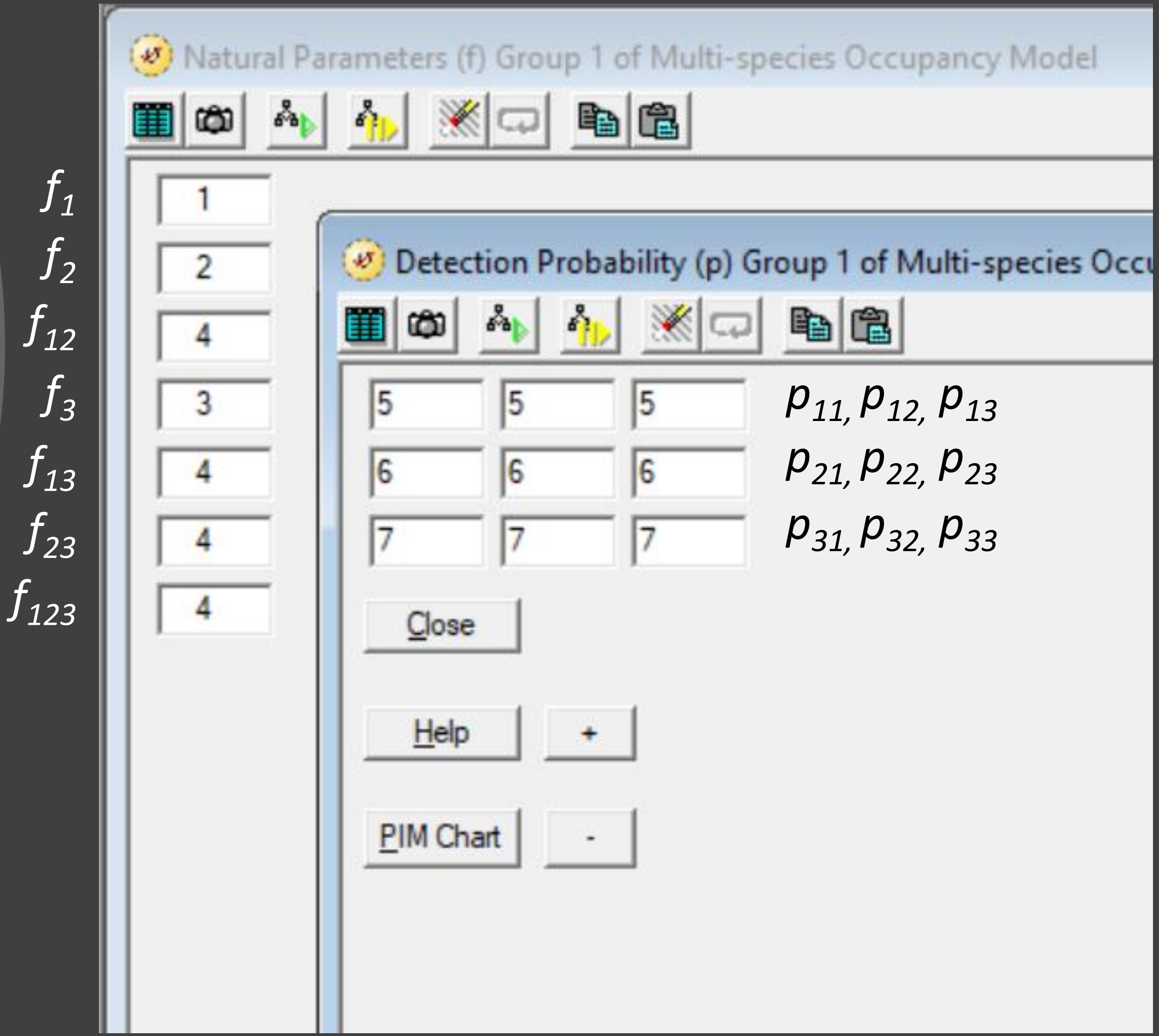
- We will model the effect of Disturbance in a 5km radius on occupancy for each species
  - We again assume independence between species and constant detection probability over the occasions

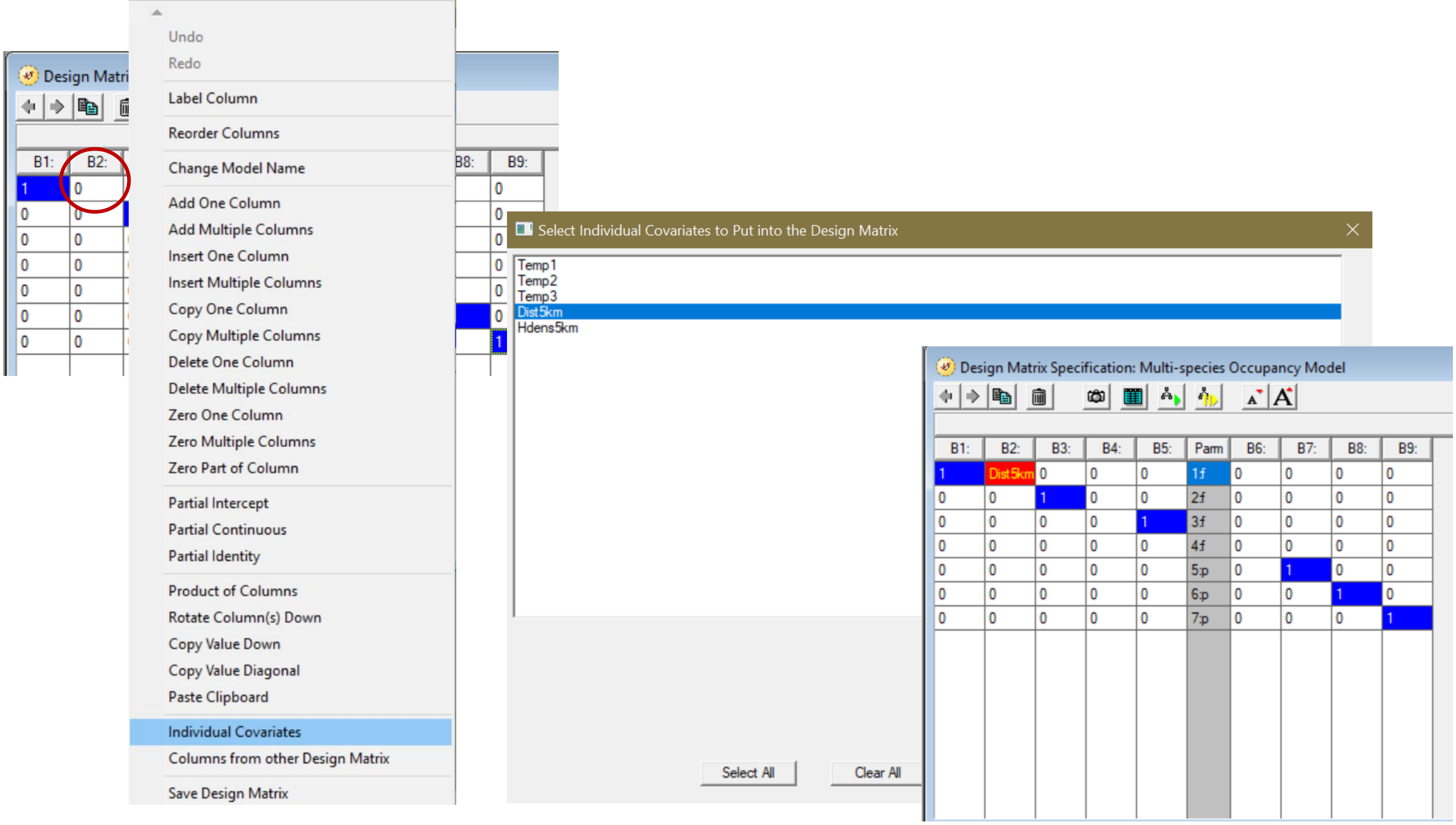
- This will require 9 parameters
  - Intercept and slope coefficients for each 1-way *f* parameter
  - Intercepts for each detection parameter (assume constant detection over surveys)

Reading in the covariate data



PIMs don’t change from our intercept-only model!




Design Matri
B1:
B2:
B8:
B9:
Undo
Redo
Label Column
Reorder Columns
Change Model Name
Add One Column
Add Multiple Columns
Insert One Column
Insert Multiple Columns
Copy One Column
Copy Multiple Columns
Delete One Column
Delete Multiple Columns
Zero One Column
Zero Multiple Columns
Zero Part of Column
Partial Intercept
Partial Continuous
Partial Identity
Product of Columns
Rotate Column(s) Down
Copy Value Down
Copy Value Diagonal
Paste Clipboard
Individual Covariates
Columns from other Design Matrix
Save Design Matrix
Select Individual Covariates to Put into the Design Matrix
Temp1
Temp2
Temp3
Dist5km
Hdens5km
Select All
Clear All
Design Matrix Specification: Multi-species Occupancy Model
B1:
B2:
B3:
B4:
B5:
Parm
B6:
B7:
B8:
B9:
Dist5km
1:f
2:f
3:f
4:f
5:p
6:p
7:p

- Each *f* should have an intercept (1) and a coefficient for Dist5km

- Each *p* should have an intercept (1)

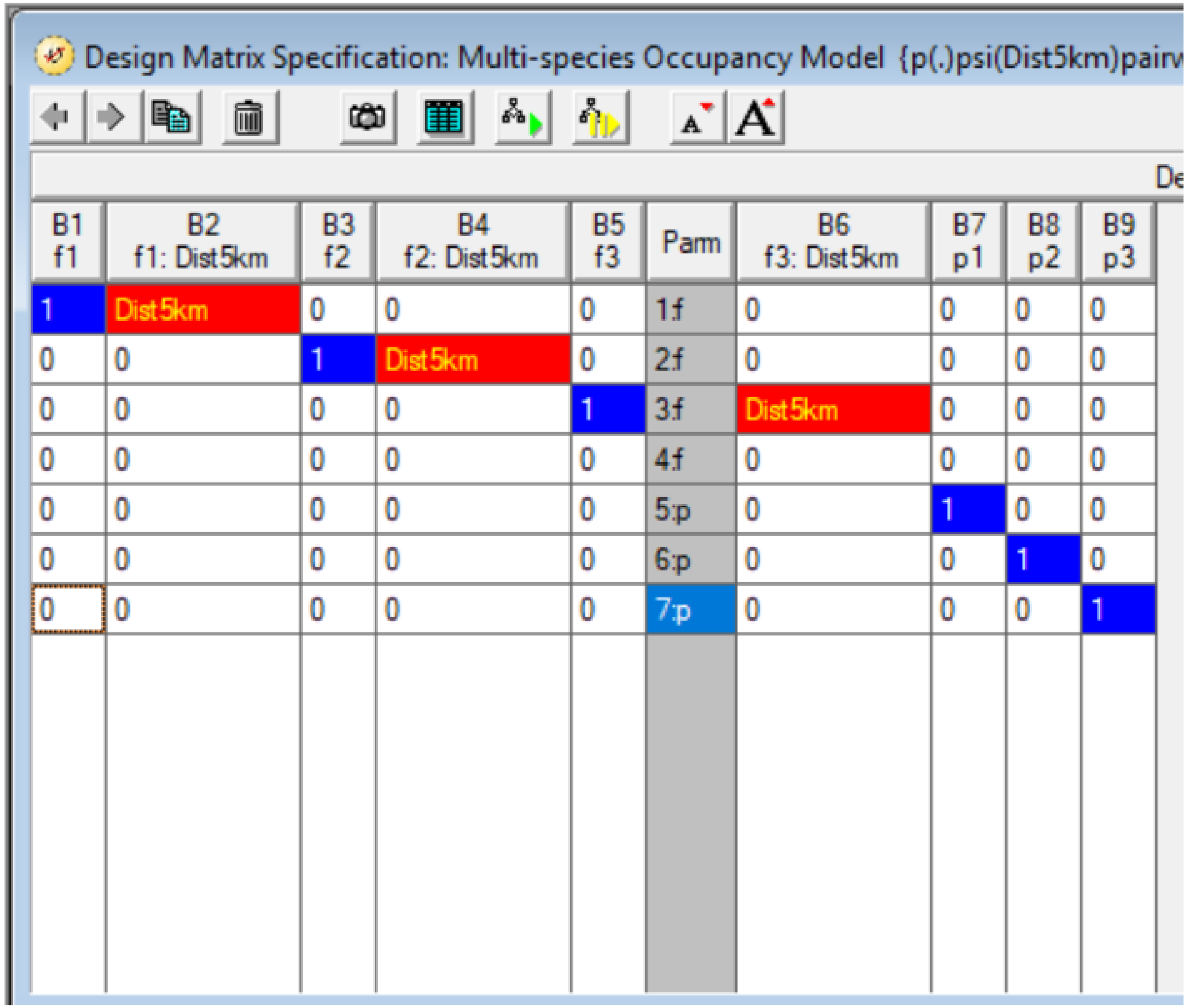
- PIM 4 should = 0

$$f_1 = \beta_1 + \beta_2(\texttt{Dist5km})$$

$$f_2 = \beta_3 + \beta_4(\texttt{Dist5km})$$

$$f_3 = \beta_5 + \beta_6(\texttt{Dist5km})$$

$$f_{12} = f_{13} = f_{23} = f_{123} = 0.$$



B1 f1	B2 f1: Dist5km	B3 f2	B4 f2: Dist5km	B5 f3	Parm	B6 f3: Dist5km	B7 p1	B8 p2	B9 p3
1	Dist5km	0	0	0	1:f	0	0	0	0
0	0	1	Dist5km	0	2:f	0	0	0	0
0	0	0	0	1	3:f	Dist5km	0	0	0
0	0	0	0	0	4:f	0	0	0	0
0	0	0	0	0	5:p	0	1	0	0
0	0	0	0	0	6:p	0	0	1	0
0	0	0	0	0	7:p	0	0	0	1

Interpreting the model

- Marginal occupancy probabilities of species 1 and 3 decline as disturbance increases.
- Species 2 probabilities did not differ from 0.

LOGIT Link Function Parameters of {p(.)psi(Dist5km)pairwise=0}

Parameter	Beta	Standard Error	95% Confidence Interval Lower	Upper
1:f1	-1.2484819	0.1358806	-1.5148078	-0.9821560
2:f1: Dist5km	-0.4968988	0.1218962	-0.7358153	-0.2579823
3:f2	-0.6288623	0.0743809	-0.7746489	-0.4830757
4:f2: Dist5km	-0.0018390	0.0663154	-0.1318171	0.1281391
5:f3	-1.8784183	0.0969993	-2.0685369	-1.6882997
6:f3: Dist5km	-0.2906566	0.1109116	-0.5080434	-0.0732697
7:p1	-1.0962125	0.1384526	-1.3675797	-0.8248454
8:p2	-0.3328904	0.0763580	-0.4825520	-0.1832288
9:p3	-0.2529186	0.1183246	-0.4848349	-0.0210023

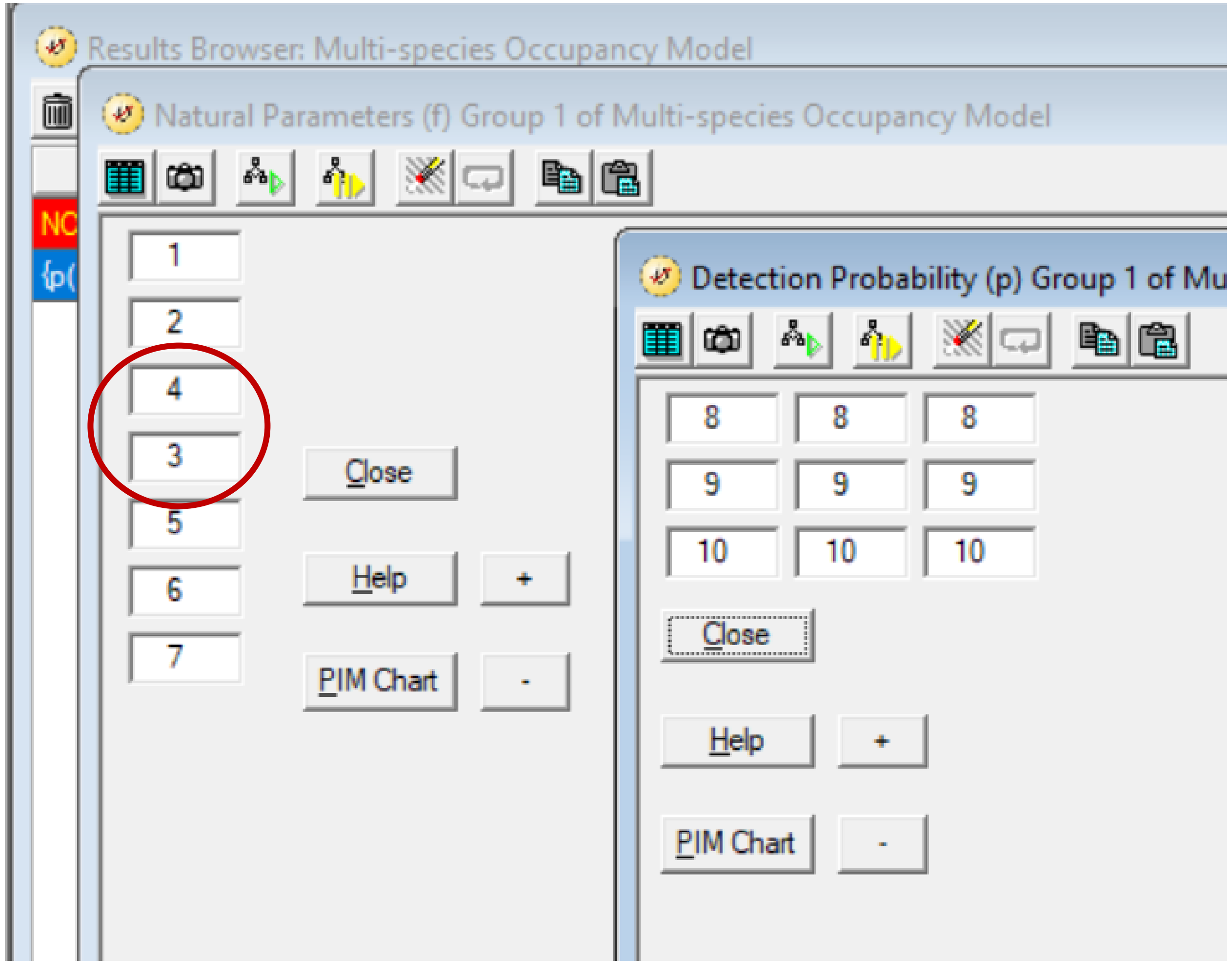
Incorporating species dependence

- Let's add pairwise interactions to our last model, intercepts only
- We will keep f_{123} at 0

- Hints:
  - We will now have 12 covariate columns when we build our design matrix
  - Remember, *f* PIM ordering is non-intuitive
  - Make sure *f* PIM numbering is distinct from *p* PIMs

Try it yourself! We'll go over the solution in ~15min.

PIMs



Results Browser: Multi-species Occupancy Model
Natural Parameters (f) Group 1 of Multi-species Occupancy Model
1
2
4
3
5
6
7
Close
Help
+
PIM Chart
-
Detection Probability (p) Group 1 of Mu
8 8 8
9 9 9
10 10 10
Close
Help
+
PIM Chart
-

Design Matrix

$$f_1 = \beta_1 + \beta_2(\texttt{Dist5km})$$

$$f_2 = \beta_3 + \beta_4(\texttt{Dist5km})$$

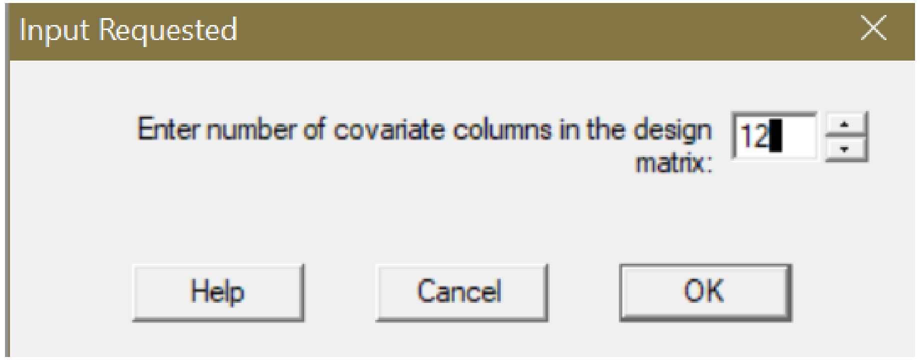
$$f_3 = \beta_5 + \beta_6(\texttt{Dist5km})$$

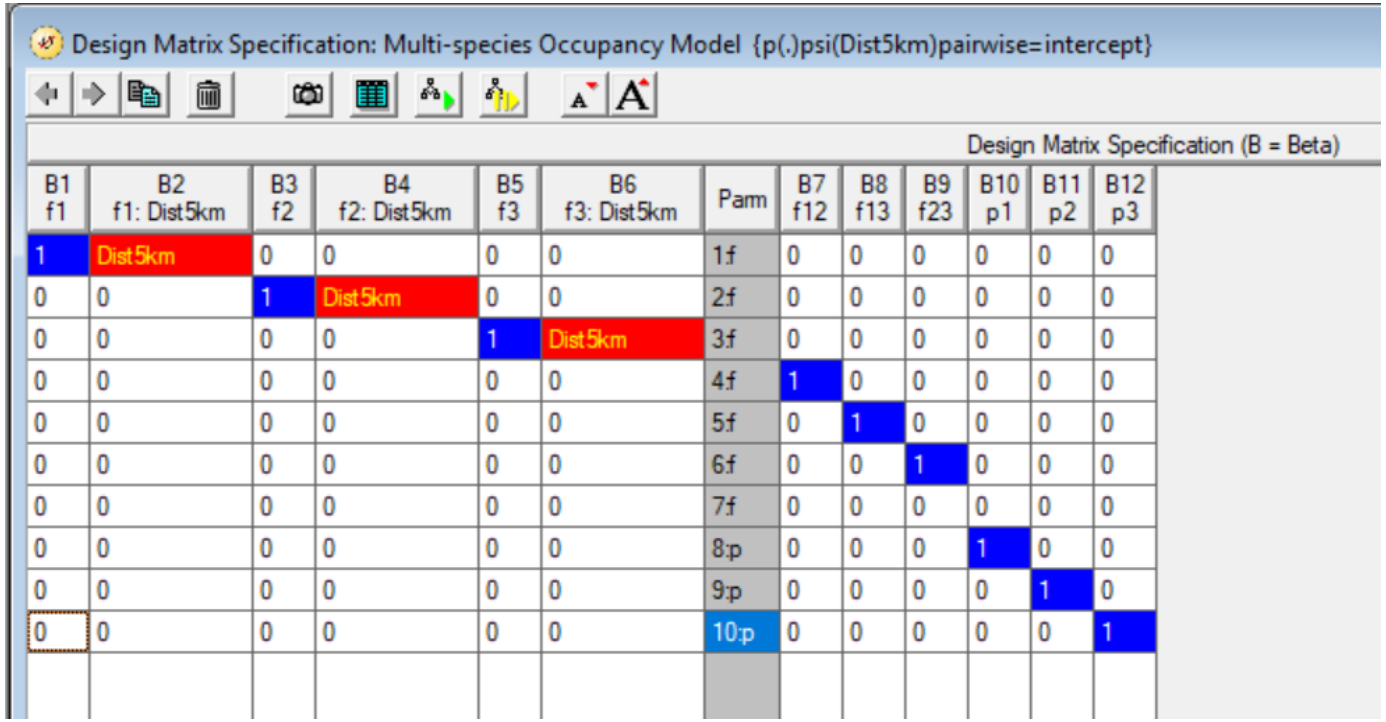
$$f_{12} = \beta_7$$

$$f_{13} = \beta_8$$

$$f_{23} = \beta_9$$

$$f_{123} = 0.$$





B1 f1	B2 f1: Dist5km	B3 f2	B4 f2: Dist5km	B5 f3	B6 f3: Dist5km	Parm	B7 f12	B8 f13	B9 f23	B10 p1	B11 p2	B12 p3
1	Dist5km	0	0	0	0	1:f	0	0	0	0	0	0
0	0	1	Dist5km	0	0	2:f	0	0	0	0	0	0
0	0	0	0	1	Dist5km	3:f	0	0	0	0	0	0
0	0	0	0	0	0	4:f	1	0	0	0	0	0
0	0	0	0	0	0	5:f	0	1	0	0	0	0
0	0	0	0	0	0	6:f	0	0	1	0	0	0
0	0	0	0	0	0	7:f	0	0	0	0	0	0
0	0	0	0	0	0	8:p	0	0	0	1	0	0
0	0	0	0	0	0	9:p	0	0	0	0	1	0
0	0	0	0	0	0	10:p	0	0	0	0	0	1

Interpreting the model

- Spp 1 is more likely to occur at sites where spp 2 also occurs
- Same with spp 2 and 3
- Spp 1 less likely to occur where spp 3 occurs
- 1-way *f* parameter relationships with Dist5km – now in absence of other species

LOGIT Link Function Parameters of {p(.)psi(Dist5km)pairwise=intercept}

Parameter	Beta	Standard Error	95% Confidence Interval Lower	Upper
1:f1	-1.8524512	0.1824997	-2.2101507	-1.4947517
2:f1: Dist5km	-0.5830343	0.1308062	-0.8394146	-0.3266541
3:f2	-1.3173365	0.1379392	-1.5876973	-1.0469757
4:f2: Dist5km	0.1691242	0.0783651	0.0155285	0.3227199
5:f3	-2.2417766	0.1554859	-2.5465291	-1.9370242
6:f3: Dist5km	-0.3955531	0.1182077	-0.6272402	-0.1638660
7:f12	1.7614294	0.2661226	1.2398291	2.2830297
8:f13	-1.5045616	0.3825297	-2.2543198	-0.7548033
9:f23	1.4582382	0.2535373	0.9613051	1.9551714
10:p1	-1.0934334	0.1373733	-1.3626850	-0.8241818
11:p2	-0.3296039	0.0760041	-0.4785719	-0.1806358
12:p3	-0.2514913	0.1181558	-0.4830767	-0.0199059

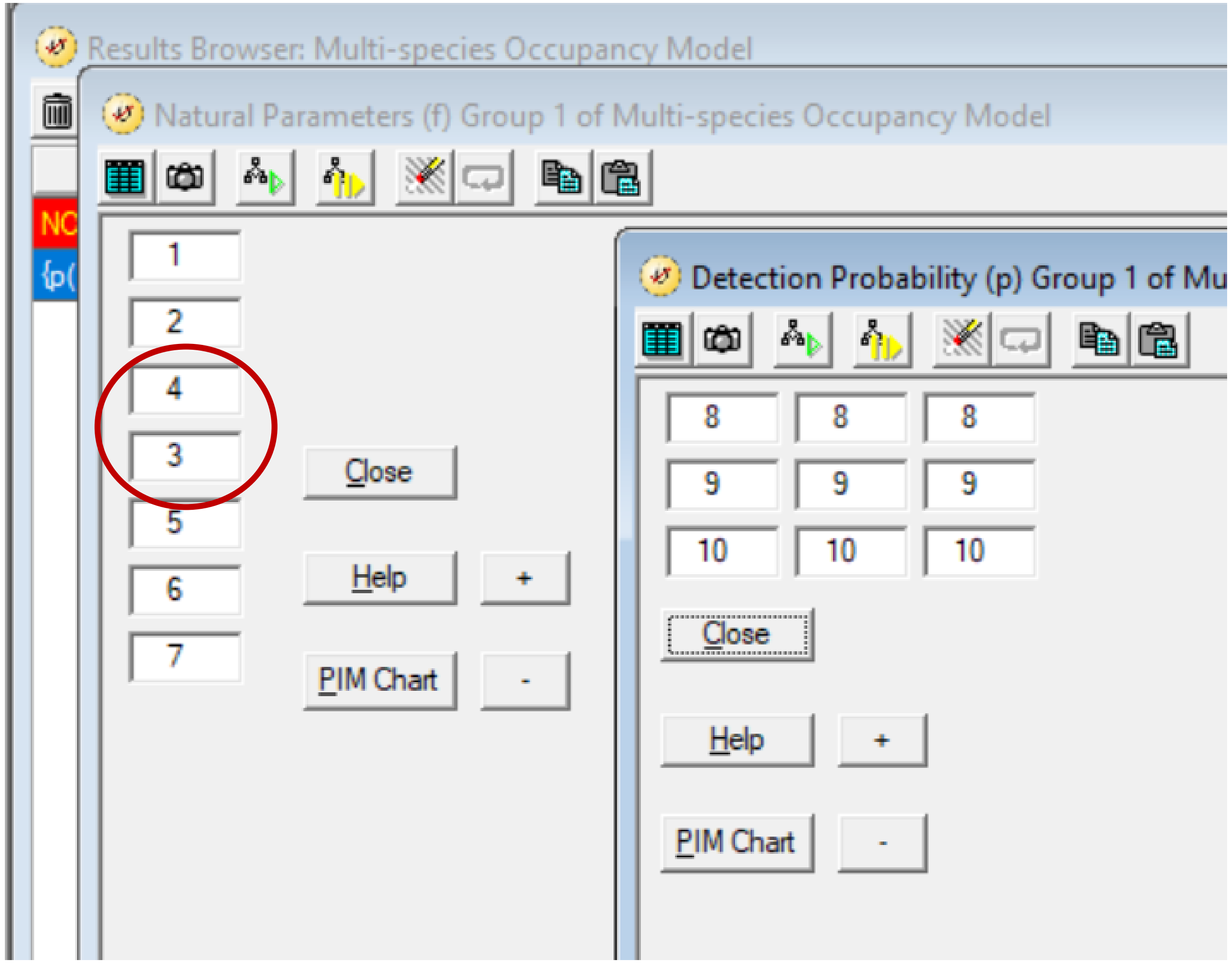
Fitting the model – adding covariates to model pairwise interactions

- Model the probability each pair of species occurs together as a function of average Housing Density in a 5km radius
  - Add this to our last model
- Assume $f_{123} = 0$
- Hint: this will require 15 covariate columns
  - Intercept and slope coefficients for each 1-way *f* parameter AND 2-way *f* parameter
  - Intercepts for each detection parameter (assume constant detection over surveys)

Try it yourself! We'll go over the solution in ~15min.

Same as our previous model assuming constant pairwise interactions

PIMs



Design Matrix

$$f_1 = \beta_1 + \beta_2(\texttt{Dist5km})$$

$$f_2 = \beta_3 + \beta_4(\texttt{Dist5km})$$

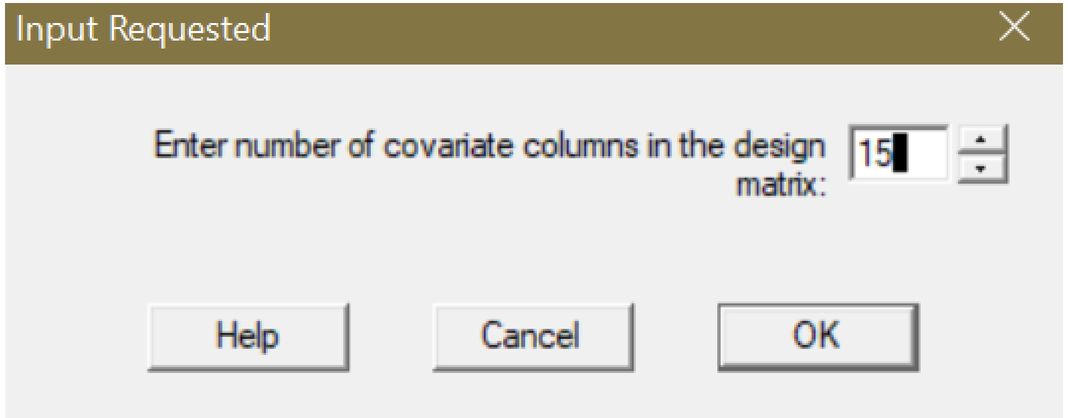
$$f_3 = \beta_5 + \beta_6(\texttt{Dist5km})$$

$$f_{12} = \beta_7 + \beta_8(\texttt{HDens5km})$$

$$f_{13} = \beta_9 + \beta_{10}(\texttt{HDens5km})$$

$$f_{23} = \beta_{11} + \beta_{12}(\texttt{HDens5km}).$$

$$f_{123} = 0.$$



Design Matrix Specification (B = Beta)

B1:	B2:	B3:	B4:	B5:	B6:	B7:	Parm	B8:	B9:	B10:	B11:	B12:	B13:	B14:	B15:
1	Dist5km	0	0	0	0	0	1:f	0	0	0	0	0	0	0	0
0	0	1	Dist5km	0	0	0	2:f	0	0	0	0	0	0	0	0
0	0	0	0	1	Dist5km	0	3:f	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	4:f	HDens5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	5:f	0	1	HDens5	0	0	0	0	0
0	0	0	0	0	0	0	6:f	0	0	0	1	HDens5	0	0	0
0	0	0	0	0	0	0	7:f	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	8:p	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	9:p	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	10:p	0	0	0	0	0	0	0	1

Interpreting the model

- Spp 1 and spp 2 are less likely to occur together in areas of high housing density
- Spp 1 and 3 more likely to occur together in areas of high housing density
- Same for spp 2 and 3

LOGIT Link Function Parameters of {p(.)f-single(Dist)f-pair(Hdens)}

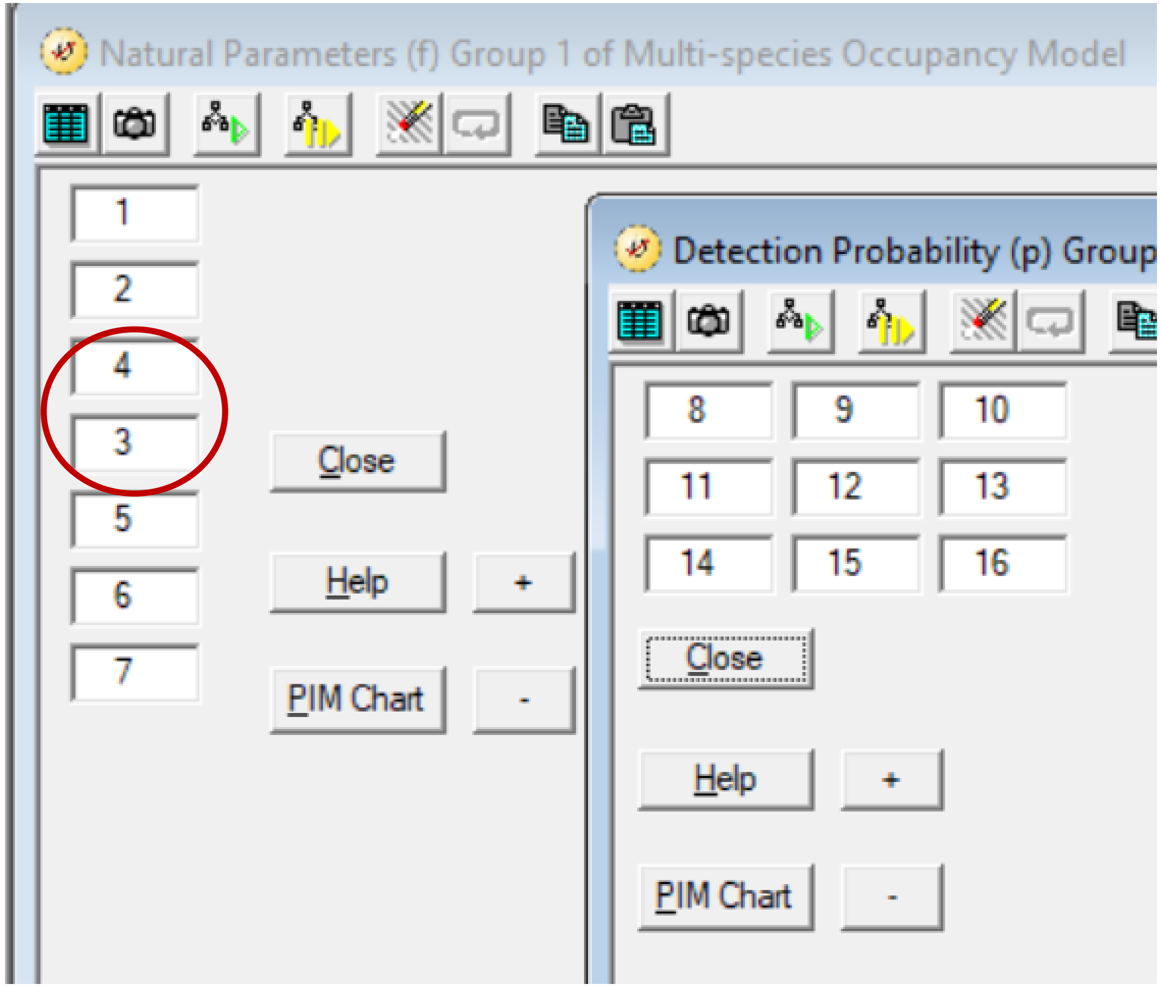
Parameter	Beta	Standard Error	95% Confidence Interval Lower	Upper
1:f1	-1.9742560	0.2086447	-2.3831996	-1.5653123
2:f1: Dist	-0.6133389	0.1335544	-0.8751055	-0.3515723
3:f2	-1.3668626	0.1544098	-1.6695057	-1.0642194
4:f2:Dist	0.2019554	0.0835044	0.0382868	0.3656239
5:f3	-2.3299580	0.1652128	-2.6537751	-2.0061409
6:f3: Dist	-0.2806020	0.1164656	-0.5088746	-0.0523294
7:f12	1.6808477	0.3210020	1.0516838	2.3100117
8:f12: Hdens	-1.7110133	0.5863971	-2.8603517	-0.5616749
9:f13	-1.3216684	0.3977394	-2.1012377	-0.5420991
10:f13: Hdens	0.6343204	0.2079710	0.2266972	1.0419436
11:f23	1.4910281	0.2815325	0.9392243	2.0428318
12:f23:Hdens	0.5766364	0.0804572	0.4189403	0.7343325
13:p1	-1.1180296	0.1382354	-1.3889710	-0.8470882
14:p2	-0.3919951	0.0792814	-0.5473868	-0.2366035
15:p3	-0.2498770	0.1147782	-0.4748422	-0.0249118

Fitting the model – many covariates

- Model the effect of Disturbance and Housing density on each species and pairwise interaction
- Add an effect of temperature for each occasion
  - Use only one beta per species such that *p* for each species is modeled as:
  - $\beta_0 + \beta * Temp_t$
- Assume f_{123} = 0
- Hint: this will require 24 covariate columns

Try it yourself! We'll go over the solution in ~15min.

PIMs


Natural Parameters (f) Group 1 of Multi-species Occupancy Model
1
2
4
3
5
6
7
Close
Help
+
PIM Chart
-
Detection Probability (p) Group
8
9
10
11
12
13
14
15
16
Close
Help
+
PIM Chart
-

Design Matrix

Design Matrix Specification (B = Beta)

B1 f1	B2 f1:Dist	B3 f1:Hdens	B4 f2	B5 f2:Dist	B6 f2:HDens	B7 f3	B8 f3:Dist	B9 f3:Hdens	B10 f12	B11 f12:Dist	B12 f12:Hdens	Parm	B13 f13	B14 f13:Dist	B15 f13:Hdens	B16 f23	B17 f23:Dist	B18 f23:Hdens	B19 p1	B20 p1:Temp	B21 p2	B22 p2:Temp	B23 p3	B24 p3:Temp
1	Dist5km	HDens5km	0	0	0	0	0	0	0	0	0	1:f	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	Dist5km	HDens5km	0	0	0	0	0	0	2:f	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	Dist5km	HDens5km	0	0	0	3:f	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	Dist5km	HDens5km	4:f	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	5:f	1	Dist5km	HDens5km	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	6:f	0	0	0	1	Dist5km	HDens5km	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	7:f	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	8:p	0	0	0	0	0	0	1	Temp1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	9:p	0	0	0	0	0	0	1	Temp2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	10:p	0	0	0	0	0	0	1	Temp3	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	11:p	0	0	0	0	0	0	0	0	1	Temp1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	12:p	0	0	0	0	0	0	0	0	1	Temp2	0	0
0	0	0	0	0	0	0	0	0	0	0	0	13:p	0	0	0	0	0	0	0	0	1	Temp3	0	0
0	0	0	0	0	0	0	0	0	0	0	0	14:p	0	0	0	0	0	0	0	0	0	0	1	Temp1
0	0	0	0	0	0	0	0	0	0	0	0	15:p	0	0	0	0	0	0	0	0	0	0	1	Temp2
0	0	0	0	0	0	0	0	0	0	0	0	16:p	0	0	0	0	0	0	0	0	0	0	1	Temp3

Interpreting the model

- We can see there are issues with some estimates (f1 and f1: Hdens)
- This is where running in a Bayesian framework may prove helpful

Parameter	Beta	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
1:f1	-29.007262	0.0000000	-29.007262	-29.007262
2:f1:Dist	-2.6910195	0.7727428	-4.2055954	-1.1764436
3:f1:Hdens	-94.325285	0.0000000	-94.325285	-94.325285
4:f2	-1.4818867	0.1523445	-1.7804820	-1.1832913
5:f2:Dist	0.1232555	0.1096895	-0.0917360	0.3382469
6:f2:HDens	0.0249994	0.2021198	-0.3711555	0.4211543
7:f3	-2.1616760	0.1658262	-2.4866953	-1.8366567
8:f3:Dist	-0.2524620	0.1762570	-0.5979257	0.0930016
9:f3:Hdens	0.2922377	0.1179816	0.0609938	0.5234816
10:f12	20.058578	1.4353274	17.245336	22.871819
11:f12:Dist	2.1779588	0.7877755	0.6339188	3.7219988
12:f12:Hdens	59.384205	4.2231677	51.106797	67.661614
13:f13	8.1685366	3.2099368	1.8770603	14.460013
14:f13:Dist	0.6441192	0.4218879	-0.1827812	1.4710195
15:f13:Hdens	34.626262	10.934378	13.194881	56.057643
16:f23	1.4005123	0.2887813	0.8345009	1.9665237
17:f23:Dist	-0.1708798	0.2962316	-0.7514938	0.4097341
18:f23:Hdens	0.1560184	0.2543303	-0.3424691	0.6545058
19:p1	-1.4954624	0.1398802	-1.7696276	-1.2212971
20:p1:Temp	-0.3203248	0.0783615	-0.4739133	-0.1667363
21:p2	-0.3778195	0.0741682	-0.5231892	-0.2324499
22:p2:Temp	-0.0532776	0.0645978	-0.1798893	0.0733340
23:p3	-0.2908377	0.1196860	-0.5254223	-0.0562531
24:p3:Temp	-0.0359246	0.1094114	-0.2503710	0.1785217

Summary

- MARK is a fairly “friendly” interface for easily running multi-species models
- Special attention must be paid to PIMs and the Design Matrix when specifying models
- Trying to run a model with a large number of covariates may lead to instability, we can potentially remedy some of that within a Bayesian framework