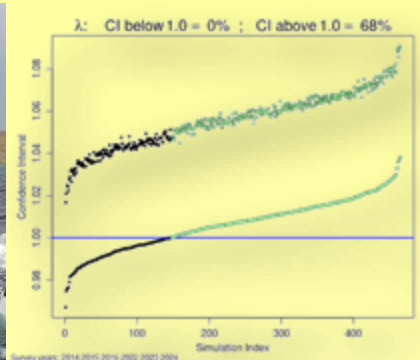
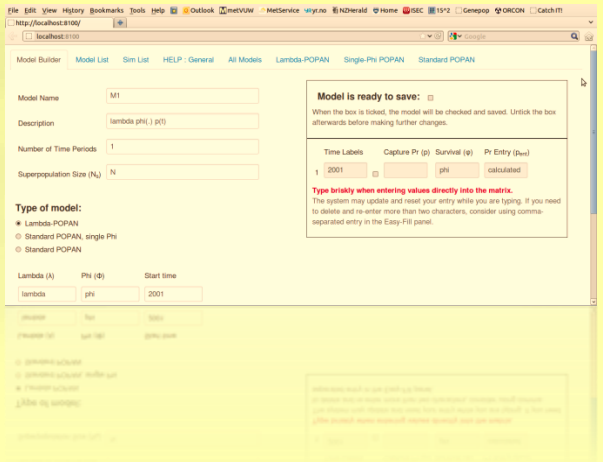
CaPow!

Capture-recapture Power analysis and simulation





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Motivation: Detecting Trends

- Planning a long-term capture-recapture study, e.g. for whale populations
- Wish to know whether the population is growing or declining
- λ = Annual population growth rate

$$\frac{EN_{t+1}}{EN_t} = \lambda$$

- Will the study be able to deliver a significant result for λ ?

Power Analysis

- If the true λ is 1.03 (3% annual growth), will my study design deliver an estimate significantly different from 1?

Is my model getting it right?

- Will my sample sizes deliver correct confidence interval coverage?
- Impact of model misspecification: e.g. what if survival and birth aren't constant and I assume they are?

CaPow : easy model exploration

- Runs ***R*** through web browser (RShiny)
- Build Model-sets:
  - what models you want to fit
- Build Simulation-sets:
  - numbers for demographic parameters
- Build Projects:
  - each Project combines one Simulation-set and one Model-set
- Run projects and collect results

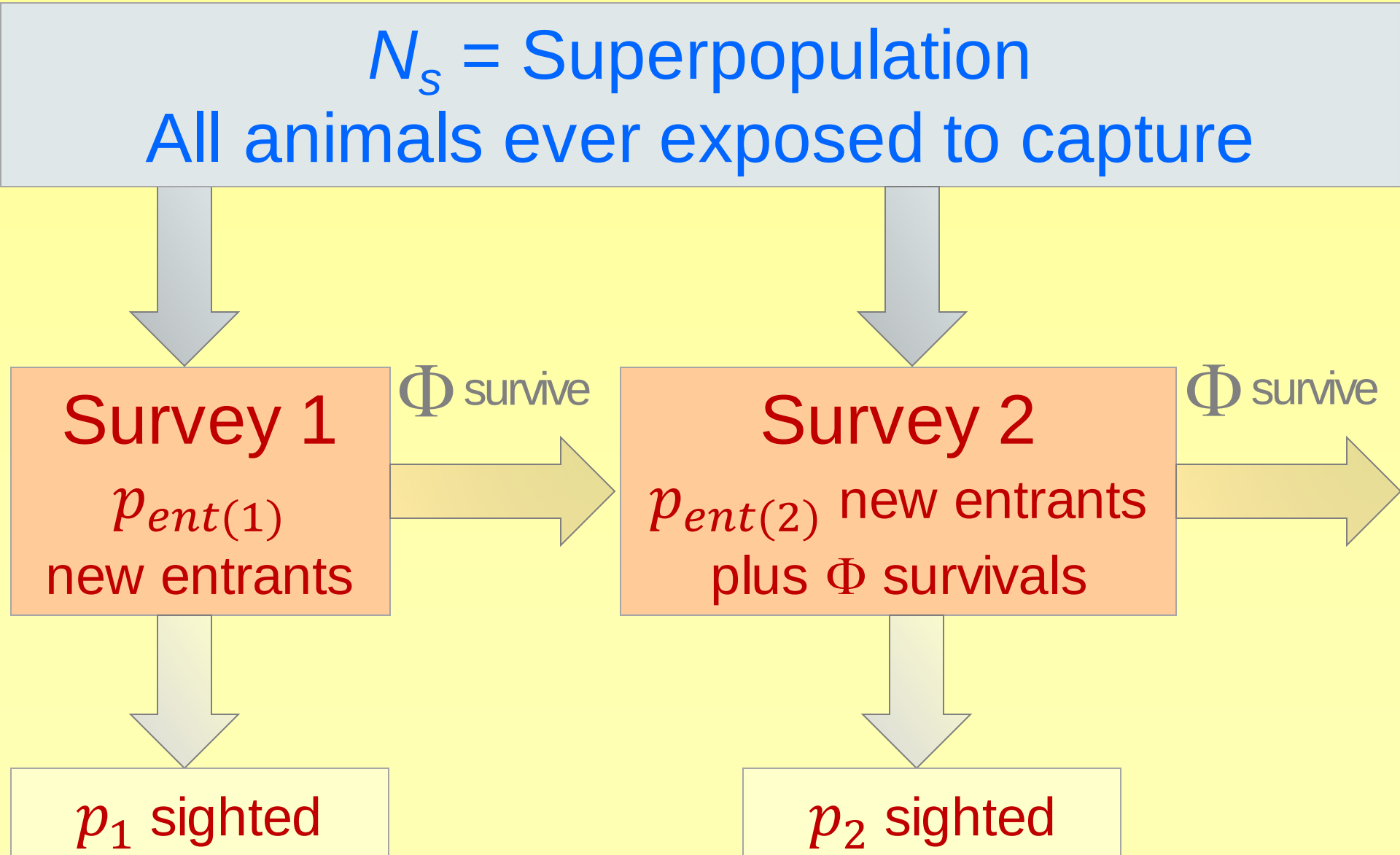
POPAN Model

Schwarz, C. J. and Arnason, A. N.

A general methodology for the analysis of open-model capture recapture experiments.

Biometrics 52, 860-873, 1996

POPAN Model


N_s = Superpopulation
All animals ever exposed to capture
Survey 1
$p_{ent(1)}$
new entrants
Φ survive
Survey 2
$p_{ent(2)}$ new entrants
plus Φ survivals
Φ survive
p_1 sighted
p_2 sighted

λ-POPAN Model

Carroll, E.L., Brooks, L., Baker, C.S., Burns, D., Garrigue, C., Hauser, N., Jackson, J.A., Poole, M.M., Fewster, R.M.

Assessing the design and power of capture−recapture studies to estimate demographic parameters for the Endangered Oceania humpback whale population

Endangered Species Research, 28, 147-162, 2015

Carroll, E.L., Childerhouse, S.J., Fewster, R.M., Patenaude, N.J., Steel, D., Dunshea, G., Boren, L., Baker, C.S.

Accounting for female reproductive cycles in a superpopulation capture–recapture framework

Ecological Applications, 23, 1677-1690, 2013

λ-POPAN Model

- Estimates N_s and λ together
- N_s = Superpopulation size
- λ = Annual population growth rate

$$\frac{EN_{t+1}}{EN_t} = \lambda$$

- Φ = Annual survival probability
- $p_1, \ p_2, \ldots$: capture probabilities

λ-POPAN Model

- λ = Annual population growth rate

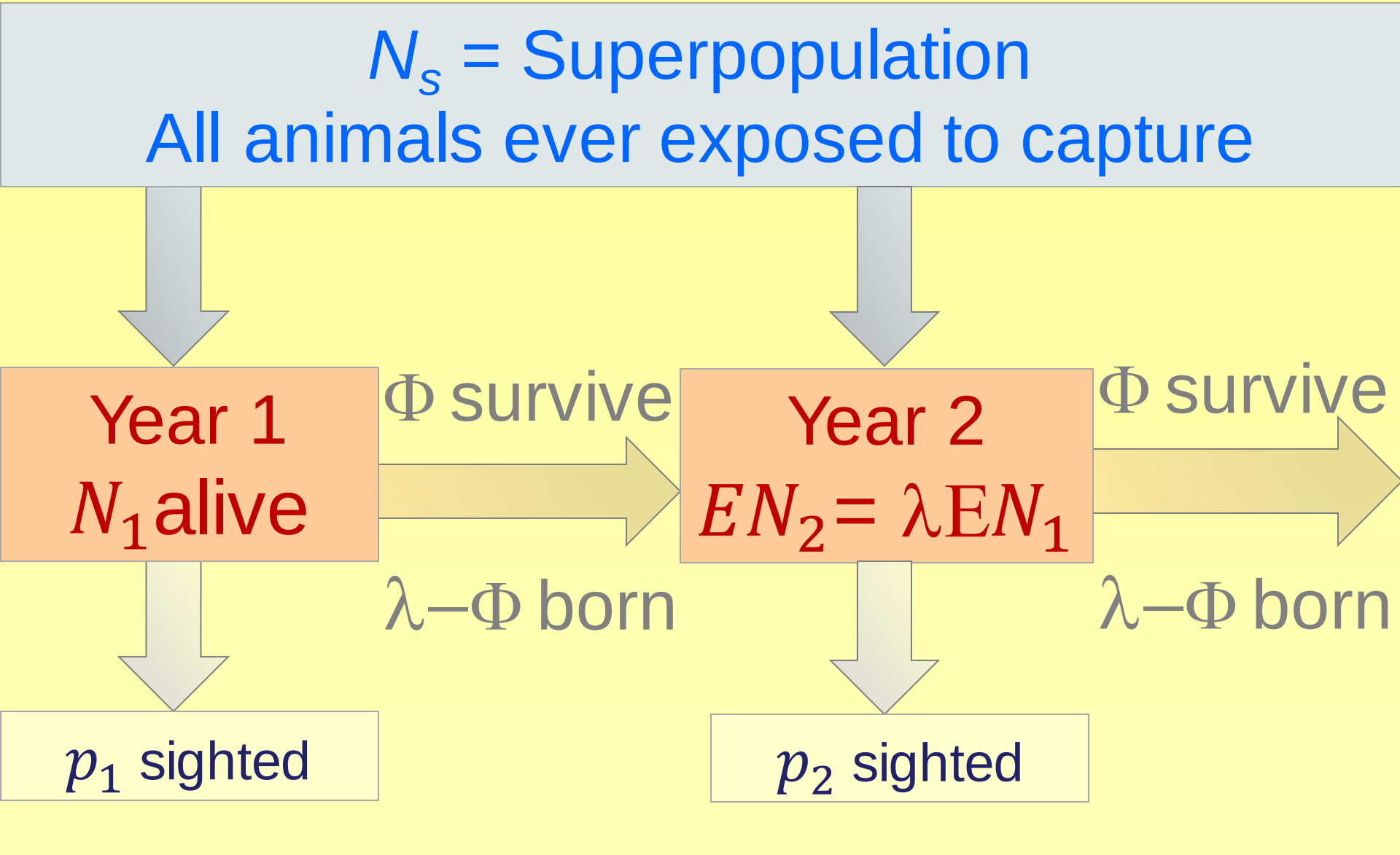
$$\frac{EN_{t+1}}{EN_t} = \lambda$$

λ-POPAN just constrains

$p_{ent(1)}, p_{ent(2)}, \cdots$

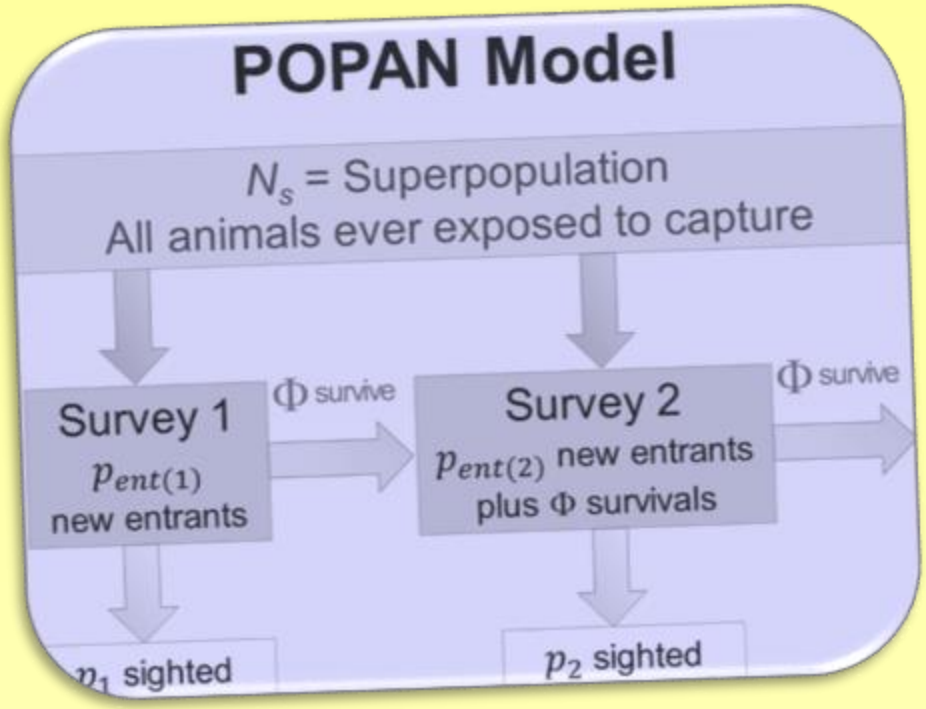
to follow a smooth growth curve

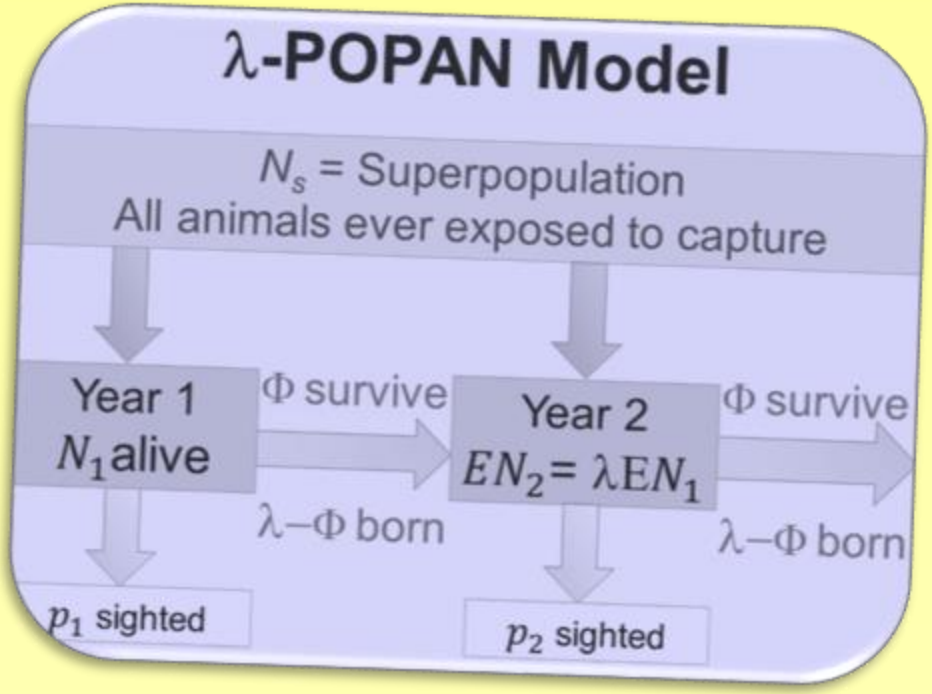
λ-POPAN Model



CaPow : easy model exploration

- Simulates and fits general POPAN models and λ-POPAN models





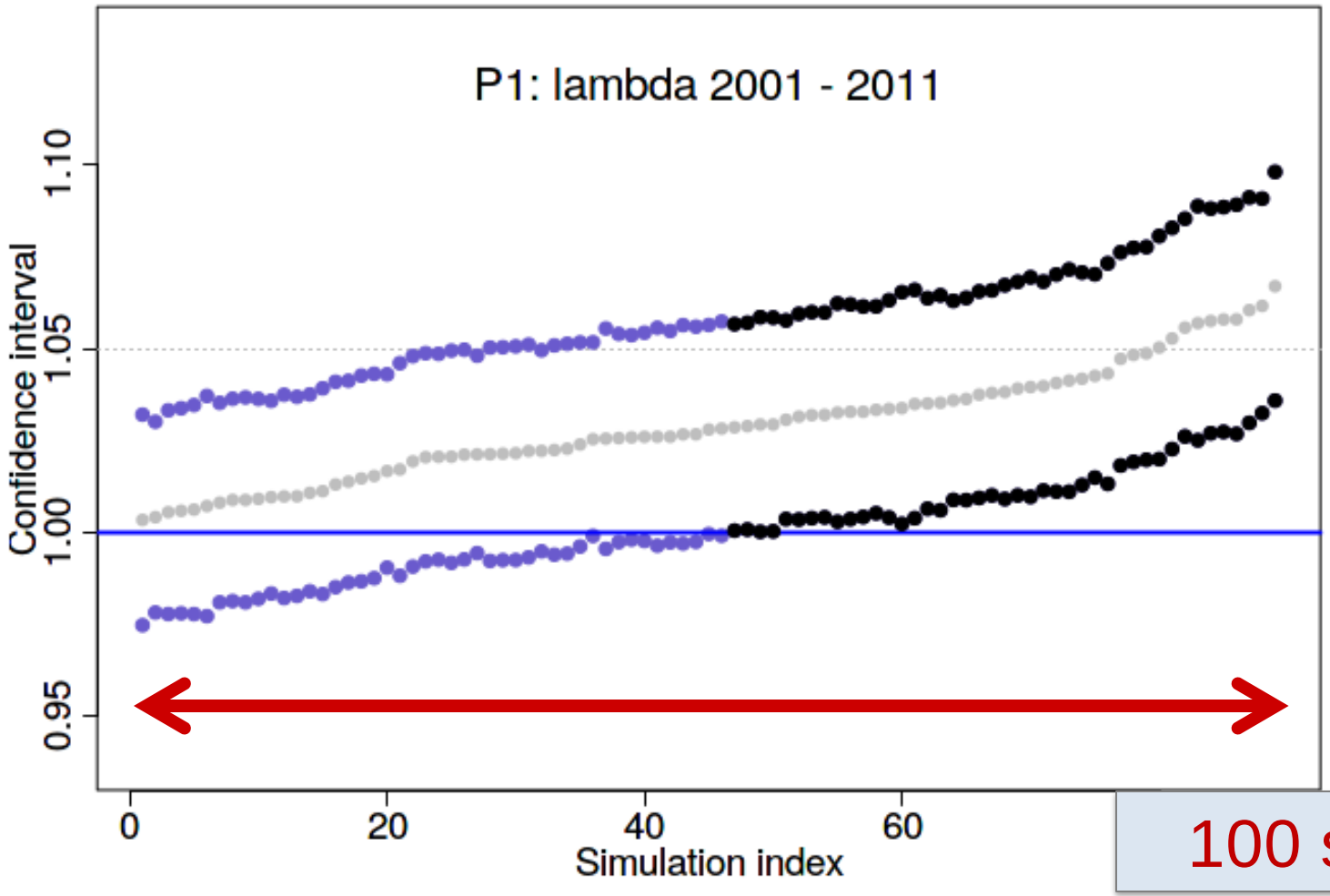
- We'll focus on λ-POPAN models today

Power Analysis

- Run simulations and fit λ-POPAN
- POWER = proportion of simulations with statistically significant trend:
  - λ > 1 : population increasing
  - λ < 1 : population decreasing
- Trend is significant if λ=1 is excluded from 95% confidence interval

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1	lambda 2001 - 2011	lambda	1	48.31	48.31	0.00



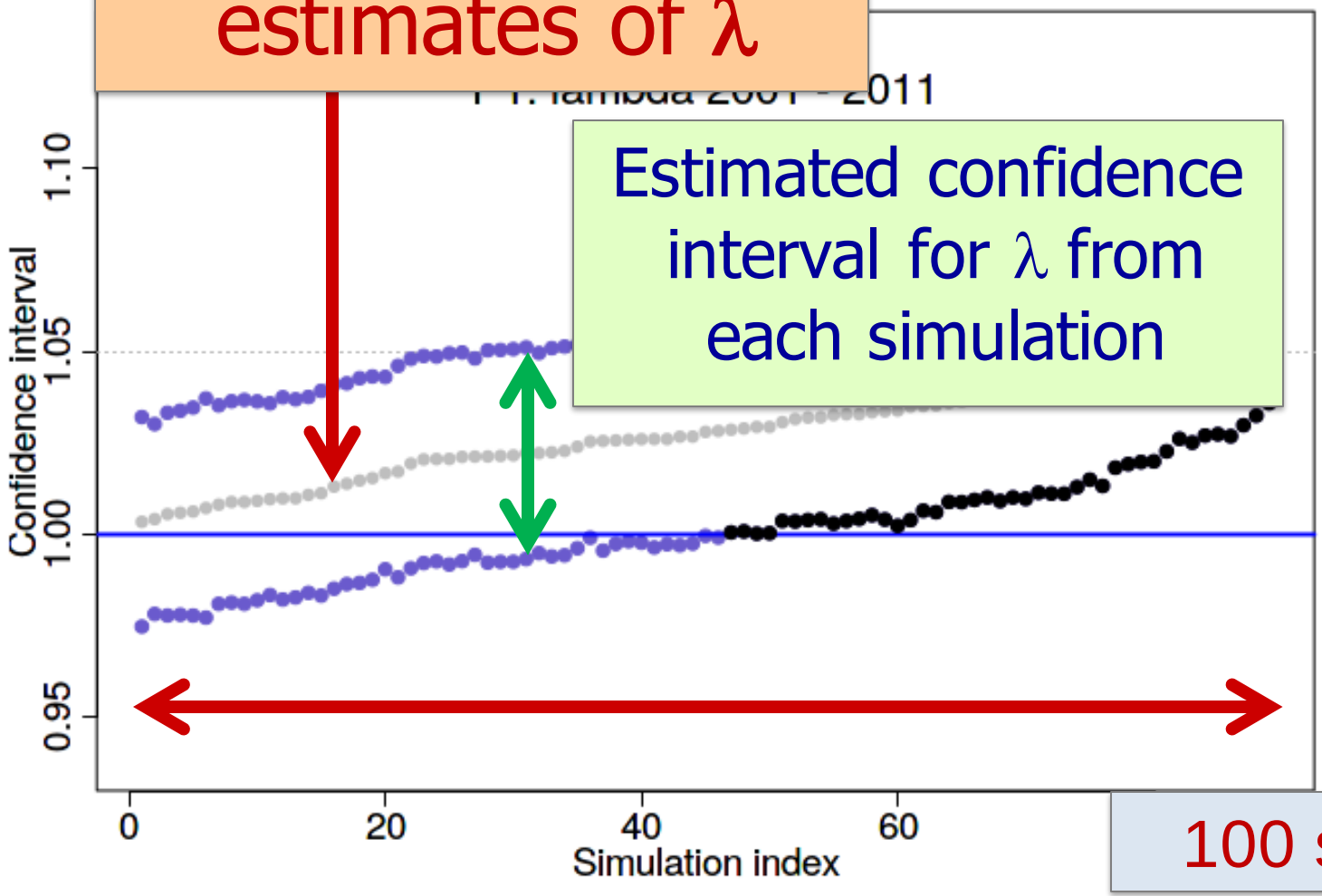
$\lambda=1$ Query value

100 simulations

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1	lambda 2001 - 2011	lambda	1	48.31	48.31	0.00

Grey points: 100 estimates of λ



Estimated confidence interval for λ from each simulation

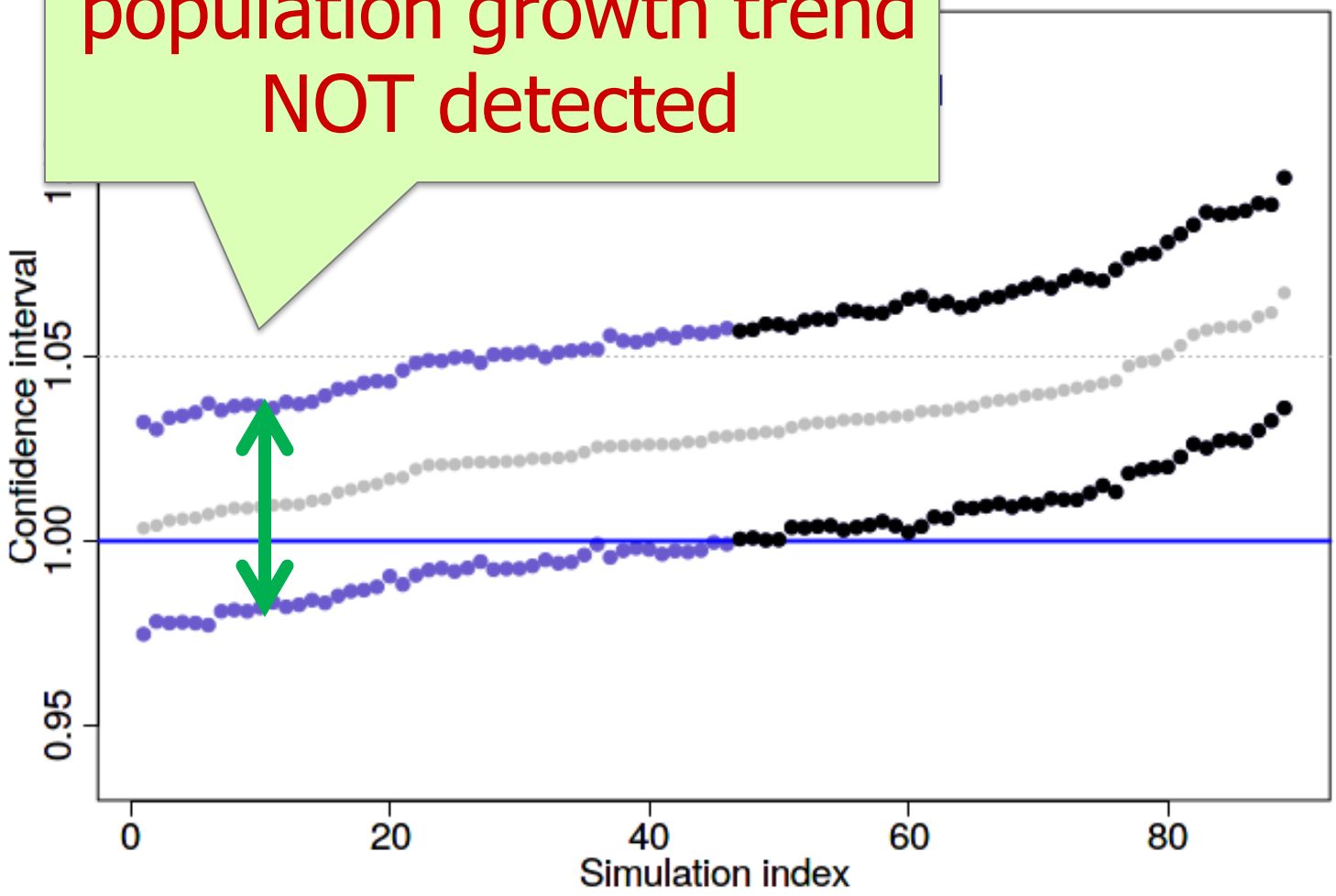
λ=1 Query value

100 simulations

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P				8.31	48.31	0.00

CI for this simulation contains λ=1: population growth trend NOT detected

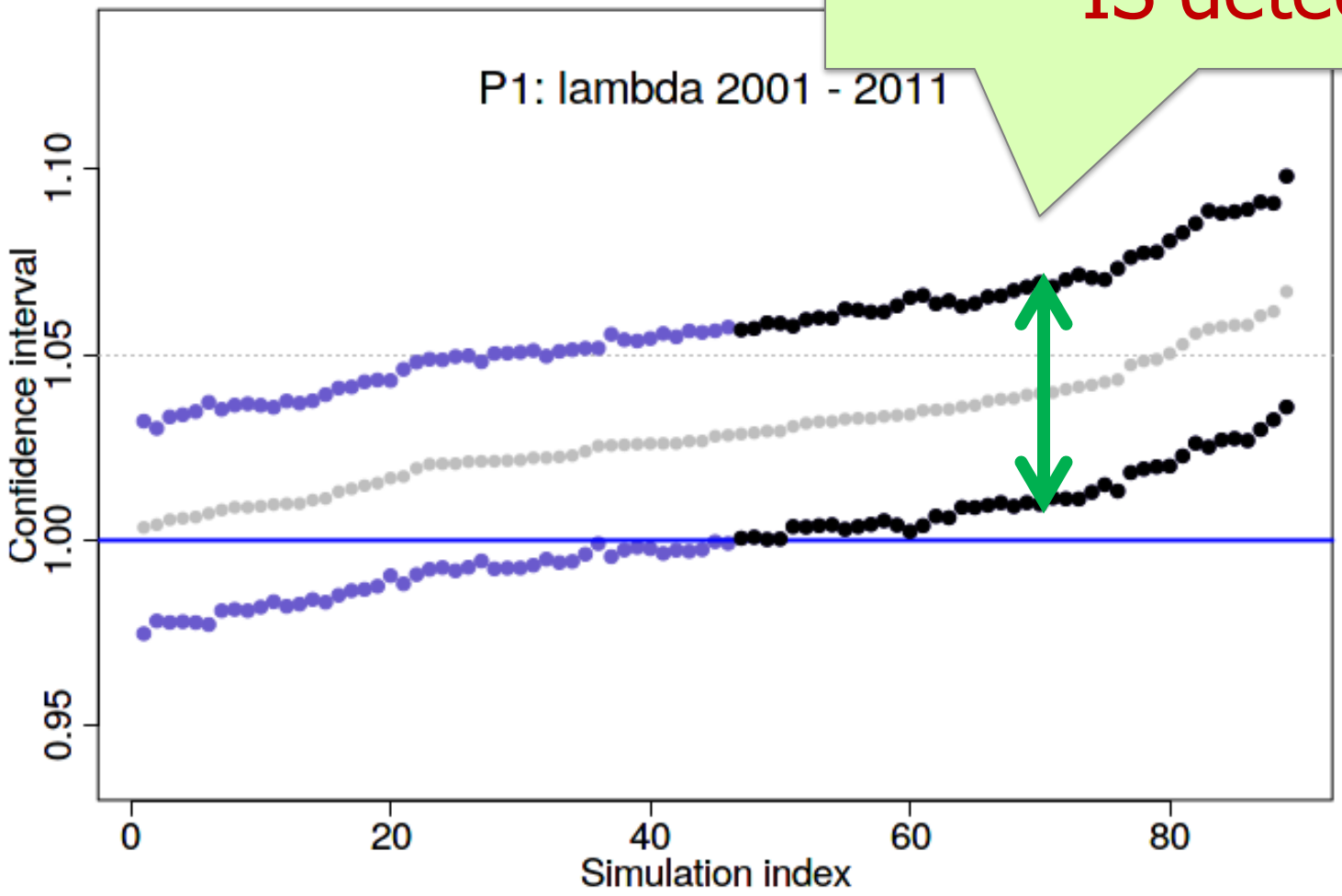


λ=1 Query value

lambda: all time

Project	Description	Parameter	Queried Value	Ov (%)
P1	lambda 2001 - 2011	lambda	1	

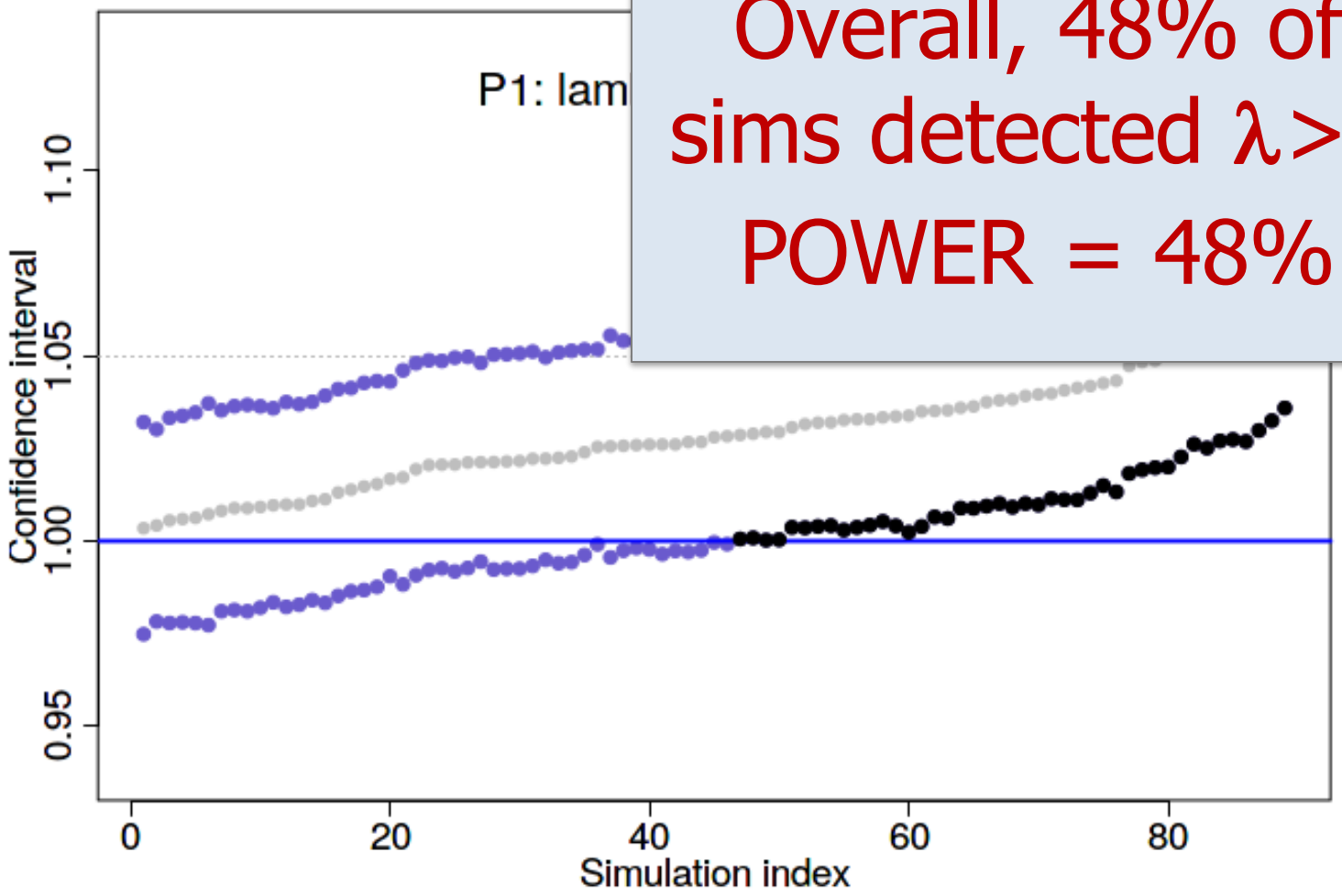
CI for this simulation EXCLUDES λ=1: population growth trend IS detected



λ=1 Query value

lambda: all time

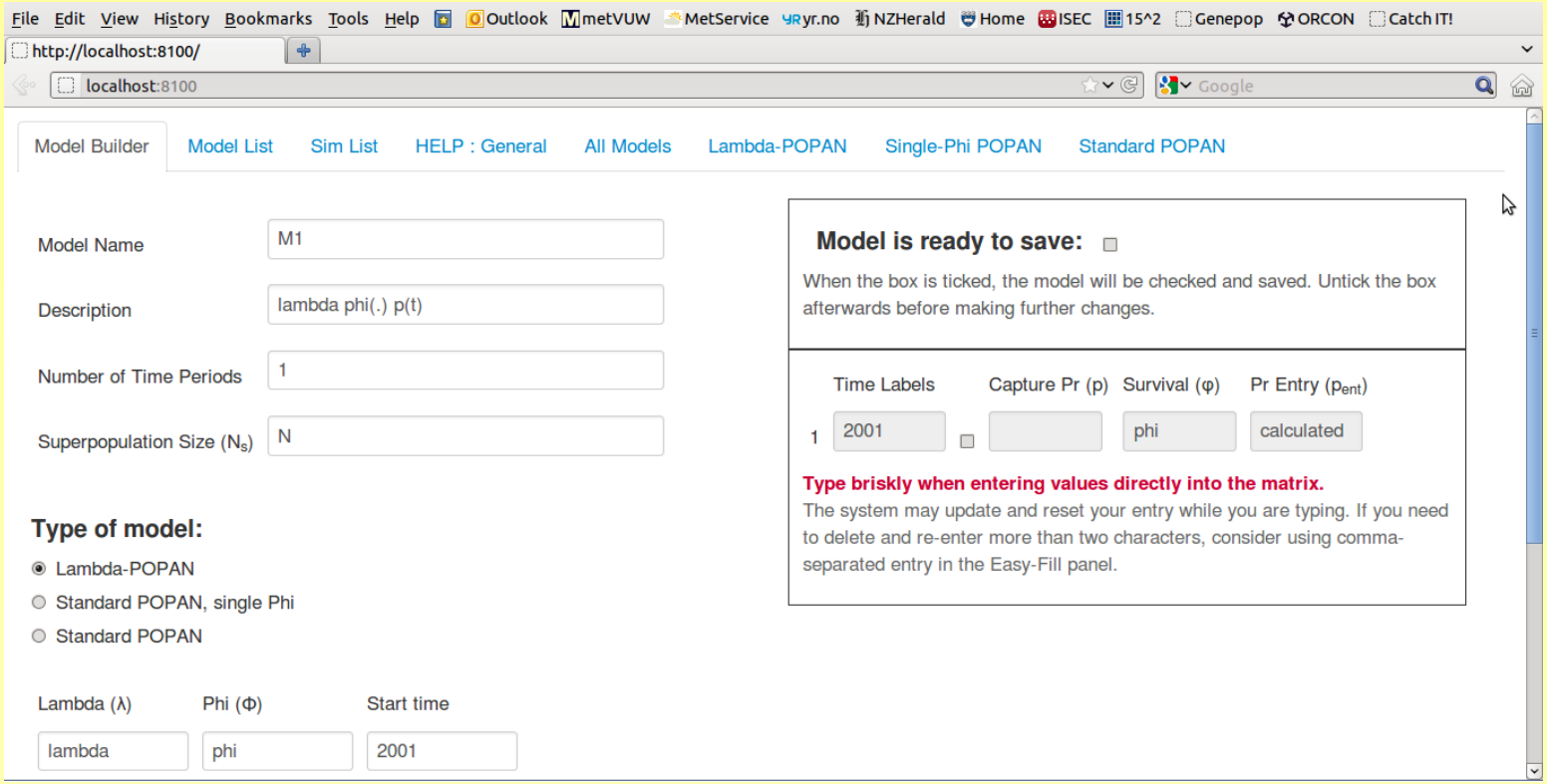
Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1	lambda 2001 - 2011	lambda	1	48.31	48.31	0.00

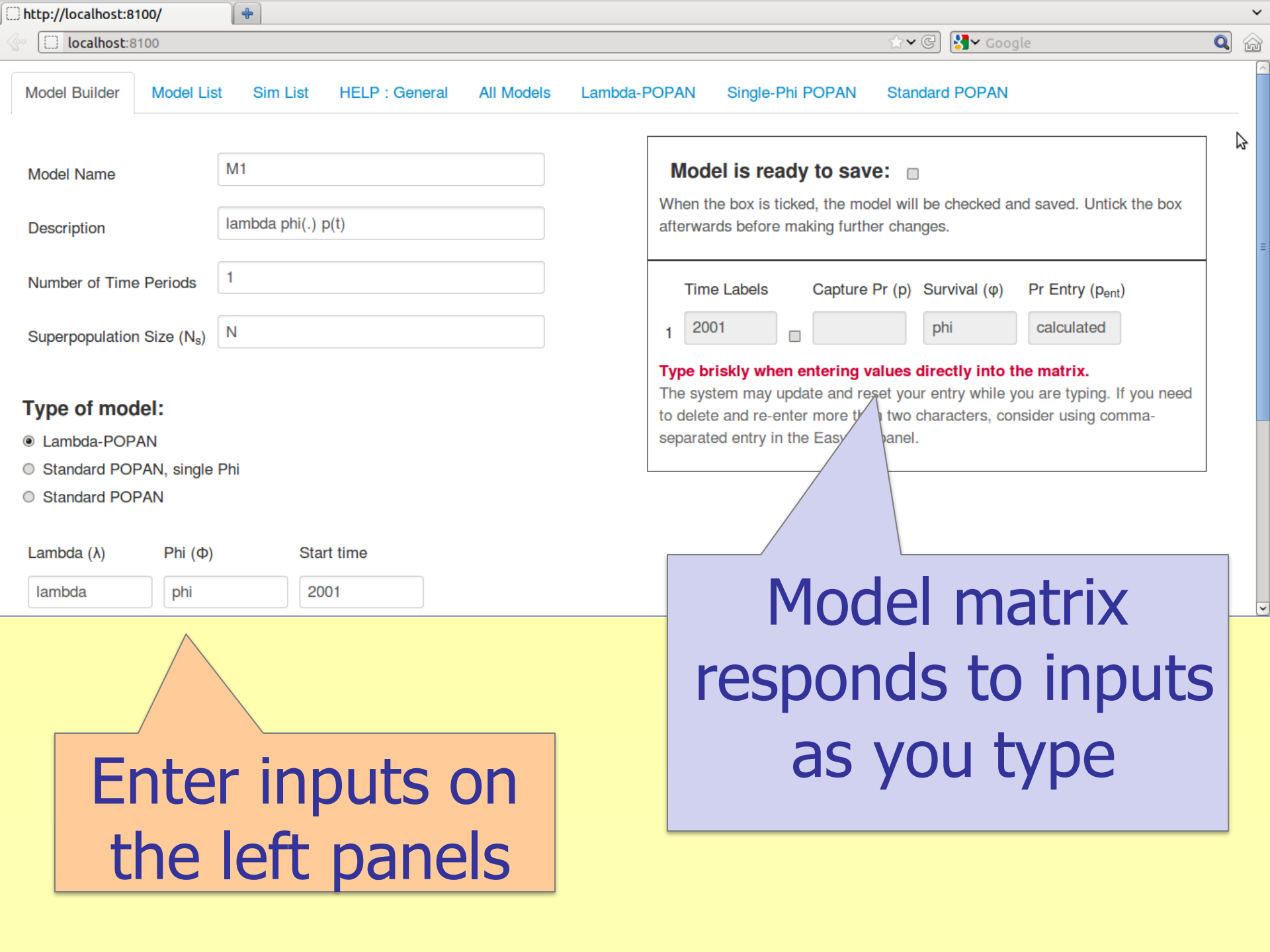


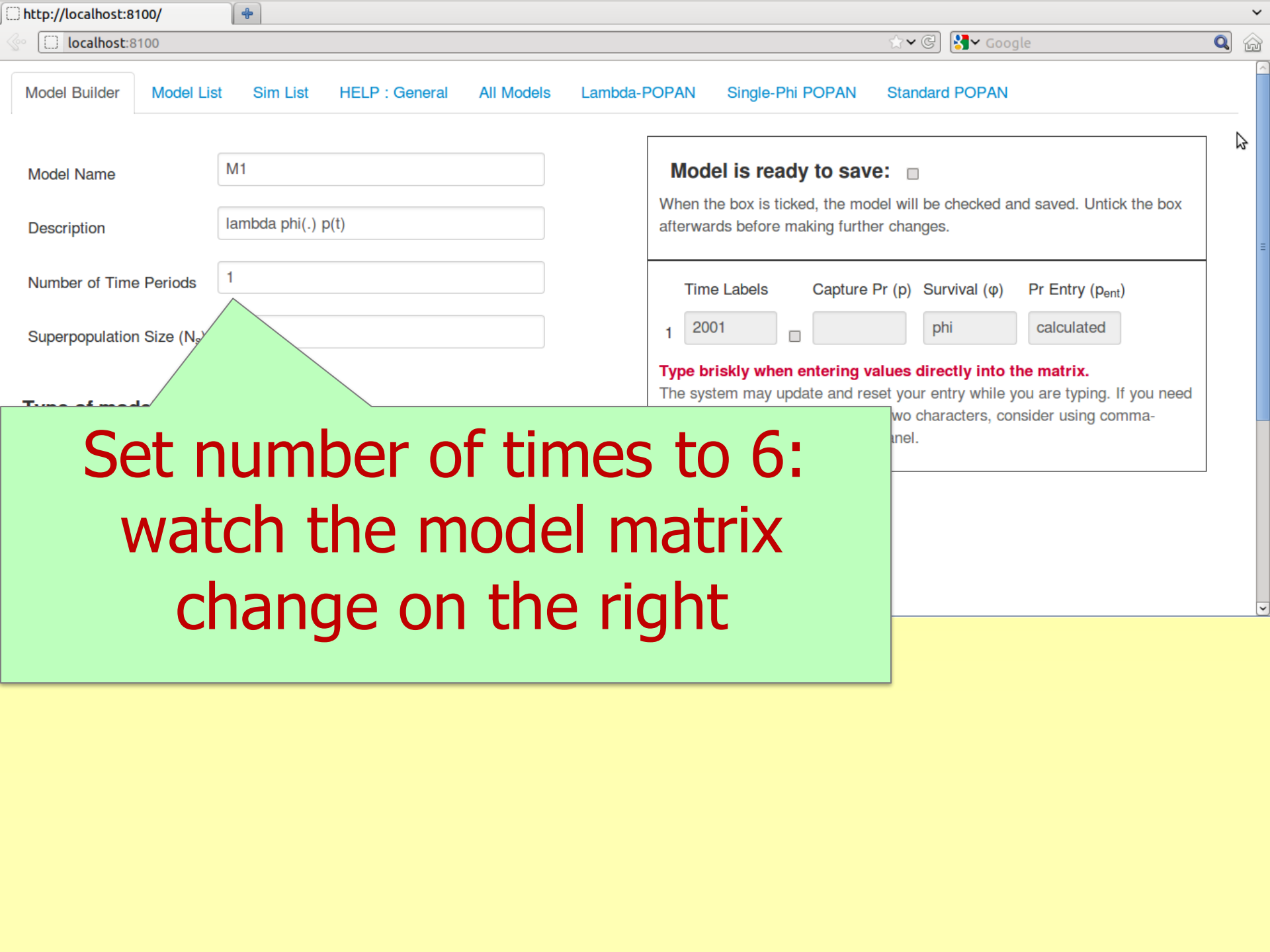
Overall, 48% of sims detected $\lambda > 1$: POWER = 48%

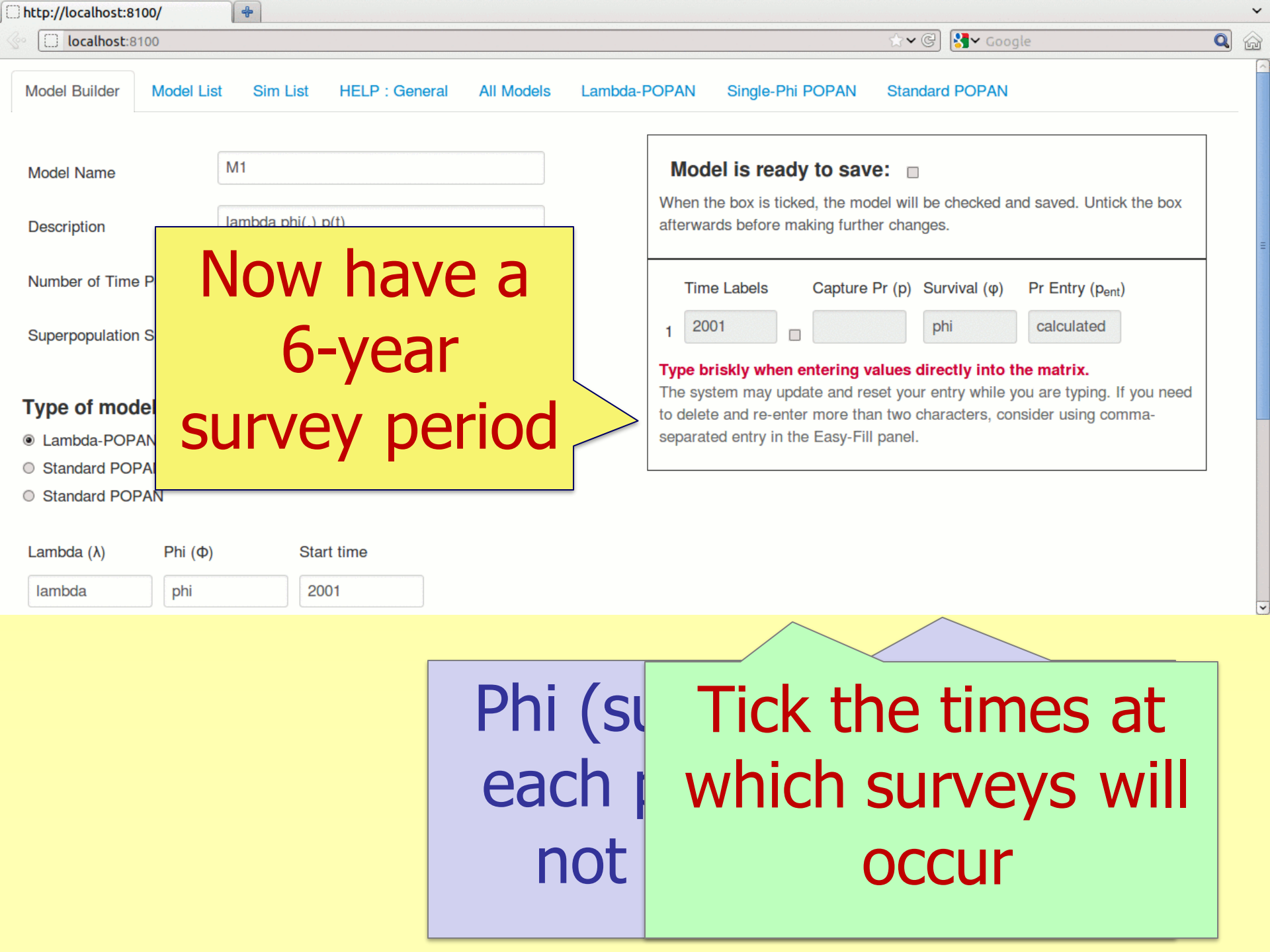
Building Models

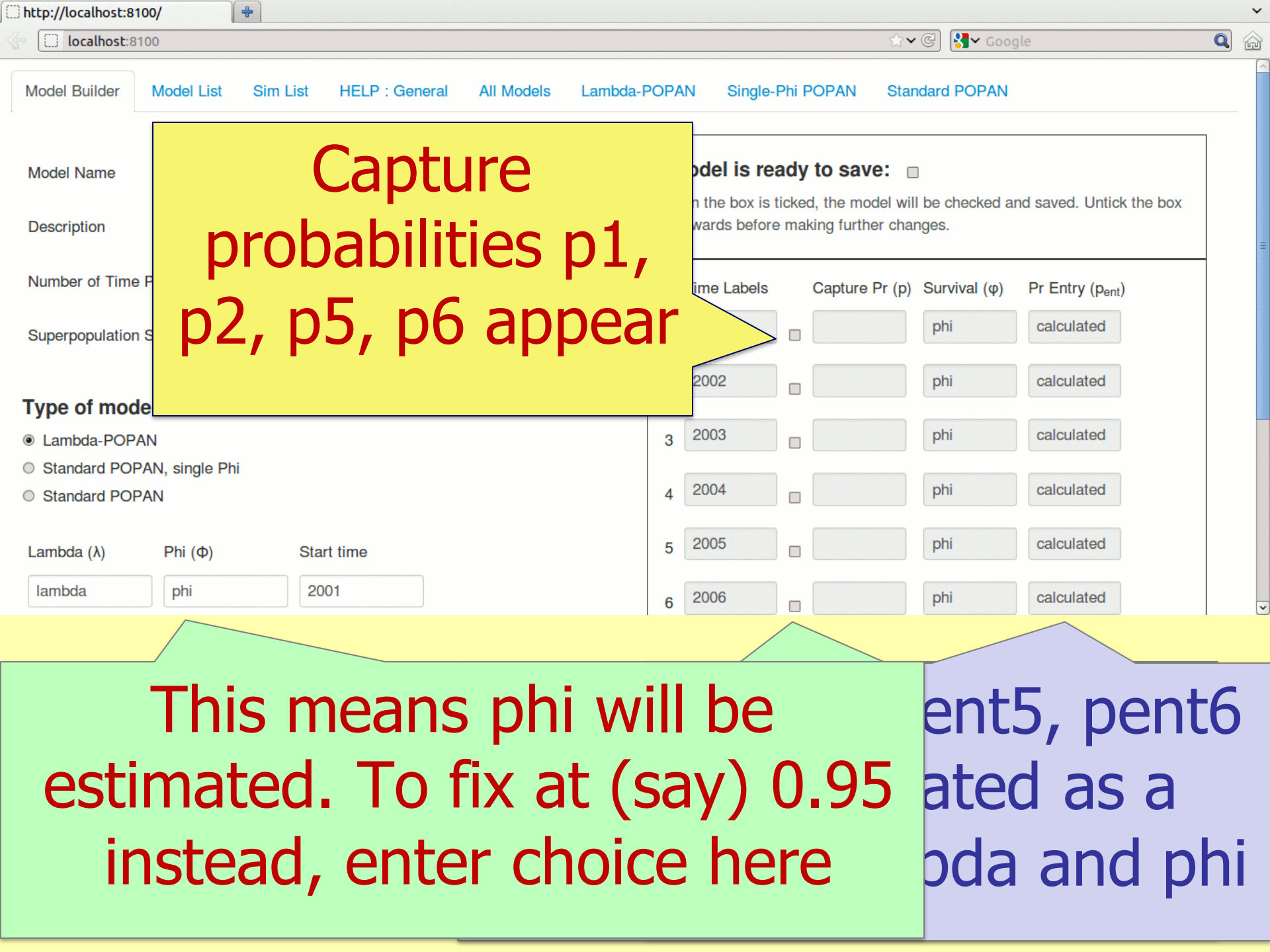
User interface is an ordinary web browser

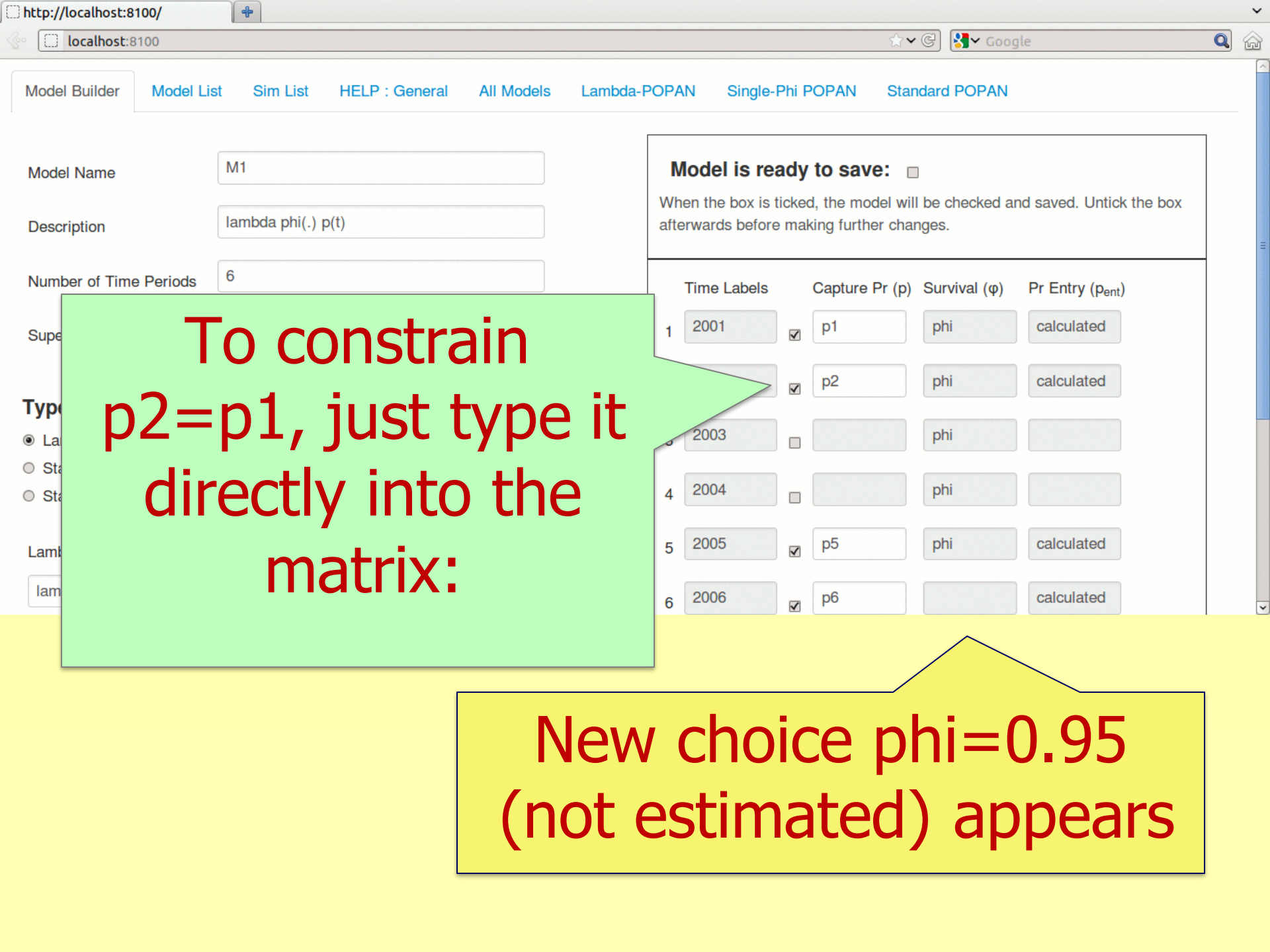


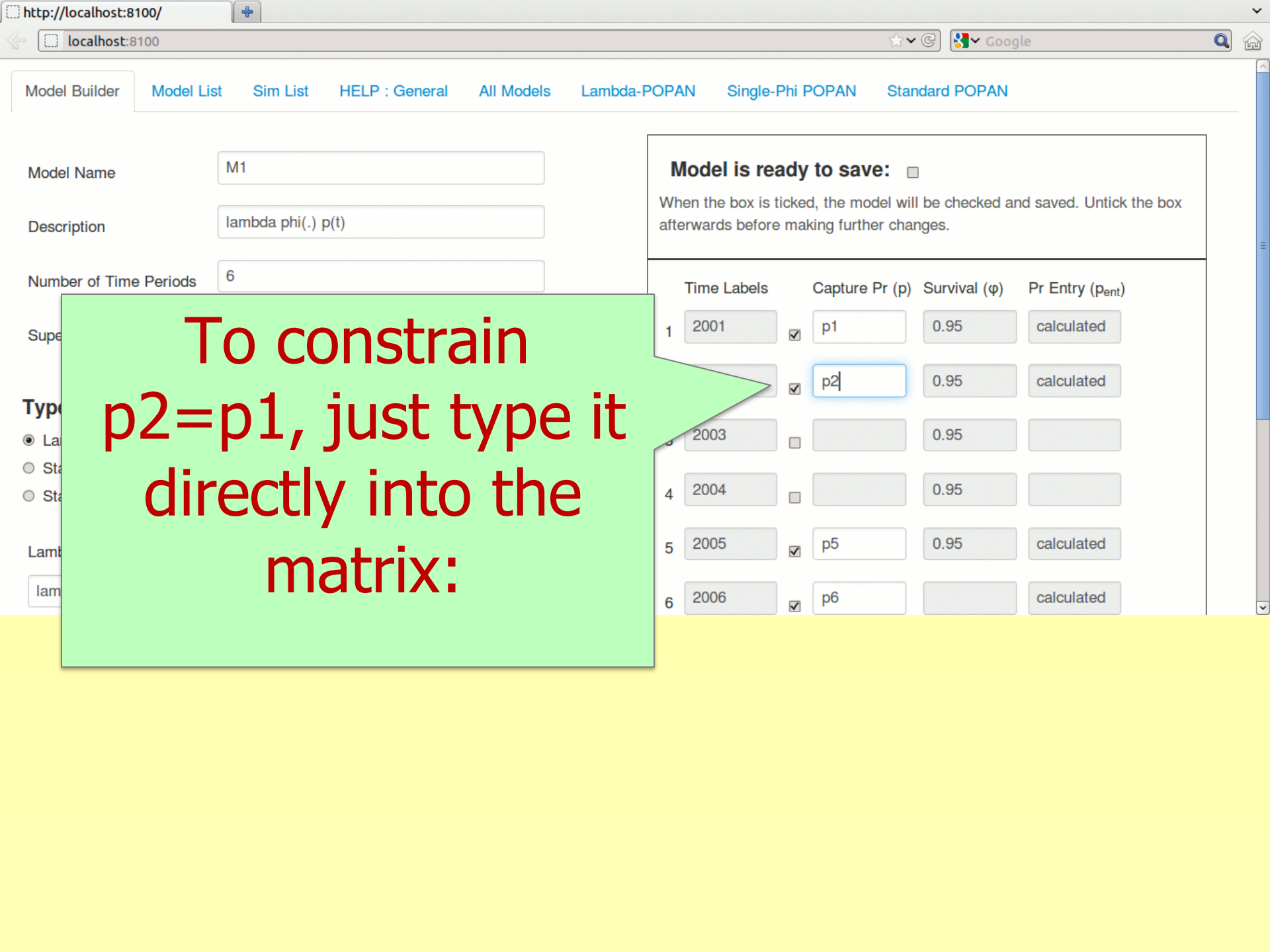

http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
M1
Description
lambda phi(.) p(t)
Number of Time Periods
1
Superpopulation Size (N_s)
N
Type of model:
Lambda-POPAN
Standard POPAN, single Phi
Standard POPAN
Lambda (λ)
Phi (Φ)
Start time
lambda
phi
2001
Model is ready to save:
When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.
Time Labels
Capture Pr (p)
Survival (φ)
Pr Entry (p_{ent})
1
2001
phi
calculated
Type briskly when entering values directly into the matrix.
The system may update and reset your entry while you are typing. If you need to delete and re-enter more th two characters, consider using comma-separated entry in the Eas panel.
Enter inputs on the left panels
Model matrix responds to inputs as you type


http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
M1
Description
lambda phi(.) p(t)
Number of Time Periods
1
Superpopulation Size (N
Model is ready to save:
When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.
Time Labels
Capture Pr (p)
Survival (φ)
Pr Entry (pent)
1
2001
phi
calculated
Type briskly when entering values directly into the matrix.
The system may update and reset your entry while you are typing. If you need
wo characters, consider using comma-
nel.
Set number of times to 6: watch the model matrix change on the right


http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
M1
Description
lambda phi( ) p(t)
Number of Time P
Superpopulation S
Type of model
Lambda-POPAN
Standard POPAN
Standard POPAN
Lambda (λ)
Phi (Φ)
Start time
lambda
phi
2001
Model is ready to save:
When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.
Time Labels
Capture Pr (p)
Survival (φ)
Pr Entry (pent)
1
2001
phi
calculated
Type briskly when entering values directly into the matrix.
The system may update and reset your entry while you are typing. If you need to delete and re-enter more than two characters, consider using comma-separated entry in the Easy-Fill panel.
Now have a 6-year survey period
Phi (su
each p
not
Tick the times at which surveys will occur


http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
Description
Number of Time P
Superpopulation S
Capture probabilities p1, p2, p5, p6 appear
odel is ready to save:
n the box is ticked, the model will be checked and saved. Untick the box
wards before making further changes.
ime Labels
Capture Pr (p)
Survival (φ)
Pr Entry (p_{ent})
2002
3 2003
4 2004
5 2005
6 2006
phi
calculated
Type of mode
Lambda-POPAN
Standard POPAN, single Phi
Standard POPAN
Lambda (λ)
Phi (Φ)
Start time
lambda
phi
2001
This means phi will be estimated. To fix at (say) 0.95 instead, enter choice here
ent5, pent6
ated as a
bda and phi


http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
M1
Description
lambda phi(.) p(t)
Number of Time Periods
6
Model is ready to save:
When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.
Time Labels
Capture Pr (p)
Survival (φ)
Pr Entry (pent)
1 2001 p1 phi calculated
p2 phi calculated
2003 phi
4 2004 phi
5 2005 p5 phi calculated
6 2006 p6 calculated
To constrain p2=p1, just type it directly into the matrix:
New choice phi=0.95 (not estimated) appears


http://localhost:8100/
localhost:8100
Google
Model Builder
Model List
Sim List
HELP : General
All Models
Lambda-POPAN
Single-Phi POPAN
Standard POPAN
Model Name
M1
Description
lambda phi(.) p(t)
Number of Time Periods
6
Model is ready to save:
When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.
Time Labels
Capture Pr (p)
Survival (φ)
Pr Entry (pent)
1
2001
p1
0.95
calculated
p2
0.95
calculated
2003
0.95
4
2004
0.95
5
2005
p5
0.95
calculated
6
2006
p6
calculated
To constrain p2=p1, just type it directly into the matrix:

Our Question

- Long-lived, slow-reproducing species (e.g. whales)
- Aim to ascertain whether population is increasing ($\lambda > 1$)
- Suspected population parameters:
  - about 400 whales alive in 2001
  - growing at about $\lambda = 1.03$ per year
  - survival at about $\Phi = 0.95$ per year

$\lambda = 1.03$ means 3% annual growth

We can fund 6 surveys 2001-2011. Should we use Blocks, or Biennial configuration?

Model M1

2 blocks

Blocks

Superpopulation, N_s:	N										
Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1	p1	p1						p1	p1	p1
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	

Model M2

Biennial

Biennial

Superpopulation, N_s:	N										
Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1		p1		p1		p1		p1		p1
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	

Model Builder | Model List | Sim List | HELP : General | All Models

Model Name: M1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): N

Enter model name (M1), description (2 blocks), and number of time periods (11 for 2001 to 2011)

Type of model:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
lambda	phi	2001

Model Builder | Model List | Sim List | HELP : General | All Models

Model Name: M1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): N

Type of model:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ): lambda

Phi (Φ): phi

Start time: 2001

Typing N, lambda, and phi into these boxes just specifies that these parameters will be estimated (i.e. not fixed as constants)

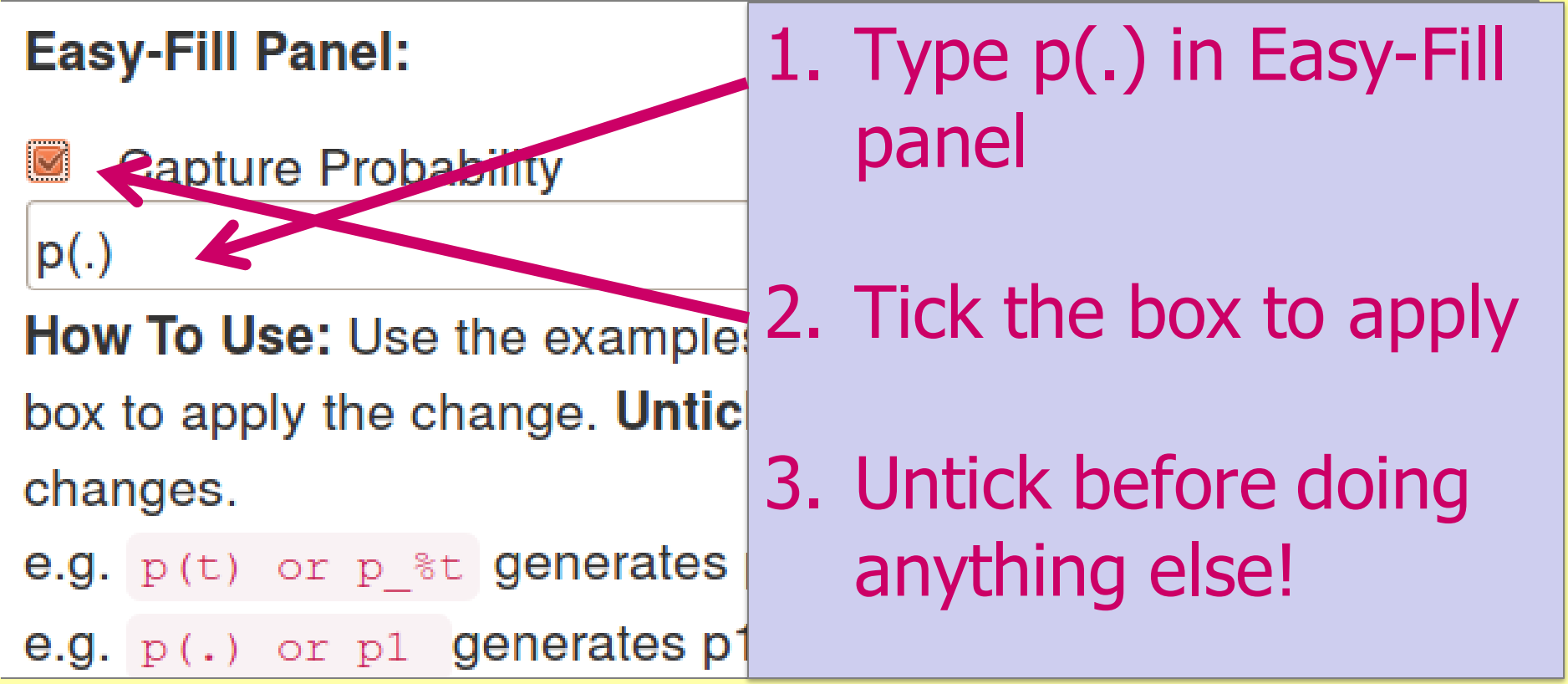
	Time Labels		Survival (φ)	Capture Pr (p)	Pr Ent
1	2001	☑	phi	p1	calcu
2	2002	☑	phi	p2	calcu
3	2003	☑	phi	p3	calcu
4	2004	☐	phi		
5	2005	☐	phi		
6	2006	☐	phi		
7	2007	☐	phi		
8	2008	☐	phi		
9	2009	☑	phi	p9	calcu
10	2010	☑	phi	p10	calcu
11	2011	☑		p11	calcu

Tick the boxes for 2 blocks of surveys:

2001, 2002, 2003

2009, 2010, 2011

Model auto-populates with one p parameter for each survey. We'll change this to p(.)


Easy-Fill Panel:
Capture Probability
p(.)
How To Use: Use the example
box to apply the change. Untic
changes.
e.g. p(t) or p_%t generates
e.g. p(.) or p1 generates p1
1. Type p(.) in Easy-Fill panel
2. Tick the box to apply
3. Untick before doing anything else!

The model matrix now shows p1 in all slots

Model Builder | Model List | Sim List | HELP : General | All Models | Lambda-POPAN | Single-Phi POPAN | Standard POPAN

Model Name: M1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): N

Type of model:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
lambda	phi	2001

Easy-Fill Panel:

☐ Capture Probability

p(.)

How To Use: Use the examples to fill in an expression. Tick the box to apply the change. **Untick the box** before making further changes.

e.g. `p(t) or p_%t` generates p1, p2, p3, ...

e.g. `p(.) or p1` generates p1, p1, p1

Model is ready to save: ☐

When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.

	Time Labels		Survival (φ)	Capture Pr (p)	Pr Entry (p_{ent})
1	2001	☑	phi	p1	calculated
2	2002	☑	phi	p1	calculated
3	2003	☑	phi	p1	calculated
4	2004	☐	phi		
5	2005	☐	phi		
6	2006	☐	phi		
7	2007	☐	phi		
8	2008	☐	phi		
9	2009	☑	phi	p1	calculated
10	2010	☑	phi	p1	calculated
11	2011	☑		p1	calculated

Check everything and save the model

Model Builder | Model List | Sim List | HELP : General | All Models | Lambda-POPAN | Single-Phi POPAN | Standard POPAN

Model Name: M1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): N

Type of model:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ): lambda

Phi (Φ): phi

Start time: 2001

Easy-Fill Panel:

[ ] Capture Probability

p(.)

How To Use: Use the examples to fill in an expression. Tick the box to apply the change. **Untick the box** before making further changes.

e.g. `p(t) or p_%t` generates p1, p2, p3, ...

e.g. `p(.) or p1` generates p1, p1, p1

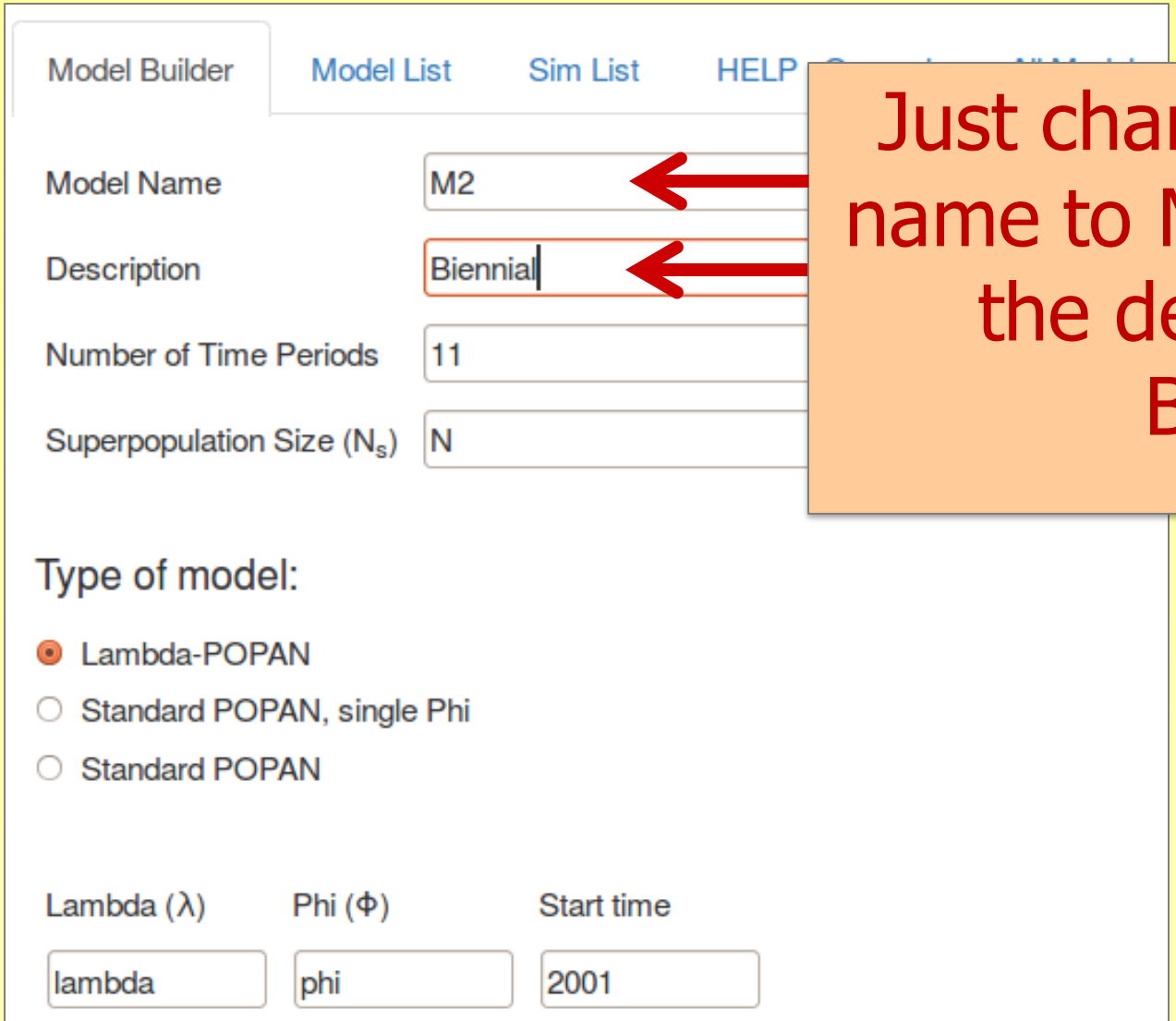
Model is ready to save: [ ]

When the box is ticked, the model will be checked and saved. Untick the box afterwards before making further changes.

	Time Labels		Survival (φ)	Capture Pr (p)	Pr Entry (p_{ent})
1	2001	☑	phi	p1	calculated
2	2002	☑	phi	p1	calculated
3	2003	☑	phi	p1	calculated
4	2004	☐	phi		
5	2005	☐	phi		
6	2006	☐	phi		
7	2007	☐	phi		
8	2008	☐	phi		
9	2009	☑	phi	p1	calculated
10	2010	☑	phi	p1	calculated
11	2011	☑		p1	calculated

Ready to build another model...

- Model M2, with Biennial surveys



Just change the model name to M2, and change the description to Biennial

1. Type p(.) in Easy-Fill panel
2. Tick the box to apply
3. Untick before doing anything else!

3	2003	☑	phi	p1	calculated
4	2004	☐	phi		
5	2005	☑	phi	p5	cal
6	2006	☐	phi		
7	2007	☑	phi	p7	cal
8	2008	☐	phi		
9	2009	☑	phi	p1	cal
10	2010	☐	phi		
11	2011	☑		p1	calculated

Tick the new Biennial survey configuration, but notice the p-parameters have auto-populated to one per year again

Check everything, Save Model & Untick the box!

Model Name: M2

Description: Biennial

Number of Time Periods: 11

Superpopulation Size (N_s): N

Type of model:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ): lambda Phi (Φ): phi Start time: 2001

Easy-Fill Panel:

[ ] Capture Probability

p(.)

How To Use: Use the examples to fill in an expression. Tick the box to apply the change. **Untick the box** before making further changes.

e.g. `p(t) or p_%t` generates p1, p2, p3, ...

e.g. `p(.) or p1` generates p1, p1, p1, ...

e.g. `0.1, p2, p3, 0.2, ...` comma-separated values.

Model is ready to save: [x]

When the box is ticked, the model will be checked and saved. Un box afterwards before making further changes.

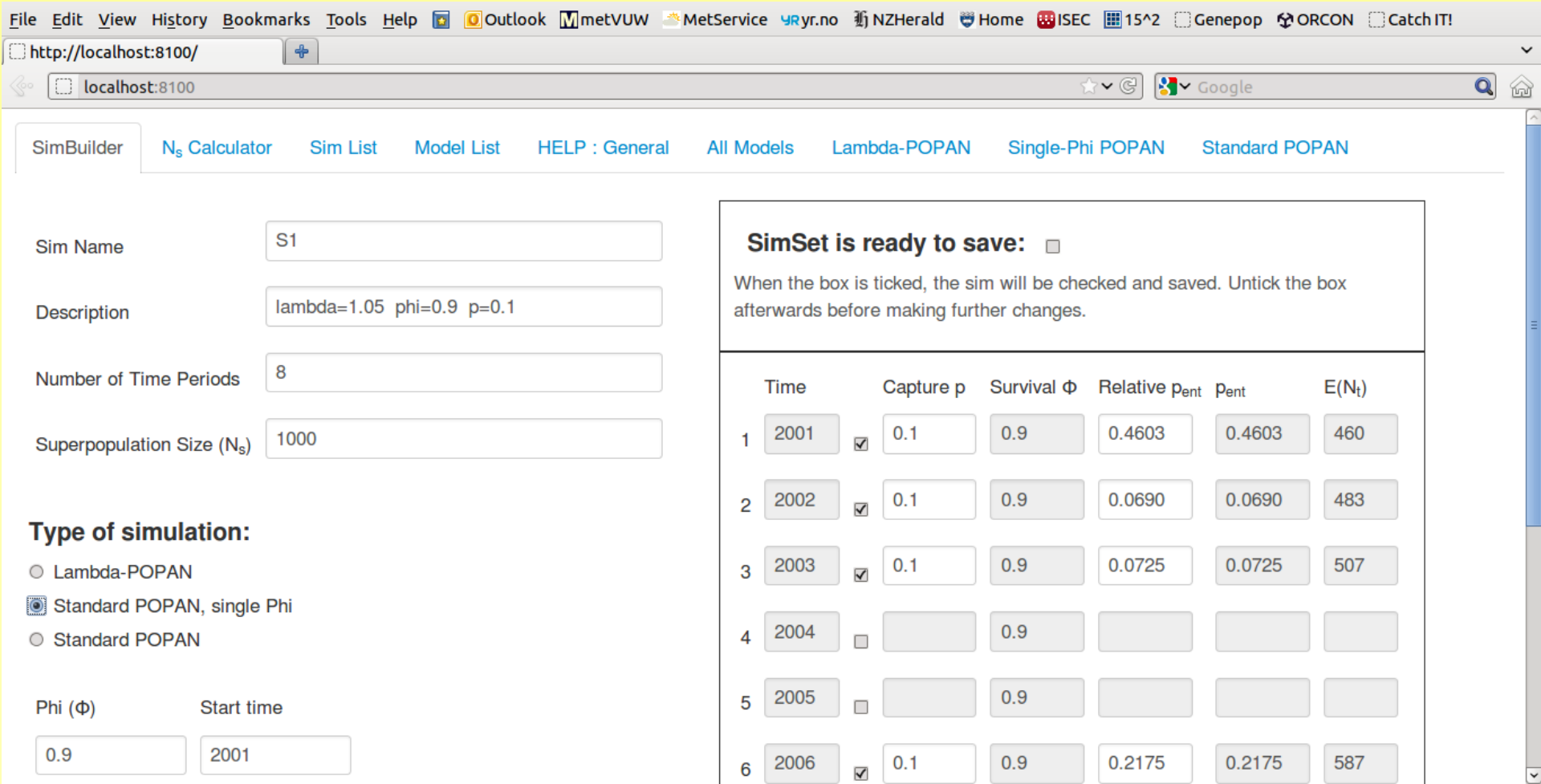
Model has been saved. Untick the box before continuing...

Confirm number:

	Time Labels		Survival (φ)	Capture Pr (p)	Pr Entry (p_{en}
1	2001	[x]	phi	p1	calculated
2	2002	[ ]	phi		
3	2003	[x]	phi	p1	calculated
4	2004	[ ]	phi		
5	2005	[x]	phi	p1	calculated
6	2006	[ ]	phi		
7	2007	[x]	phi	p1	calculated
8	2008	[ ]	phi		
9	2009	[x]	phi	p1	calculated
10	2010	[ ]	phi		
11	2011	[x]		p1	calculated

Building Simulations

- Same idea, but enter numbers instead of parameters



SimBuilder | N_s Calculator | Sim List | Model List | HELP : C

Sim Name: S1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s):

Enter sim name (S1), description (2 blocks), and number of time periods (11 for 2001 to 2011)

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
1.03	0.95	2001

Suspected population parameters:

- about 400 whales alive in 2001
- growing at about λ=1.03 per year
- survival at about Φ=0.95 per year

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
1.03	0.95	2001

SimBuilder | N_s Calculat

Sim Name

Description

Number of Time Periods 11

Superpopulation Size (N_s)

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Pl
- ( ) Standard POPAN

Lambda (λ) 1.03

Phi (Φ) 0.95

Start time 2001

These are not the same thing!

Take care when specifying the superpopulation size.

Suspected population parameters:

- about 400 whales alive in 2001
- growing at about λ=1.03 per year
- survival at about Φ=0.95 per year

N_s = Superpopulation
All animals ever exposed to capture

This means the superpopulation does not include any animals that were born and died within a survey gap

The superpopulation does not include any animals that were born and died in a survey gap

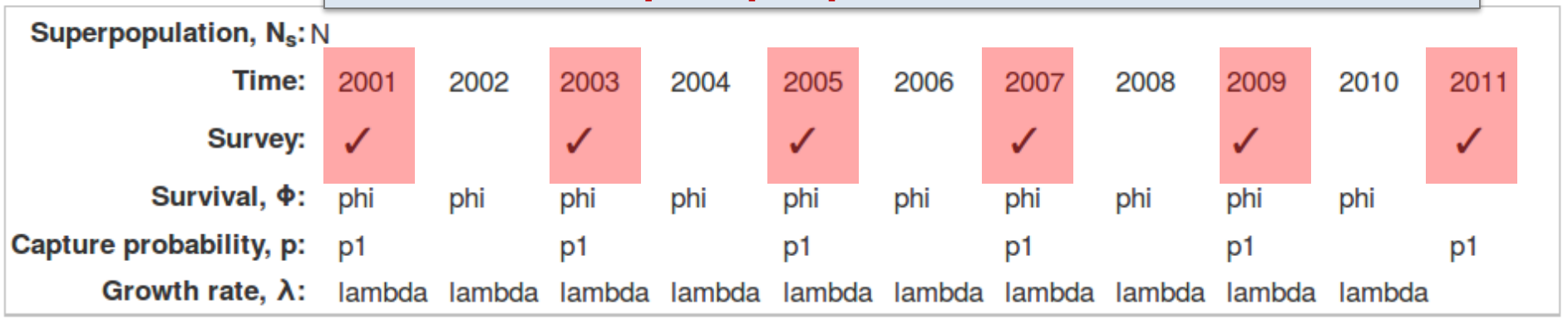
Model M1

2 blocks

For 400 animals alive in 2001 for both scenarios, we need different superpopulation sizes

Model M2

Biennial



N_s = Superpopulation
All animals ever exposed to capture

Superpopulation size N_s depends on:

- Growth rate, λ
- Survival, Φ
- Choice of survey times

For fixed N_{2001} = 400:

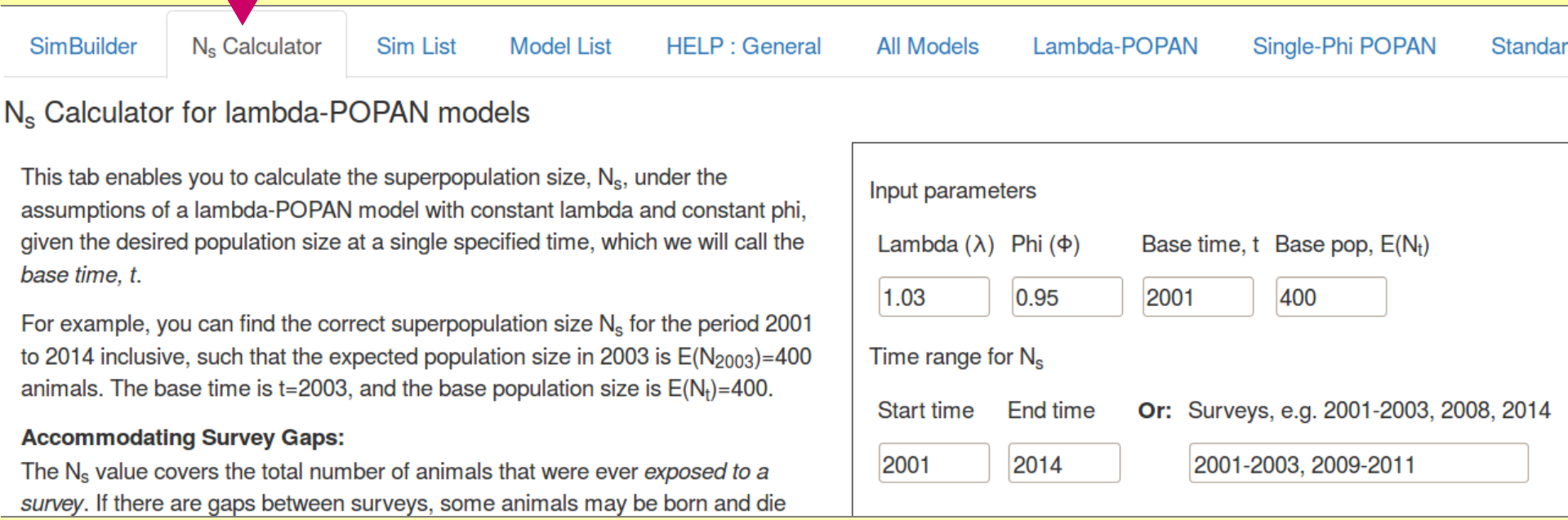
- Faster-growing pops have larger N_s
- So N_s increases with λ

- Longer-living animals have smaller N_s
  - If animals live longer, fewer ***different*** animals are needed to maintain growth
  - So N_s decreases with Φ

- More, or more regular, surveys expose more animals to capture: have larger N_s
  - So N_s depends on survey configuration

N_s Calculator Tab

- Calculates the relationship between superpopulation size, N_s, and expected number alive in a base year t, E(N_t)



Input parameters

Lambda (λ)	Phi (Φ)	Base time, t	Base pop, $E(N_t)$
1.03	0.95	2001	400

Time range for N_s

Start time	End time	Or: Surveys, e.g. 2001-2003, 2008, 2014
2001	2014	2001-2003, 2009-2011

Superpopulation size over the designated period: 742.0138

Table of results at survey times:

Survey year	Cumulative N_s		
2001	400	0	
2002	432	0	
2003	465	0.[illegible]	[illegible]
2009	660	0.262	506.70
2010	700	0.055	521.90
2011	742	0.056	537.60

Suspected population parameters:

- about 400 whales alive in 2001
- growing at about λ=1.03 per year
- survival at about Φ=0.95 per year

Input parameters

Lambda (λ)	Phi (Φ)	Base time, t	Base pop, $E(N_t)$
1.03	0.95	2001	400

Time range for N_s

Start time	End time	**Or:** Surveys, e.g. 2001-2003, 2008, 2014
2001	2014	2001-2003, 2009-2011

Enter 2-block surveys separated by commas: e.g.

e.g. 2001-2003, 2009-2001

or: 2001,2002,2003,2009,2010,2011

Input parameters

Lambda (λ)	Phi (Φ)	Base time, t	Base pop, $E(N_t)$
1.03	0.95	2001	400

Time range for N_s

Start time	End time	Or: Surveys, e.g. 2001-2003, 2008, 201
2001	2014	2001-2003, 2009-2011

Superpopulation size over the designated period: 742.0138

Table of results at survey times:

Survey year	Cumulative N_s	p_{ent}	$E(N_t)$
2001	400	0.539	400.00
2002	432	0.043	412.00
2003	465	0.044	424.40
2009	660	0.262	506.70
2010	700	0.055	521.90
2011	742	0.056	537.60

Answer:
Superpopulation size needed for Sim S1 is N_s =742

Check it gives the right answer: N=400 in 2001

1. Back on SimBuilder tab, enter N_s = 742
2. Check it gives the right value EN_{2001} = 400
3. Leave capture probability at 0.1 everywhere

Sim Name: S1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): 742

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
1.03	0.95	2001

Easy-Fill Panel:

☐ Capture Probability

0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1

SimSet is ready to save ☐

When the box is ticked, the sim will be checked and saved. Untick the box afterwards before making further changes.

	Time		Survival Φ	Capture p	Relative p_{ent}	p_{ent}	$E(N_t)$
1	2001	☑	0.95	0.1	0.5391	0.5391	400
2	2002	☑	0.95	0.1	0.0431	0.0431	412
3	2003	☑	0.95	0.1	0.0444	0.0444	424
4	2004	☐	0.95				
5	2005	☐	0.95				
6	2006	☐	0.95				
7	2007	☐	0.95				
8	2008	☐	0.95				
9	2009	☑	0.95	0.1	0.2625	0.2625	507

Check everything; Save SimSet; Untick box!

SimBuilder | N_s Calculator | Sim List | Model List | HELP : General | All Models | Lambda-POPAN | Single-Phi POPAN | Standard F

Sim Name: S1

Description: 2 blocks

Number of Time Periods: 11

Superpopulation Size (N_s): 742

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
1.03	0.95	2001

Easy-Fill Panel:

[ ] Capture Probability

0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1

How To Use: Use the examples to fill in an expression. Tick the box to apply the change. **Untick the box** before making further changes.

e.g. `0.2` generates 0.2, 0.2, 0.2, ...

e.g. `0.1, 0.2, 0.3, ...` comma-separated values.

SimSet is ready to save: [x]

When the box is ticked, the sim will be checked and saved. Untick the box afterwards before making further changes.

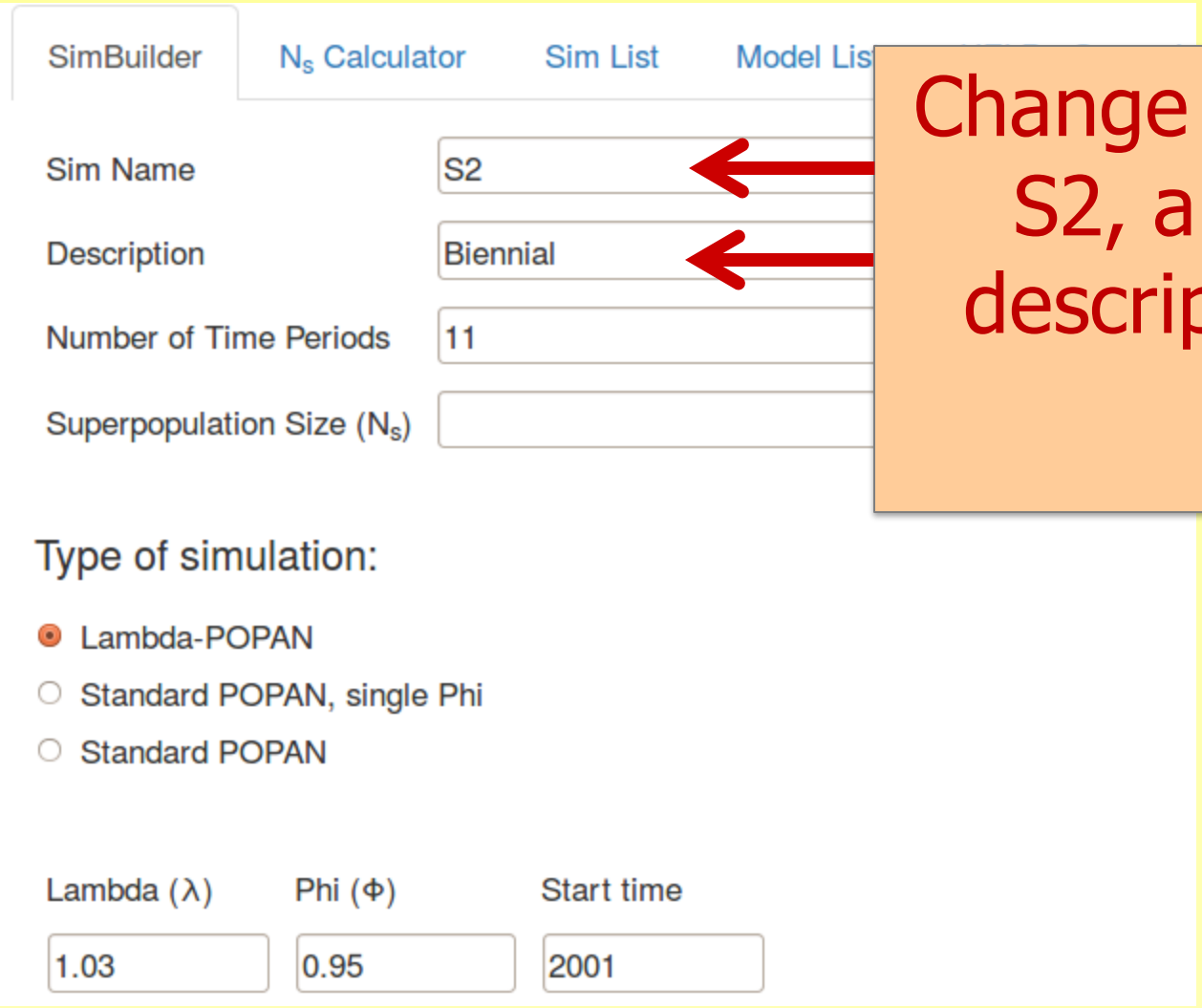
SimSet has been saved. Untick the box before continuing...

Confirm number:

	Time		Survival Φ	Capture p	Relative p_{ent}	p_{ent}	$E(N_t)$
1	2001	[x]	0.95	0.1	0.5391	0.5391	400
2	2002	[x]	0.95	0.1	0.0431	0.0431	412
3	2003	[x]	0.95	0.1	0.0444	0.0444	424
4	2004	[ ]	0.95				
5	2005	[ ]	0.95				
6	2006	[ ]	0.95				
7	2007	[ ]	0.95				
8	2008	[ ]	0.95				
9	2009	[x]	0.95	0.1	0.2625	0.2625	507
10	2010	[x]	0.95	0.1	0.0546	0.0546	522
11	2011	[x]		0.1	0.0563	0.0563	538

Ready to build another SimSet...

- SimSet S2, with Biennial surveys



Change the sim name to S2, and change the description to Biennial

	Time		Survival Φ	Capture p	Relative p_{ent}	p_{ent}	$E(N_t)$
1	2001	☑	0.95	0.1	0.5278	0.5278	
2	2002	☐	0.95				
3	2003	☑	0.95	0.1	0.0836		
4	2004	☐	0.95				
5	2005	☑	0.95	0.1	0.0887		
6	2006	☐	0.95				
7	2007	☑	0.95	0.1	0.0941	0.0941	
8	2008	☐	0.95				
9	2009	☑	0.95	0.1	0.0998	0.0998	
10	2010	☐	0.95				
11	2011	☑		0.1	0.1059	0.1059	

Tick the new Biennial survey configuration

Use N_s calculator tab to find the correct superpopulation size

Input parameters

Lambda (λ)	Phi (Φ)	Base time, t	Base pop, $E(N_t)$
1.03	0.95	2001	400

Time range for N_s

Start time	End time	**Or:** Surveys, e.g. 2001-2003, 2008, 2014
2001	2014	2001,2003,2005,2007,2009,2011

Superpopulation size over the designated period: 757.8086

Table of results at survey times:

Survey year	Cumulative N_s	p_{ent}	$E(N_t)$
2001	400	0.528	400.00
2003	463	0.084	424.40
2005	531	0.089	450.20

Answer: 758. Check it gives the right answer: N=400 in 2001

Back on the SimBuilder tab:

- Enter N_s=758
- Check everything; Save SimSet; Untick box!

SimBuilder | N_s Calculator | Sim List | Model List | HELP : General | All Models | Lambda-POPAN | Single-Phi POPAN | Standard POPAN

Sim Name: S2

Description: Biennial

Number of Time Periods: 11

Superpopulation Size (N_s): 758

Type of simulation:

- (•) Lambda-POPAN
- ( ) Standard POPAN, single Phi
- ( ) Standard POPAN

Lambda (λ)	Phi (Φ)	Start time
1.03	0.95	2001

Easy-Fill Panel:

☐ Capture Probability

0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1

SimSet is ready to save: ☑

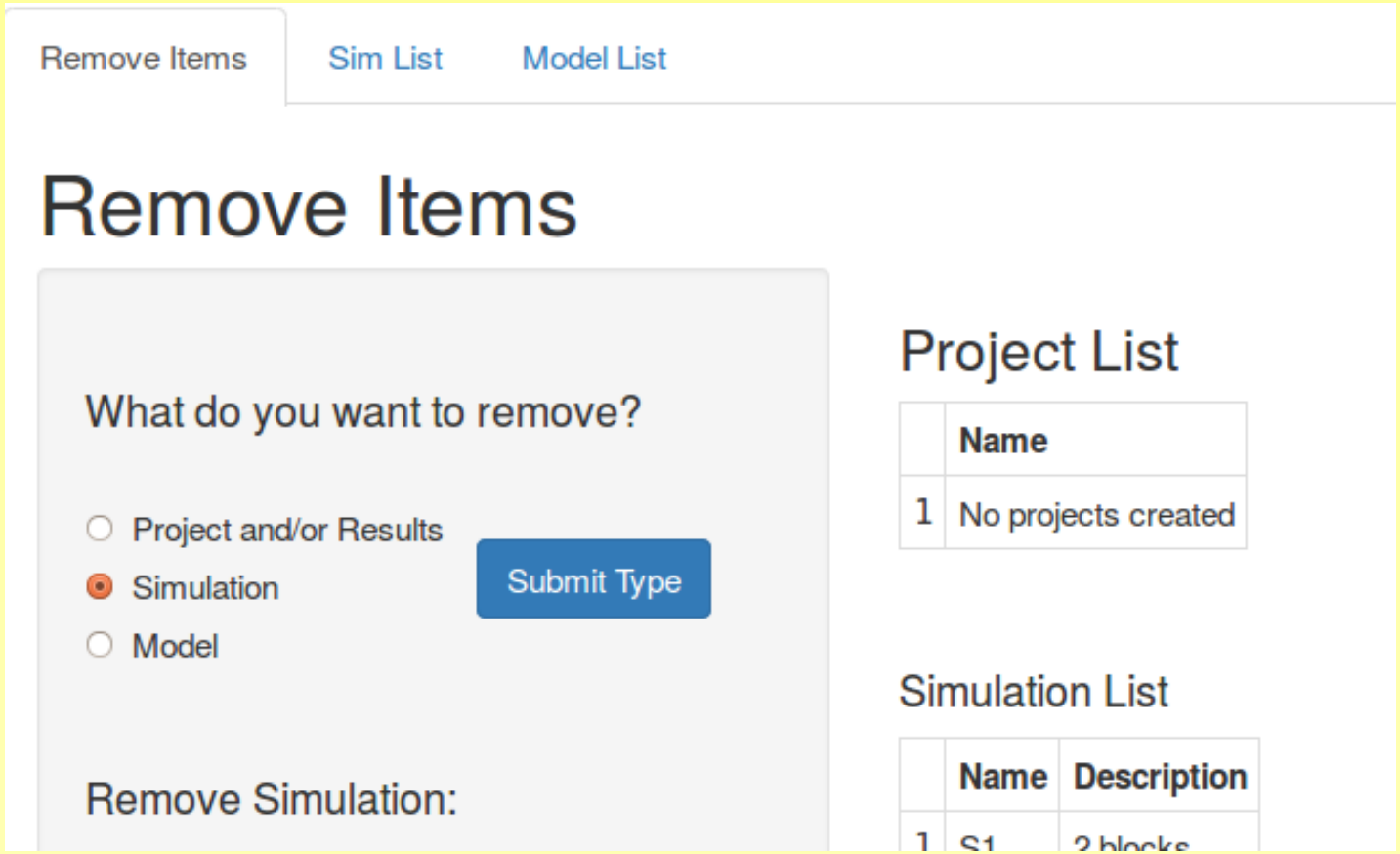
When the box is ticked, the sim will be checked and saved. Untick the box afterwards before making further changes.

SimSet has been saved. Untick the box before continuing...

Confirm number:

	Time		Survival Φ	Capture p	Relative p_{ent}	p_{ent}	E(N_t)
1	2001	☑	0.95	0.1	0.5278	0.5278	400
2	2002	☐	0.95				
3	2003	☑	0.95	0.1	0.0836	0.0836	424
4	2004	☐	0.95				
5	2005	☑	0.95	0.1	0.0887	0.0887	450
6	2006	☐	0.95				
7	2007	☑	0.95	0.1	0.0941	0.0941	478

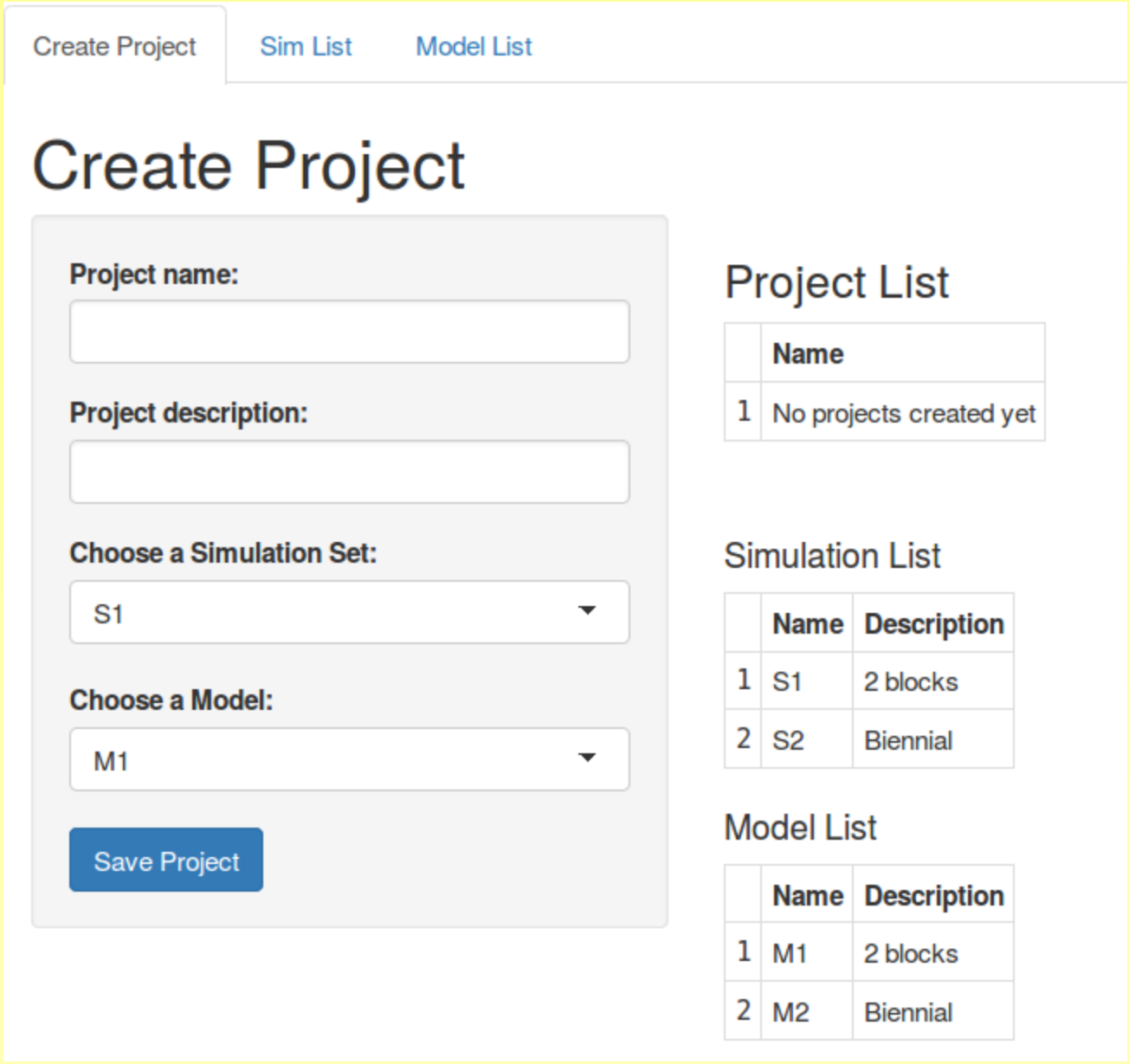
If you ever need to remove anything...



Building Projects

- A Project combines a Simulation set and a Model
- Only Sims and Models defined over the same survey years can be combined
- Otherwise you can combine anything you wish:
  - simulate from a lambda-model, fit a non-lambda model;
  - simulate with variable p, fit with constant p; ...

ProjectBuilder Interface



Reference lists of Sims and Models

Create Project | Sim List | Model List

This tab displays a reference list of SimSets already created. It is not affected by any changes made in this session.

SimSet S1

2 blocks

Superpopulation, N_s: 742

Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Capture probability, p:	0.1	0.1	0.1						0.1	0.1	0.1
Growth rate, λ:	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	
Entry proportion, p_{ent}:	0.5391	0.0431	0.0444						0.2625	0.0546	0.0563
$E(N_t)$:	400	412	424						507	522	538

SimSet S2

Biennial

Superpopulation, N_s: 758

Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	

Create Project | Sim List | Model List

Create Project

Project name:

P1

Project description:

2 blocks

Choose a Simulation Set:

S1

Choose a Model:

M1

Save Project

Project List

Create Project P1 with description "2 blocks"

P1 is combination of S1 and M1. Make selections and click Save Project.

Model List

	Name	Description

Create Project | Sim List | Model List

Create Project

Project name:

P2

Project description:

Biennial

Choose a Simulation Set:

S2

Choose a Model:

M2

Save Project

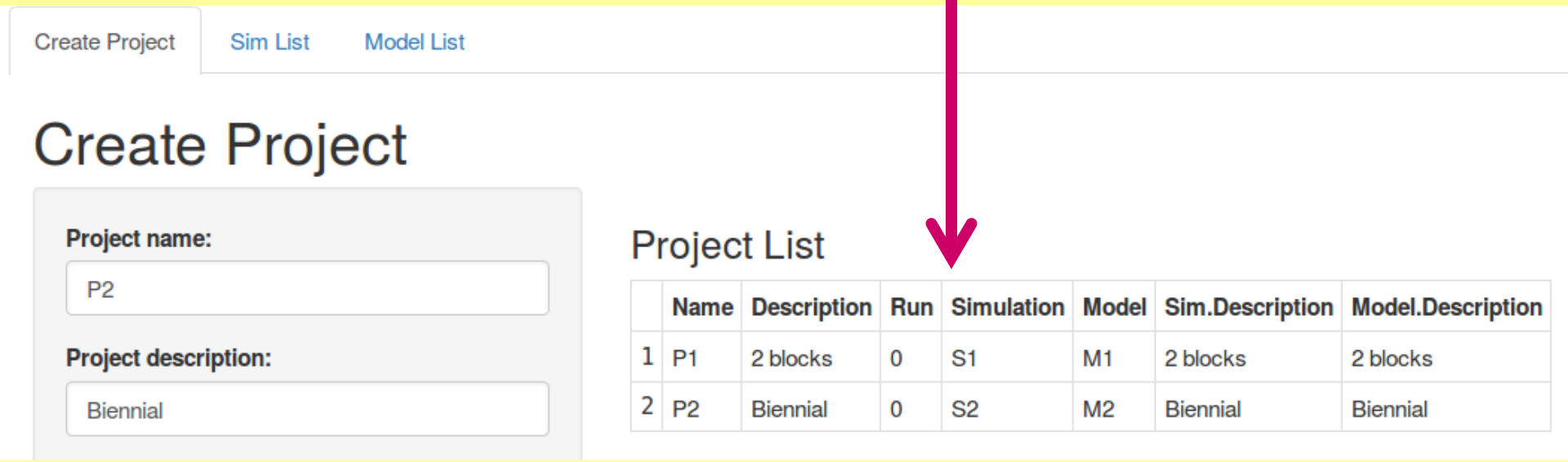
Project List

Create Project P2 with description "Biennial"

P2 is combination of S2 and M2. Make selections and click Save Project.

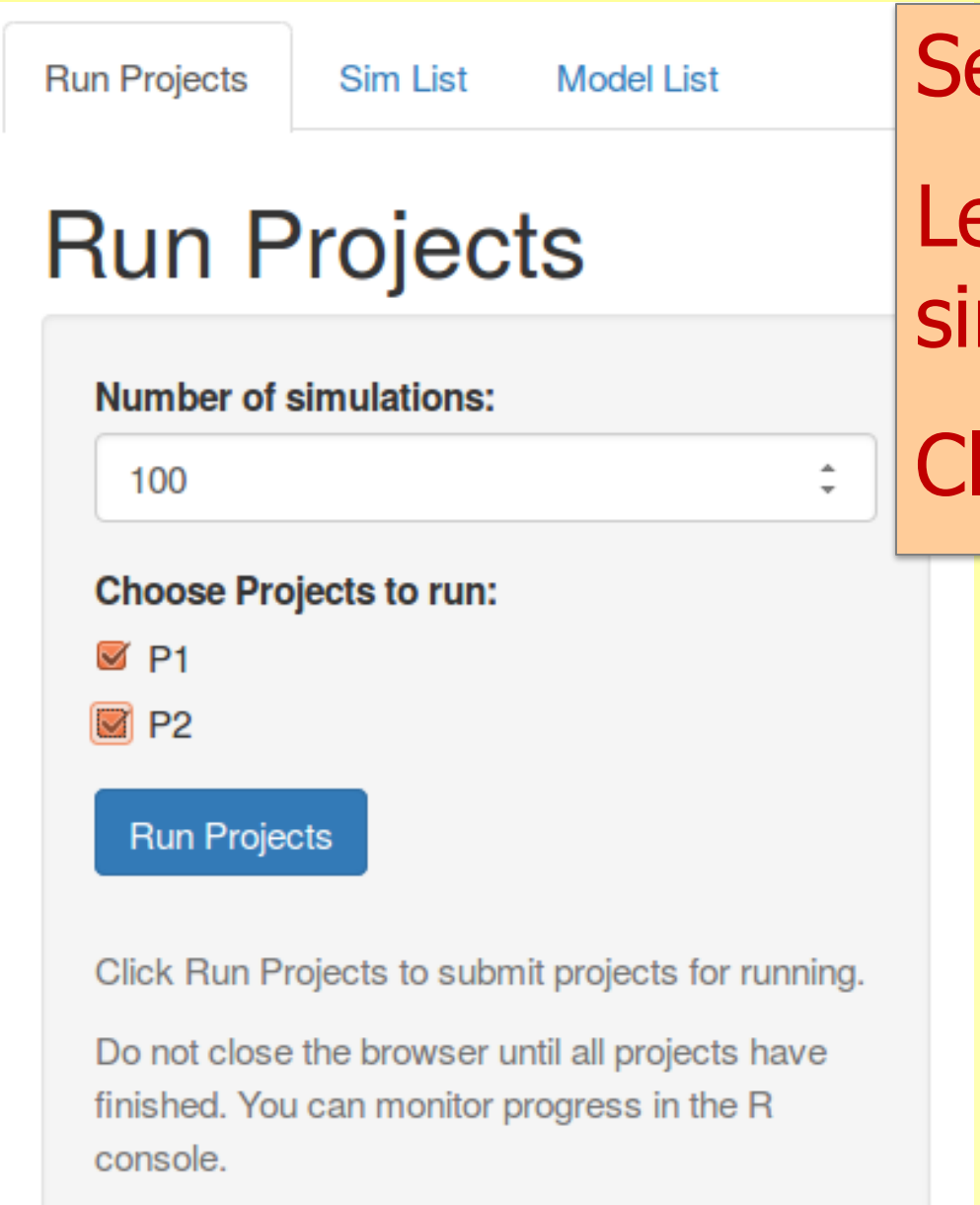
	Name	Description
1	M1	2 blocks
2	M2	Biennial

The two projects are now listed on the right



	Name	Description	Run	Simulation	Model	Sim.Description	Model.Description
1	P1	2 blocks	0	S1	M1	2 blocks	2 blocks
2	P2	Biennial	0	S2	M2	Biennial	Biennial

Run Projects



Select Projects P1 and P2

Leave number of simulations at 100

Click Run!

Run Projects

Number of simulations:

100

Choose Projects to run:

- [x] P1
- [x] P2

Run Projects

Click Run Projects to submit projects for running.

Do not close the browser until all projects have finished. You can monitor progress in the R console.

Finished running the following projects:

- P1
- P2

Some systems show progress in the R console window;

Otherwise, wait for the interface to come live again with the Finished message.

Power Console

Click Go!

Parameter:

lambda

Queried value:

1

Confidence level:

0.95

Include Projects:

- P1
- P2

Power Summaries | Plot se | Sim List | Model List

Power Display

Overall Power (%): percentage of simulations in which the queried value is outside the confidence interval. Specifies power to detect the true parameter differs from the queried value.

CI Above (%): the CI lies wholly above the queried value. Specifies power to detect the true parameter is greater than the queried value.

CI Below (%): the CI lies wholly below the queried value. Specifies power to detect the true parameter is less than the queried value.

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1	lambda 2001 - 2011	lambda	1	62.00	62.00	0.00
P2	lambda 2001 - 2011	lambda	1	51.00	50.00	1.00

Select projects P1 and P2;

Test lambda against Queried Value = 1

Power Console

Parameter:

lambda

Queried value:

1

Confidence level:

0.95

Include Projects:

- P1
- P2

Power S

Overall Po
Specifies

CI Above
than the q

CI Below
than the queried value.

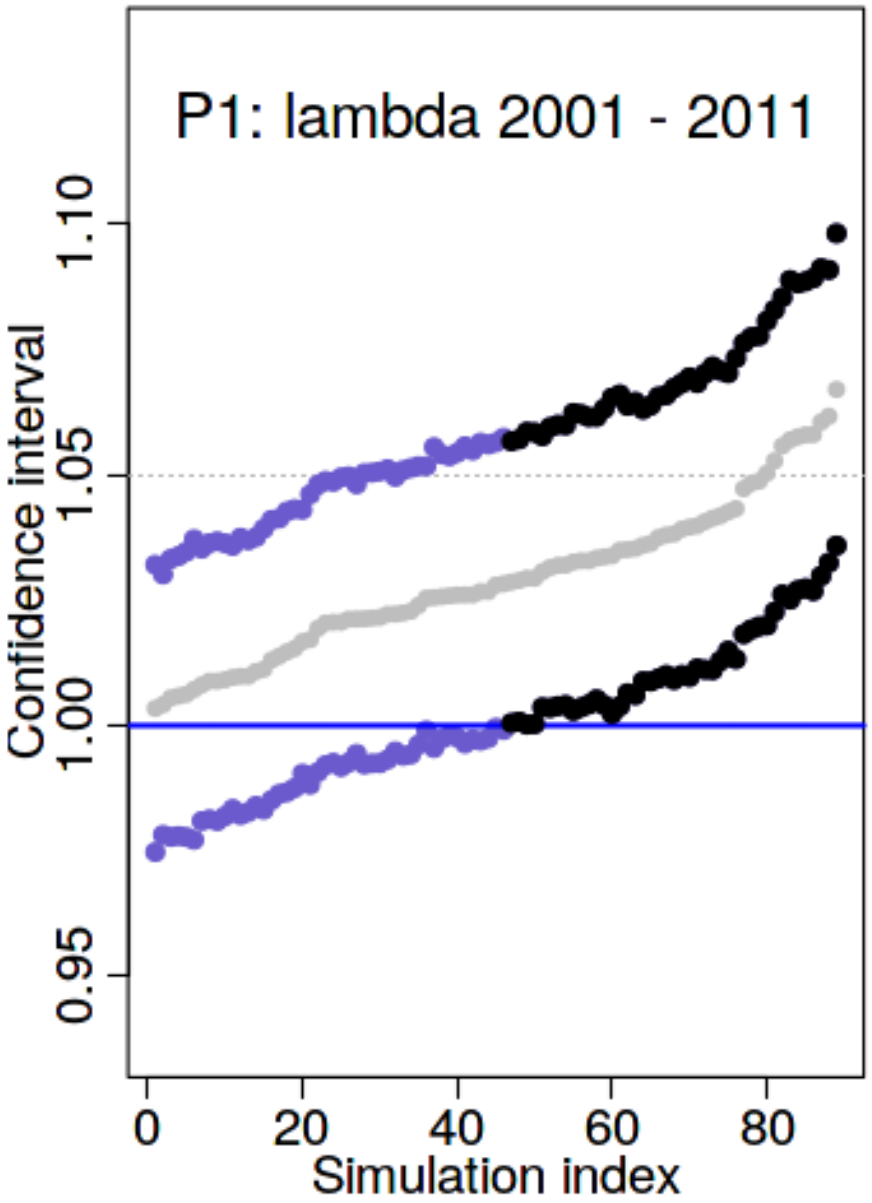
Project P1 typically scores 10-20% higher power than Project P2

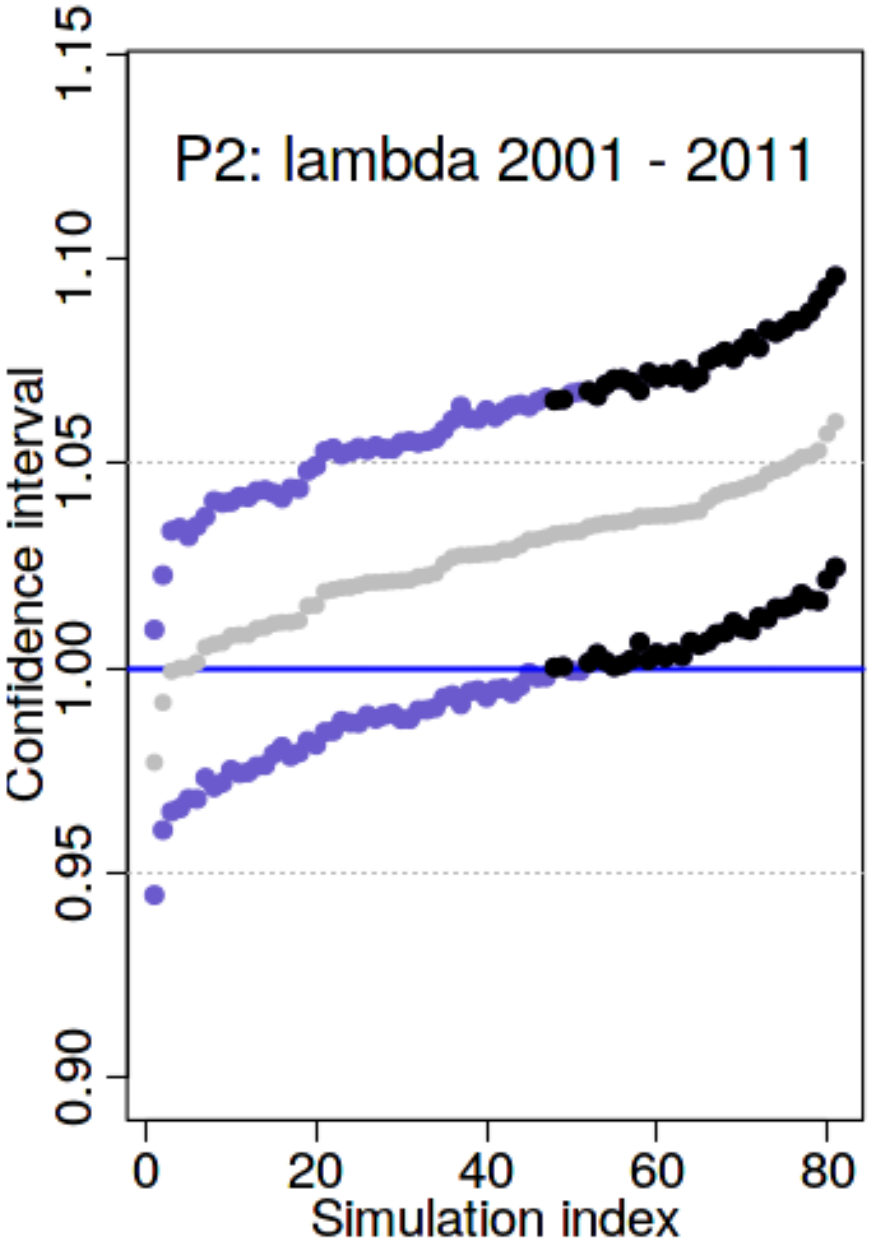
- Blocks seem to be better than evenly-spaced surveys!

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1	lambda 2001 - 2011	lambda	1	53.69	53.69	0.00
P2	lambda 2001 - 2011	lambda	1	39.81	39.81	0.00

Results shown here from 500 sims

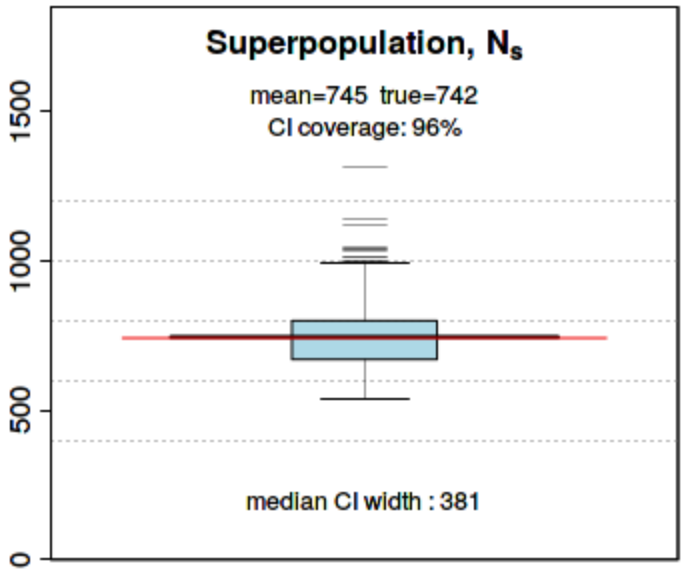


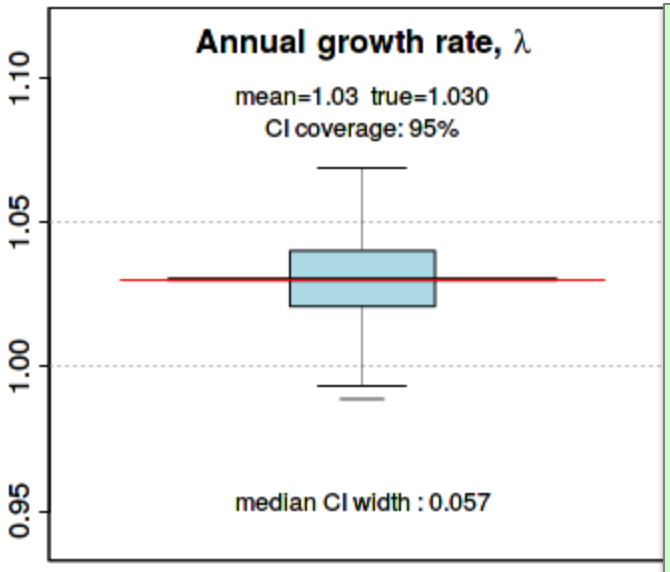


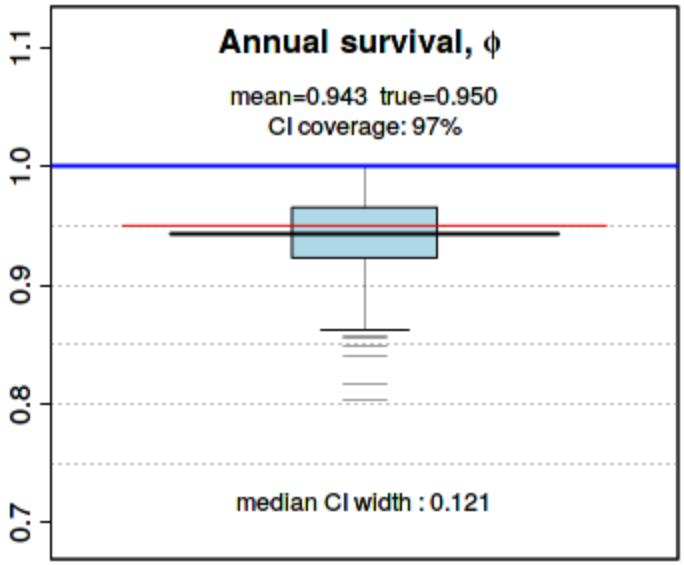
Results shown here from 100 sims

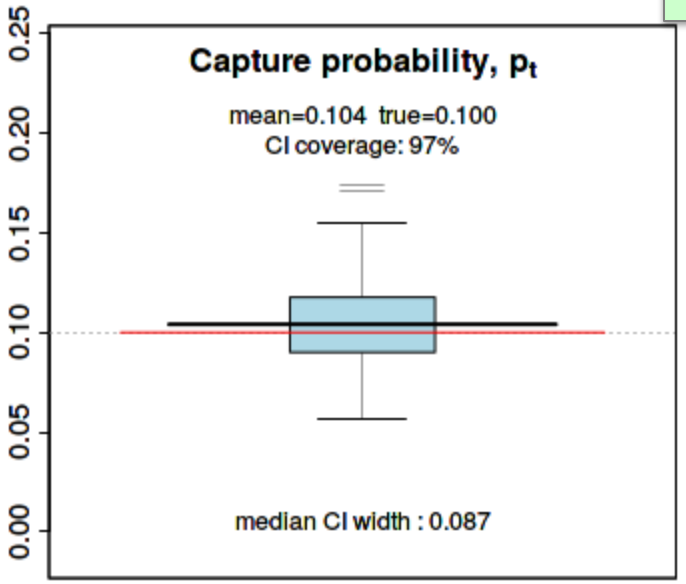
Plot Project Results

Project P1





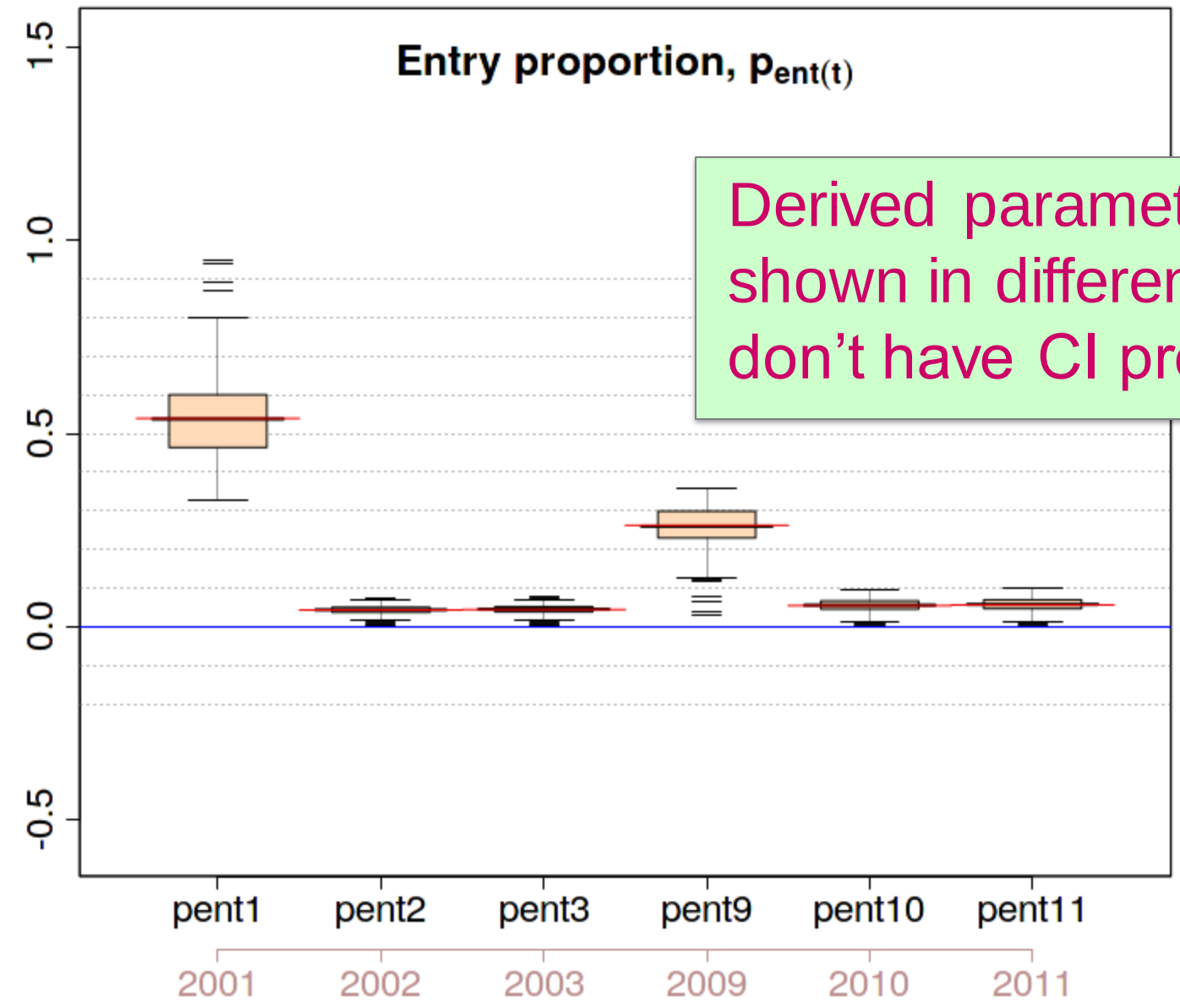




Boxplots show good properties for all estimated parameters

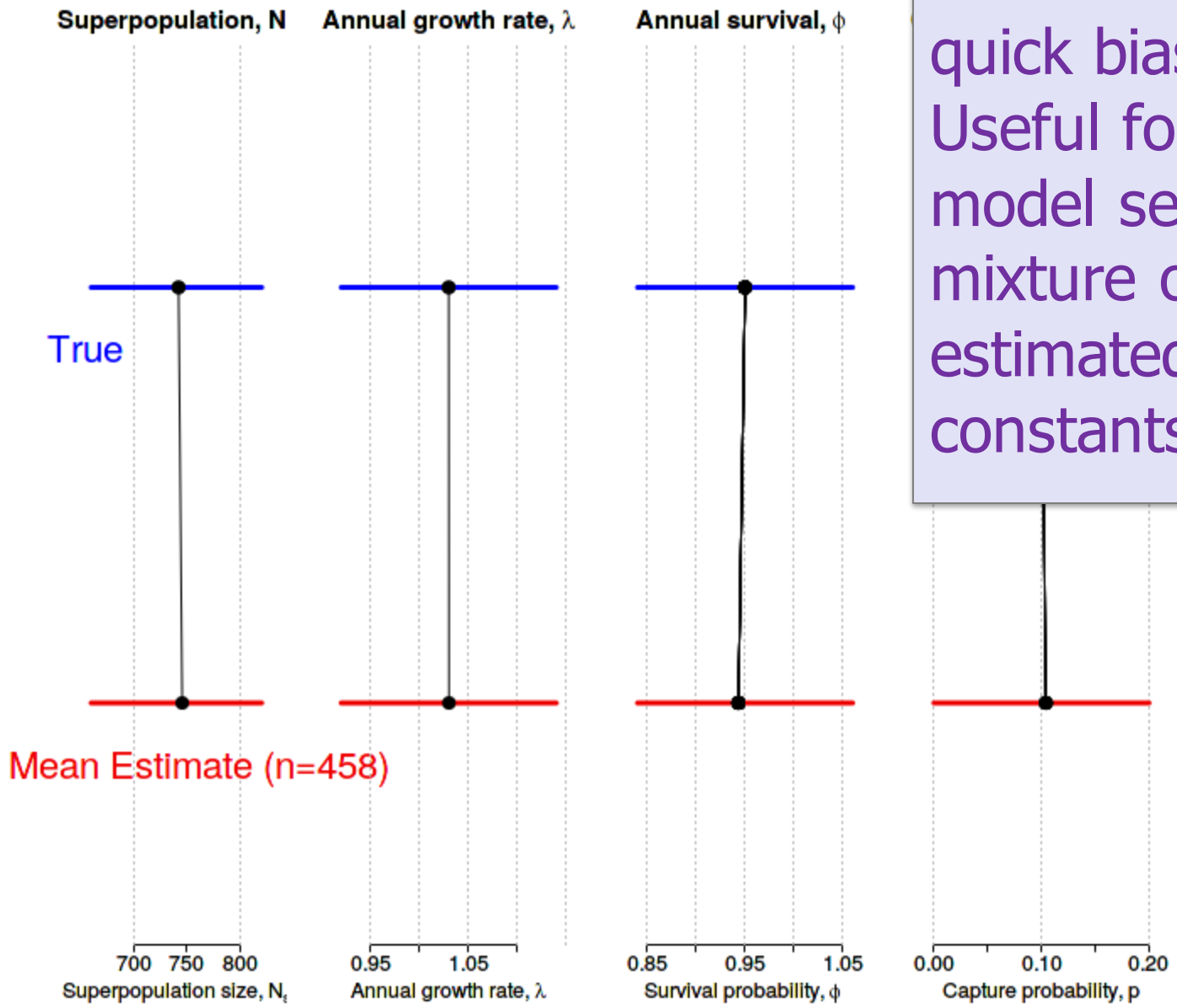
Results shown here from 500 sims

Project P1



Derived parameters (p_{ent}) are shown in different colour and don't have CI properties

Project P1

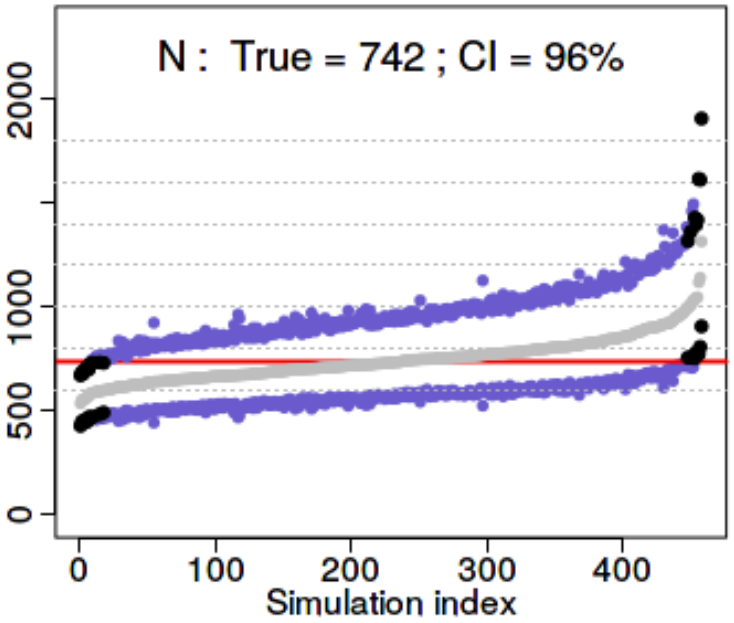


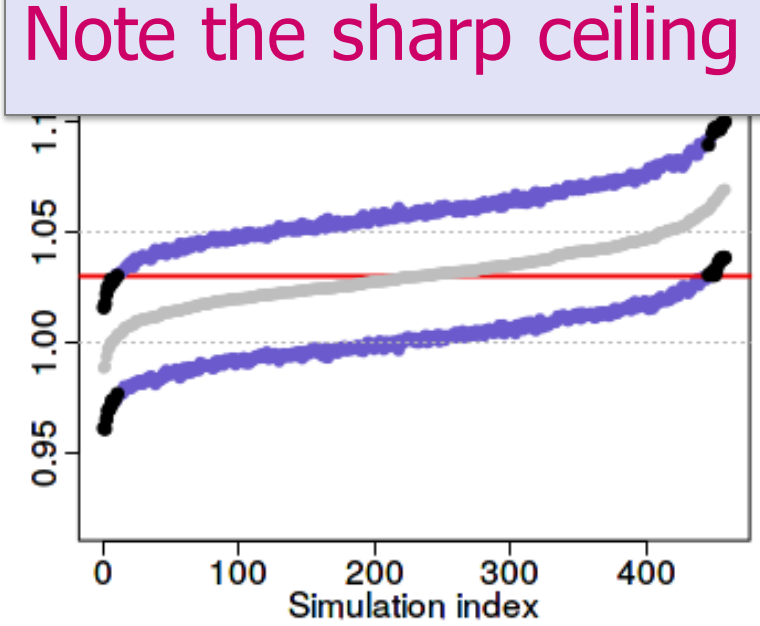
Mean-Plots offer a quick bias check. Useful for complicated model setups with a mixture of parameters estimated and fixed as constants

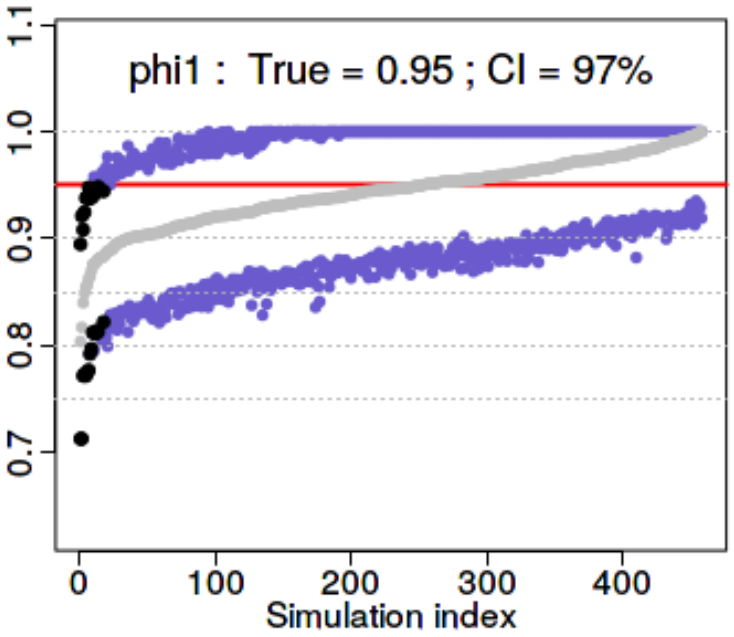
Project P1

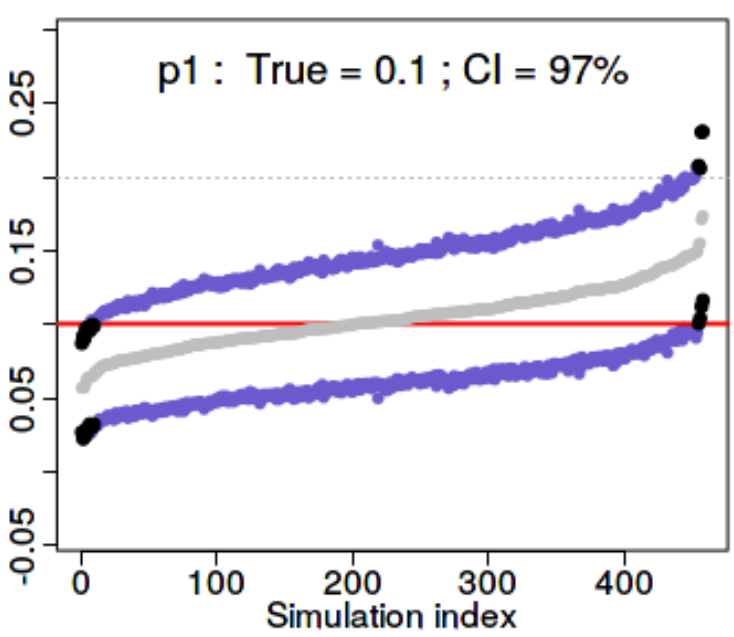
CI plots look good

Note the sharp ceiling at phi=1









Summary Tables

No CI or variance properties given for derived parameters like p_{ent}

Boxplots | Mean Plots | CI Plots | Summary Tables | Project List | Model List

☐ Show definitions

Project P1

Parameter	Treatment	TrueValue	meanEst	relativeBias	empiricalSD	empiricalCV	RMSE	meanSE	meanEstCV	medCIwidth	CIcover
N	Estimated	742.00	745.42	0.00	102.80	0.14	102.74	101.72	0.14	380.75	0.96
lambda	Estimated	1.03	1.03	0.00	0.01	0.01	0.01	0.01	0.01	0.06	0.95
phi1	Estimated	0.95	0.94	-0.01	0.03	0.03	0.03	0.04	0.04	0.12	0.97
p1	Estimated	0.10	0.10	0.04	0.02	0.20	0.02	0.02	0.22	0.09	0.97
pent1	Derived	0.54	0.54	-0.00	0.10	0.19	0.10				
pent2	Derived	0.04	0.04	0.01	0.01	0.23	0.01				
pent3	Derived	0.04	0.05	0.01	0.01	0.23	0.01				
pent9	Derived	0.26	0.26	-0.01	0.05	0.20	0.05				
pent10	Derived	0.05	0.06	0.03	0.01	0.27	0.01				
pent11	Derived	0.06	0.06	0.03	0.02	0.27	0.02				

Summary

- Fitting diagnostics look good for projects P1 and P2
- No obvious bias; CI coverage close to 95%
- So we can trust the results from the power analysis:
  - Project P1 (two blocks of 3 surveys) has higher power to detect $\lambda > 1$ than Project P2 (biennial surveys)

Blocks seem to be better than regularly-spaced surveys (experimental result only)

Model M1

2 blocks

Superpopulation, N_s:	N										
Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1	p1	p1						p1	p1	p1
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	

Model M2

Biennial

Superpopulation, N_s:	N										
Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1		p1		p1		p1		p1		p1
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	

A project I made earlier...

Look at what has been done by looking at the Model List, Sim List, and Project List tabs

Power console

Power Summaries | Plot settings | Project List | Sim List | Model List

This tab displays a referen
session.

Model M1.pconst

3 blocks; p(.)

Model M1.pconst fits a single capture probability parameter p1

Superpopulation, N_s:	N															
Time:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1	p1	p1					p1	p1	p1					p1	p1	p1
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda

Model M1.pvar

3 blocks; p(t)

Model M1.pvar fits a different capture probability for each survey

Superpopulation, N_s:	N															
Time:	2001															17
Survival, Φ:	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	phi	
Capture probability, p:	p1	p2	p3					p8	p9	p10					p15	p16	p17
Growth rate, λ:	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda	lambda

Power Summaries Plo

This tab displays a reference

SimSet S1.pconst

3 blocks; p=0.1

Sim S1.pconst simulates all surveys with a single capture probability p=0.1

Superpopulation, N_s:	891															
Time:	2001															
Survey:	✓	✓	✓				✓	✓	✓				✓	✓	✓	
Survival, Φ:	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Capture probability, p:	0.1	0.1	0.1				0.1	0.1	0.1				0.1	0.1	0.1	
Growth rate, λ:	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	
Entry proportion, p_{ent}:	0.4487	0.0314	0.0320				0.1542	0.0361	0.0368				0.1771	0.0414	0.0423	
E(N_t):	400	408	416				459	468	478				527	538	549	

SimSet S1.pvar

3 blocks; p=0.08, 0.19, 0.12

Sim S1.pvar simulates with capture probabilities 0.08, 0.10, 0.12 within each block of three surveys

Superpopulation, N_s:	891															
Time:	200															
Survey:	✓															
Survival, Φ:	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Capture probability, p:	0.08	0.1	0.12				0.08	0.1	0.12				0.08	0.1	0.12	
Growth rate, λ:	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	
Entry proportion, p_{ent}:	0.4487	0.0314	0.0320				0.1542	0.0361	0.0368				0.1771	0.0414	0.0423	

Projects combine constant p and variable p in every combination of sim / model:

simC.fitC : correct, simple model

simC.fitV : correct but inefficient model

simV.fitC : WRONG MODEL!

simV.fitV : correct, complex model

	Name	Description	Run	Simulation	Model	Sim_Description	Model_Description
1	P1.simC.fitC	Sim const p; Fit const p	1	S1.pconst	M1.pconst	3 blocks; p=0.1	3 blocks; p(.)
2	P1.simC.fitV	Sim const p; Fit variable p	1	S1.pconst	M1.pvar	3 blocks; p=0.1	3 blocks; p(t)
3	P1.simV.fitC	Sim variable p; Fit const p	1	S1.pvar	M1.pconst	3 blocks; p=0.08, 0.19, 0.12	3 blocks; p(.)
4	P1.simV.fitV	Sim variable p; Fit variable p	1	S1.pvar	M1.pvar	3 blocks; p=0.08, 0.19, 0.12	3 blocks; p(t)

Compare the 4 projects for query-value $\lambda = 1$:

Hmm! The WRONG project does the best?

			Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1.simV.fitC	lambda 2001 - 2017	lambda	1	80.44	80.44	0.00
P1.simC.fitC	lambda 2001 - 2017					00
P1.simC.fitV	lambda 2001 - 2017					00
P1.simV.fitV	lambda 2001 - 2017					00

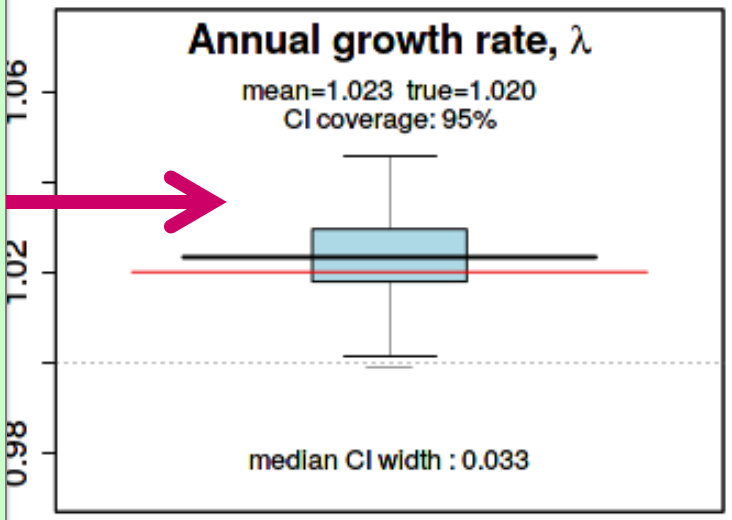
Always need to check model diagnostics through the Plot() panel to avoid getting conned by wrong results!

Plot console

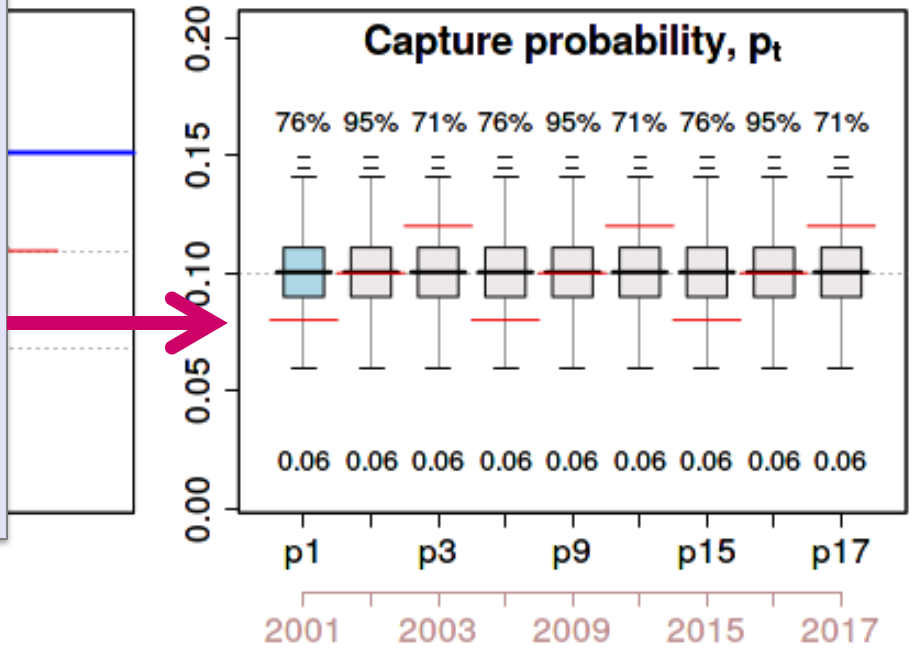
Plot the P1.simV.fitC project:

simulates variable capture probability, fits constant capture probability

Model misspecification causes small but noticeable positive bias in lambda estimates: this is why this project appeared to have the best power to detect $\lambda > 1$!



Tied capture parameters do not match the correct answers!



Restrict power display to only the three correct projects:

0.95

Include Projects:

- [x] P1.simC.fitC
- [x] P1.simC.fitV
- [ ] P1.simV.fitC
- [x] P1.simV.fitV

lambda: all time

Project	Description	Parameter	Queried Value	Overall Power (%)	CI Above (%)	CI Below (%)
P1.simC.fitC	lambda 2001 - 2017	lambda	1	69.03	69.03	0.00
P1.simC.fitV	lambda 2001 - 2017	lambda	1	15.12	15.12	0.00
P1.simV.fitV	lambda 2001 - 2017	lambda	1	12.98	12.98	0.00

Conclusion: if it's possible to sample with constant capture probability, gain a big improvement in power (~15% to ~70%).

Summary

- CaPow does model-fitting, power analysis, and simulation testing for inferential accuracy, 100% in R
- User-friendly web-browser interface
  Provides a general framework for inferential testing: combine Simulation settings & Model into Projects; run a list of Projects