

Olivier Gimenez

WRC2019, Berlin

# CAPTURE-RECAPTURE

## ECOLOGICAL QUESTIONS, METHODS

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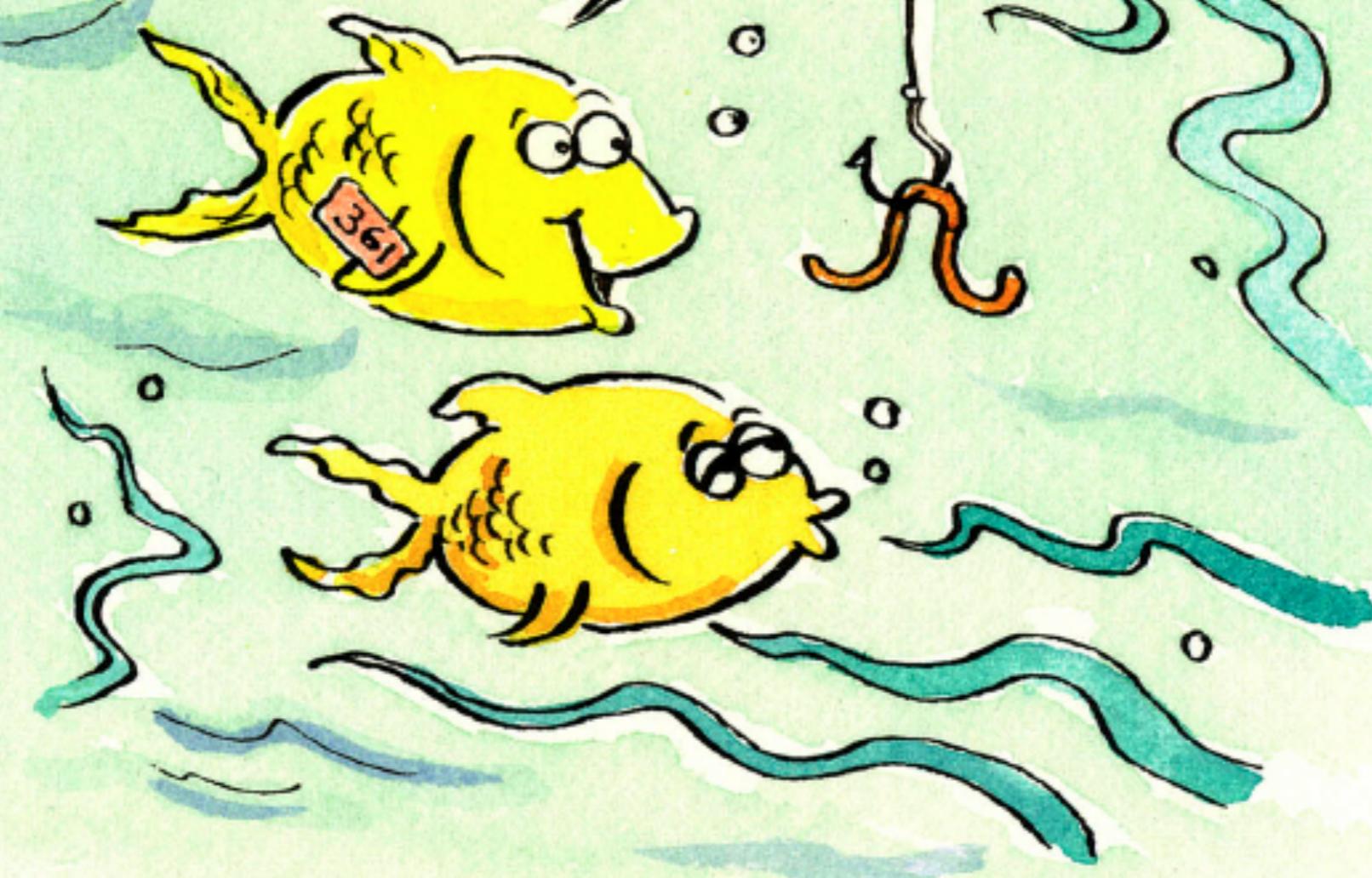
Slides, analyses, data & codes: <https://tinyurl.com/y5npsk5r>



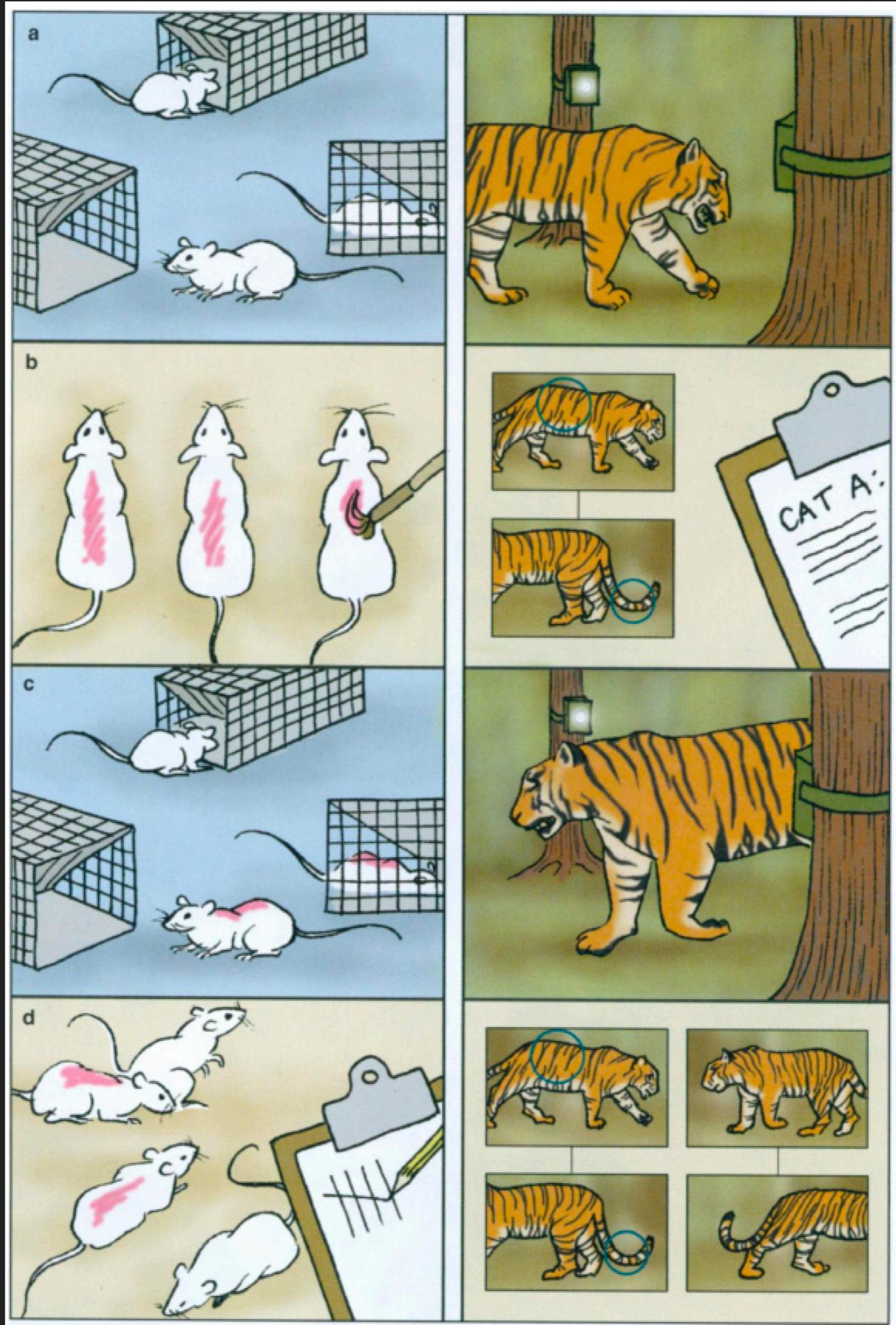
@oaggimenez

Glenders

....So I said "fool  
me once, shame on  
you, fool me tw--  
Hey, what have we  
got here...!"



The Capture-Recapture Method



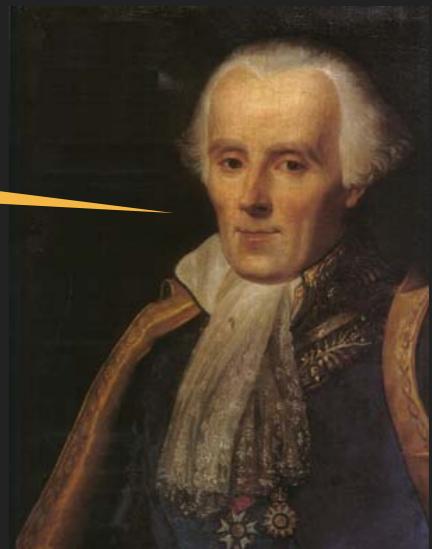
Sanderson & Trolle (2005). *American Scientist* 93: 148-155

*Population in  
the kindom, including Corsica  
island (...) year 1783.*

NOMBRE qui constituent l'ordre des généralités et provinces.	DÉNOMINATION des généralités du Royaume, l'île de Corse comprise, distingquées en pays d'élections et en pays d'Etat, la ville de Paris étant distinguée de la généralité, comme capitale du Royaume.	NÉSSES.	MARIAGES.	PROFESSIONS en religion.	MORTS			EXCÉDENT des nésesses sur les morts.
					dans la société civile.	en religion.	Total des morts.	
	PARIS (ville).....	19 387	4 873	117	18 827	126	18 953	+ 434
<i>Généralités en pays d'Élections.</i>								
1	Paris.....	45 806	10 283	71	43 158	102	43 260	- 2516
2	Orléans.....	28 393	7 103	26	31 803	45	31 848	- 3 455
3	Tours.....	49 517	12 121	47	61 156	96	61 257	- 11 735
4	Poitiers.....	26 816	6 496	45	30 512	48	30 560	- 3 741
5	Bourges.....	22 081	4 423	17	25 687	40	25 727	- 2 746
6	Limoges.....	20 516	6 408	26	26 089	30	26 319	- 197
7	La Rochelle.....	17 536	4 383	18	22 641	24	22 665	- 4 909
8	Bordeaux.....	55 114	18 585	183	49 237	72	49 314	+ 5 800
9	Auch.....	30 289	6 351	31	26 379	25	26 404	+ 3 885
10	Montauban.....	22 240	4 980	30	19 679	34	19 713	+ 2 517
11	Grenoble.....	26 848	5 436	34	21 982	42	22 024	+ 4 824
12	Lyon.....	24 218	5 405	26	20 856	60	20 916	+ 3 302
13	Riom.....	27 610	5 751	33	23 265	53	23 319	- 4 291
14	Moulin.....	26 188	5 899	15	27 493	37	27 530	- 1 352
15	Châlons.....	39 101	6 856	15	28 526	27	28 553	+ 3 528
16	Le Clermontois.....	1 523	286	"	1 175	"	1 175	+ 348
17	Soissons.....	17 863	3 907	11	14 976	31	15 007	- 2806
18	Amiens.....	20 872	5 318	19	19 410	31	19 441	+ 1 431
19	Rouen.....	28 507	7 266	46	25 989	72	26 061	+ 2 449
20	Caen.....	23 390	5 705	29	23 814	47	23 861	- 1 871
21	Alençon.....	19 122	5 010	36	21 749	42	21 791	+ 2 669
<i>Généralités en pays d'Etats.</i>								
22	Rennes.....	88 401	20 298	86	103 647	178	103 825	- 15 124
23	Perpignan.....	7 090	1 316	3	8 033	9	8 042	- 951
24	Montpellier.....	68 627	13 976	75	59 396	145	59 534	+ 9 086
25	Aix.....	78 443	5 923	27	71 815	65	71 881	+ 3 561
26	Dijon.....	42 750	9 703	48	43 855	122	43 977	- 127
27	Besançon.....	28 388	5 708	31	22 090	69	22 159	- 6 929
28	Strasbourg.....	26 147	5 415	23	20 361	44	20 403	- 5 737
29	Metz.....	14 063	2 587	19	11 521	19	11 540	- 2 523
30	Nancy.....	33 870	6 603	113	28 050	96	28 146	+ 5 774
31	Valenciennes.....	10 732	2 327	51	7 817	48	7 863	+ 2 887
32	Lille.....	28 189	6 789	130	25 898	171	26 069	+ 2 120
33	Île de Corse.....	5 349	1 068	20	4 334	25	4 359	+ 900
	Résumé du Royaume, l'île de Corse comprise .....	975 703	224 890	1 491	916 421	2 081	918 503	+ 27 201

*Observations. — Les maladies épidémiques dont les généralités de Soissons et d'Amiens ont été affligées pendant l'année 1781 n'ont pas continué en 1782; mais il n'en a pas été de même dans les généralités d'Orléans, de Tours, de Poitiers, de Bourges, de la Rochelle et d'Alençon, où ce fléau a redoublé ses ravages en 1782. La contagion a même gagné dans les généralités de Caen et de Moulin; à l'égard de celle de Bretagne, on ne peut pas attribuer aux seules maladies épidémiques la mortalité de 1782, et elle a dû être accrue par le passage et le séjour successif et continué des troupes, sorties de terre que de mer, qui y ont été employées; la ville de Brest ayant toujours été, pendant la dernière guerre, le point de réunion de presque toutes les forces maritimes opposées aux Anglais.*

*Observations sur le premier Tableau relatif à la population de Paris. — Dans ce premier Tableau, qui représente les naissances, les mariages et les morts, à Paris, depuis 1770 jusqu'en 1781, la colonne horizontale du total comprend, non seulement les naissances, les mariages, les morts et les enfans trouvés dans cet intervalle, mais encore ceux de l'année 1770, et que l'on trouve à la page 418 de nos Mémoires pour l'année 1771; ainsi, cette colonne du total est relative aux quinze années, depuis 1770 inclusivement jusqu'en 1781 exclusivement.*



Laplace 1784

# Literature review



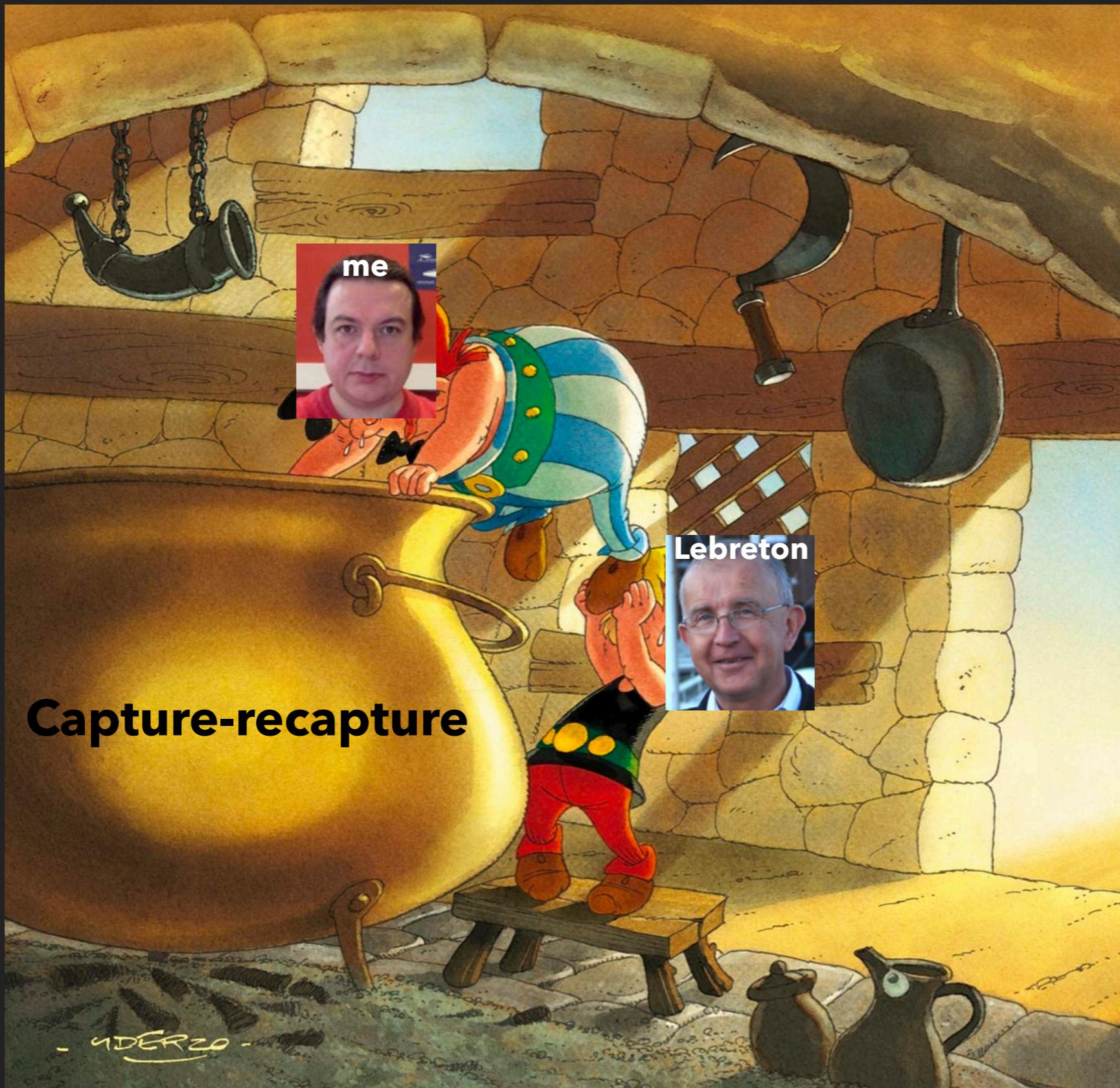
2009



2019

> 5,000 papers

# Disclaimer



# 1 ECOLOGICAL QUESTIONS

# From patterns to process and back

# From patterns to process and back

- ▶ **Abundance**  
in the 1980s

# From patterns to process and back

► **Abundance**  
in the 1980s

► **Survival**  
in the 1990s

# From patterns to process and back

- ▶ **Abundance**  
in the 1980s
- ▶ **Survival**  
in the 1990s
- ▶ **Transitions**  
in the 2000s

# From patterns to process and back

► **Abundance**  
in the 1980s

► **Survival**  
in the 1990s

► **Transitions**  
in the 2000s

- Recruitment, population growth rate
- Migration (stopover duration), dispersal

# From patterns to process and back

► Abundance  
in the 1980s

► Survival  
in the 1990s

Received: 9 May 2018 | Revised: 17 August 2018 | Accepted: 19 August 2018

DOI: 10.1111/mec.14848

INVITED REVIEWS AND SYNTHESES

WILEY **MOLECULAR ECOLOGY**

## Demographic and genetic approaches to study dispersal in wild animal populations: A methodological review

Hugo Cayuela<sup>1</sup>  | Quentin Rougemont<sup>1</sup> | Jérôme G. Prunier<sup>2</sup>  |  
Jean-Sébastien Moore<sup>1</sup> | Jean Clobert<sup>2</sup> | Aurélien Besnard<sup>3</sup> | Louis Bernatchez<sup>1</sup>

- Migration (stopover duration), dispersal

# From patterns to process and back

- ▶ **Abundance**  
in the 1980s
  - Spatially-explicit  
models

- ▶ **Survival**  
in the 1990s



- ▶ **Transitions**  
in the 2000s

# From patterns to process and back

## ► Abundance in the 1980s

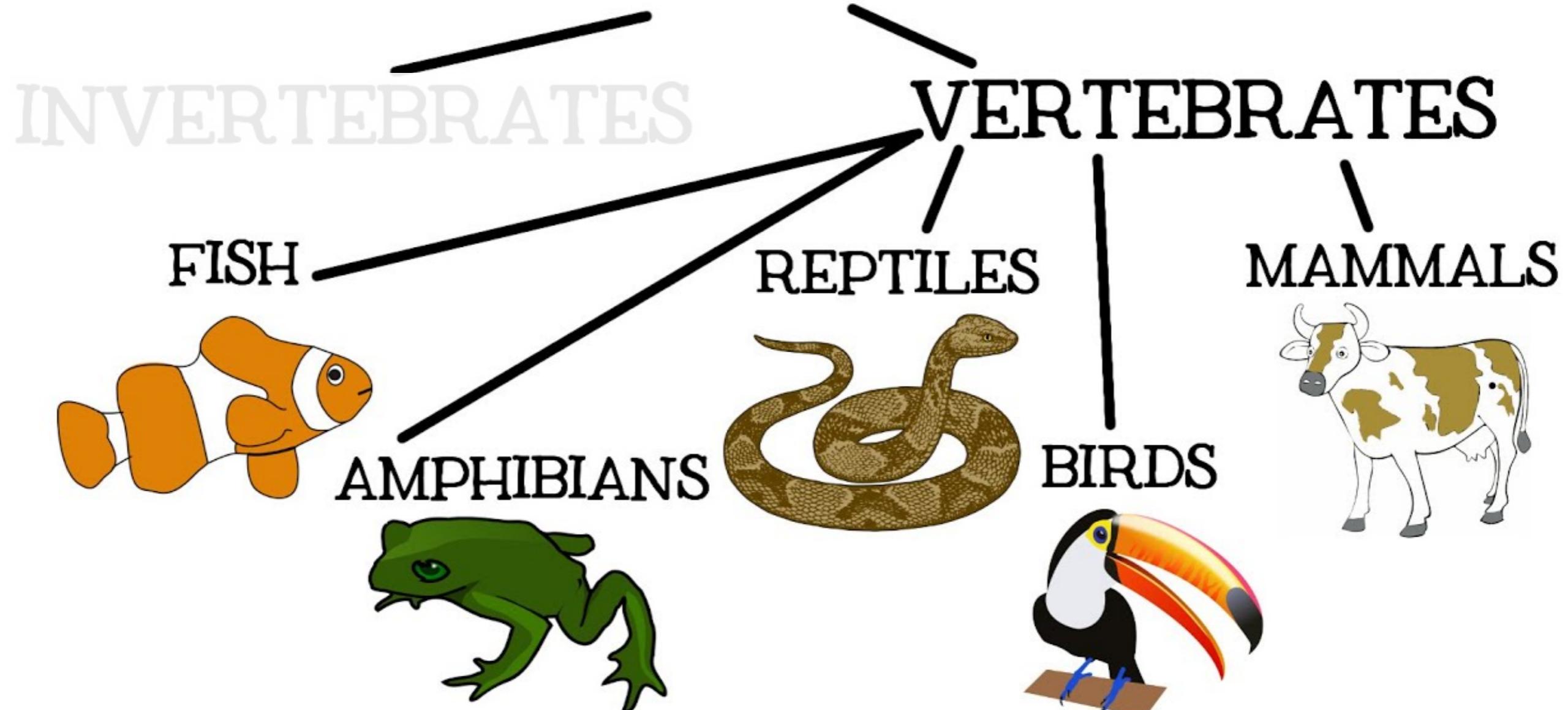
- Spatially-explicit models
- Integrated pop. models

## ► Survival in the 1990s



## ► Transitions in the 2000s

# Capture-recapture is almost all about animal demography



[youtube.com/user/watchfreeschool/featured](https://youtube.com/user/watchfreeschool/featured)



Hot topics in capture-recapture?



# Lucile Marescot: **Disease ecology**



**Lucile Marescot: Disease ecology**



**Christophe Barbraud: Threats to biodiversity**



**Lucile Marescot: Disease ecology**



**Christophe Barbraud: Threats to biodiversity**



**Antica Culina: Evolutionary ecology**



Lucile Marescot: **Disease ecology**



Christophe Barbraud: **Threats to biodiversity**



Antica Culina: **Evolutionary ecology**



Ana Sanz-Aguilar: **Behavioral ecology**



Lucile Marescot: **Disease ecology**



Christophe Barbraud: **Threats to biodiversity**



Antica Culina: **Evolutionary ecology**



Ana Sanz-Aguilar: **Behavioral ecology**



Pierre Dupont & Cyril Milleret : **Population management**

# 2 METHODOLOGICAL ASPECTS

# Non-invasive « marking » methods

# Non-invasive « marking » methods



Photo-identification

# Non-invasive « marking » methods



Photo-identification

Genetic tagging



Alexander Kopatz

# Non-invasive « marking » methods

*Ecological Applications*, 29(4), 2019, e01876

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## Genetic tagging in the Anthropocene: scaling ecology from alleles to ecosystems

CLAYTON T. LAMB,<sup>1,7</sup> ADAM T. FORD,<sup>2</sup> MICHAEL F. PROCTOR,<sup>3</sup> J. ANDREW ROYLE,<sup>4</sup> GARTH MOWAT,<sup>5,6</sup> AND STAN BOUTIN<sup>1</sup>

### Genetic tagging



Alexander Kopatz

# The rise of hidden process dynamic models

# The rise of hidden process dynamic models

Observations

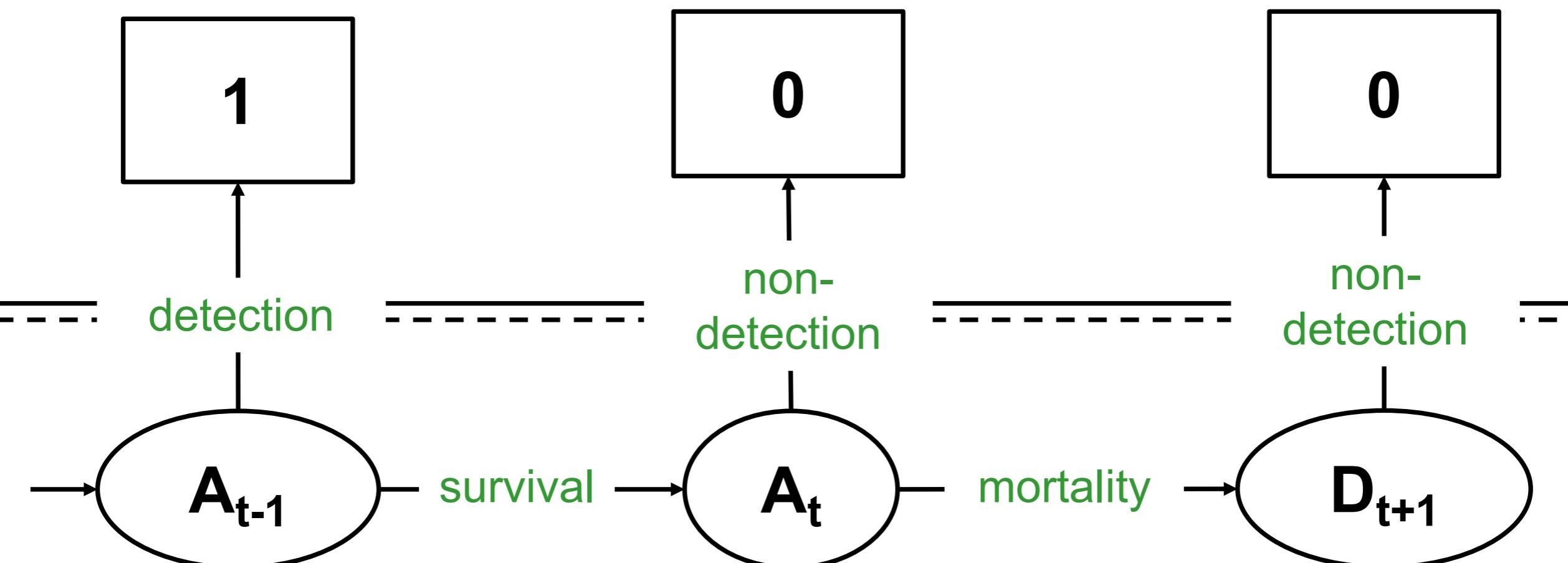
1

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0

# The rise of hidden process dynamic models

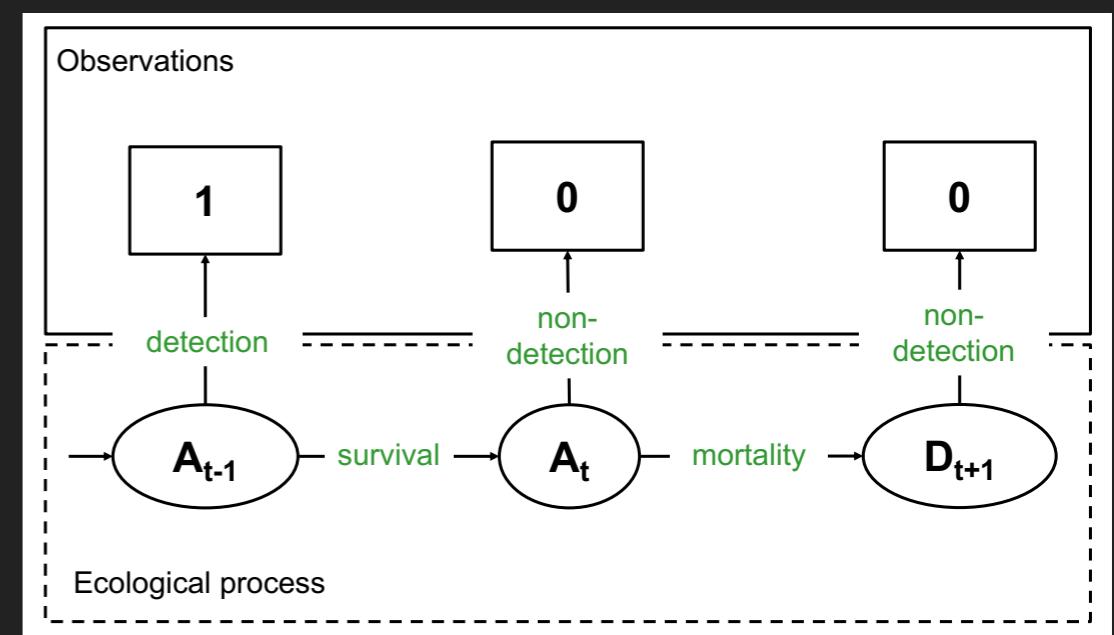
Observations



Ecological process

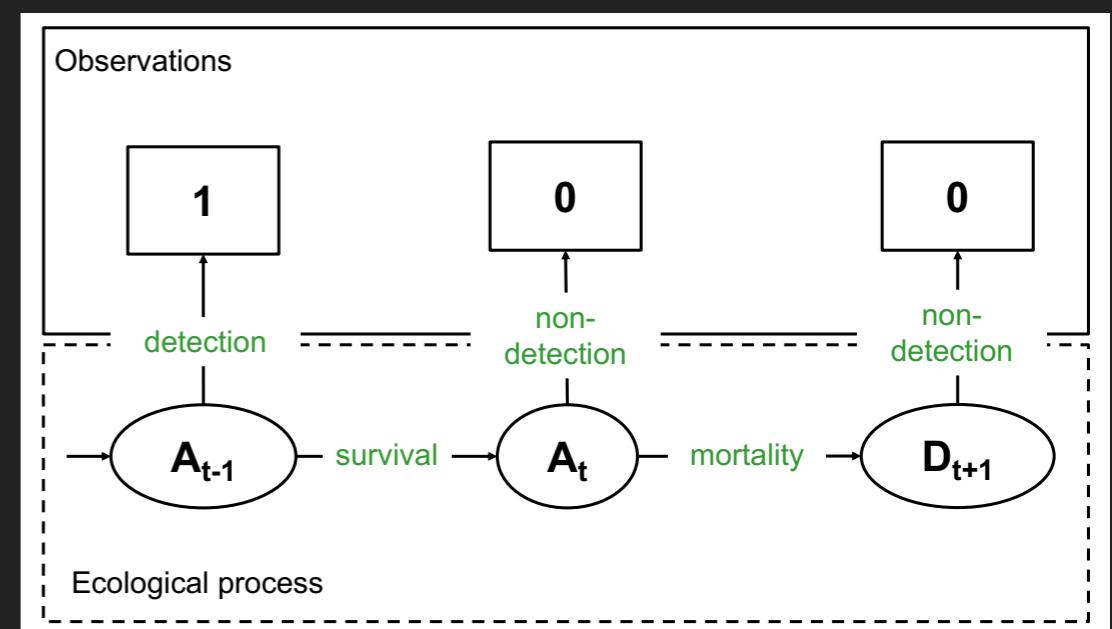
# The rise of hidden process dynamic models

- ▶ State-space models and hidden-Markov models



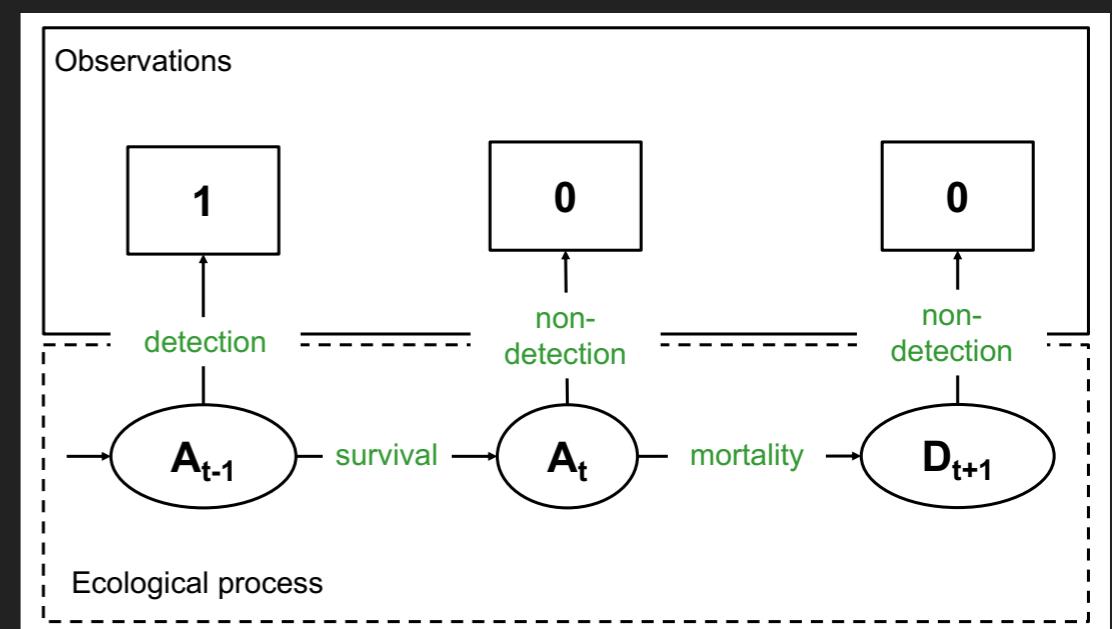
# The rise of hidden process dynamic models

- ▶ State-space models and hidden-Markov models
- ▶ Besides estimating survival and detection, we'd like to
  - Estimate hidden states (disease, activity center XY)
  - Account for uncertainties (states or id)



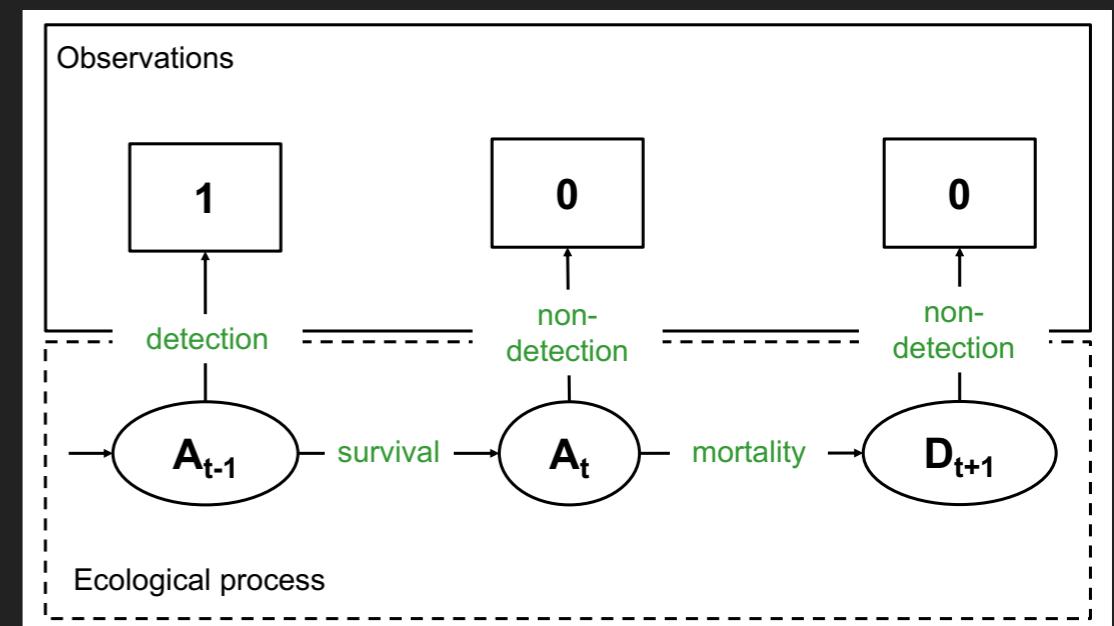
# The rise of hidden process dynamic models

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# The rise of hidden process dynamic models

- ▶ State-space models and hidden-Markov models
- ▶ Besides estimating survival and detection, we'd like to
  - Estimate hidden states (disease, activity center XY)
  - Account for uncertainties (states or id)
- ▶ Bayesian methods to the rescue, and MCMC machinery
- ▶ Random effects, spatial variation



# Combination of information



Pix by Mark Unger, tweeted by Andy Royle

# 1. Integrated population models

**Productivity data:**  
**Poisson model**

**(Non-)Detection data:**  
**Capture-recapt. Model**

**Count data:**  
**State-space model**

# 1. Integrated population models

**Productivity data:**  
Poisson model  
*fecundity*

**(Non-)Detection data:**  
Capture-recapt. Model  
*survival*

**Count data:**  
State-space model  
*abundance*

# 1. Integrated population models

**Productivity data:**  
Poisson model  
*fecundity*

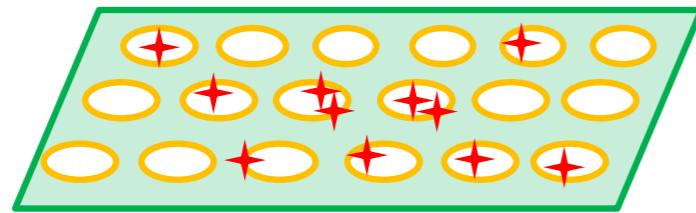
**(Non-)Detection data:**  
Capture-recapt. Model  
*survival*

**Count data:**  
State-space model  
*abundance*

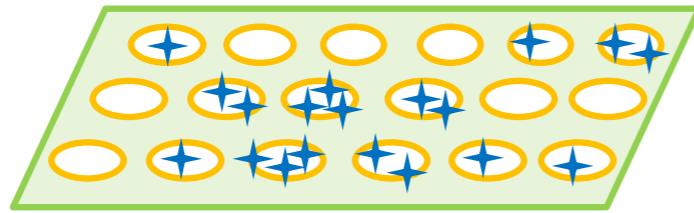
## 2. Combined data models

### Capture-recapture

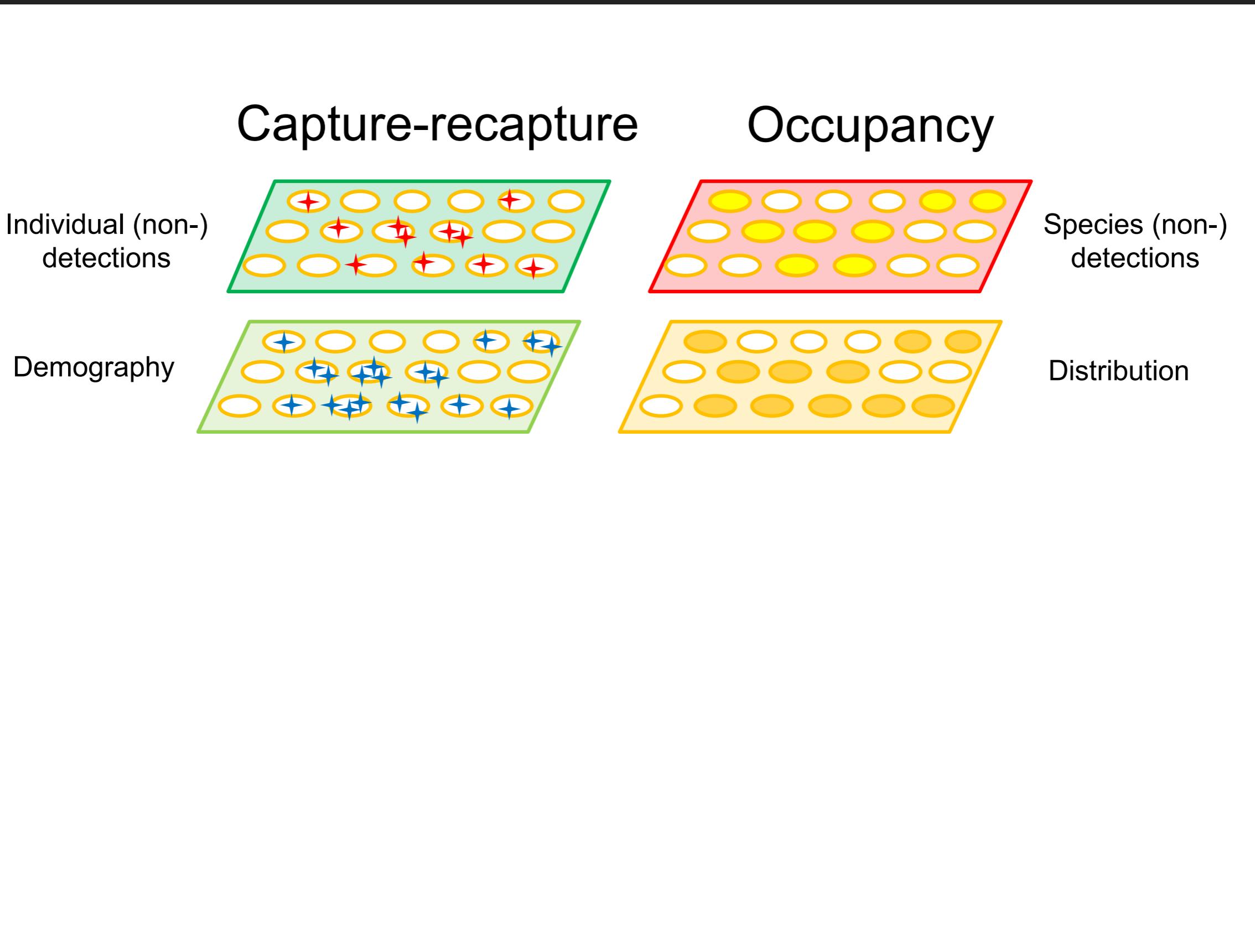
Individual (non-) detections



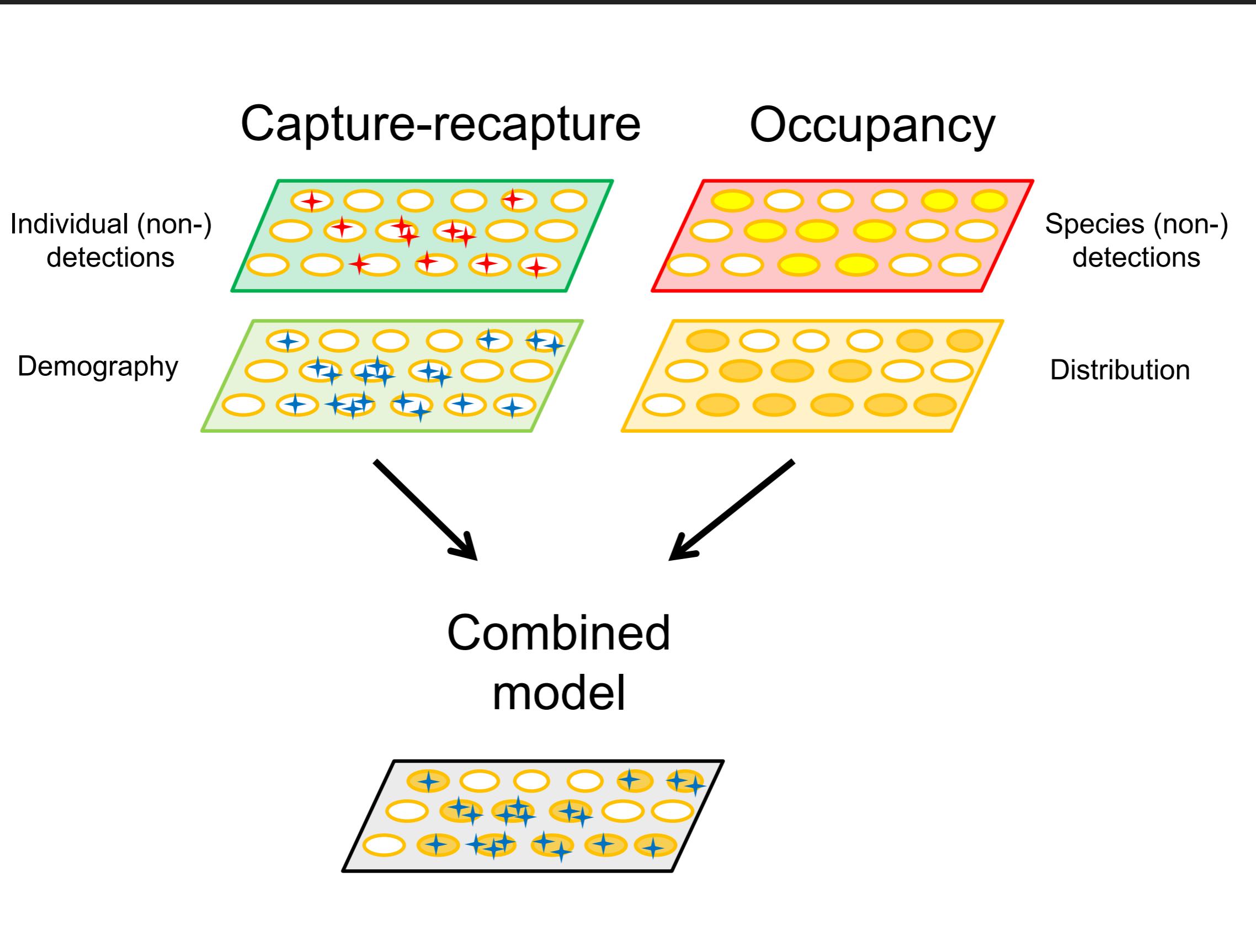
Demography



## 2. Combined data models



## 2. Combined data models



## 2. Combined data models

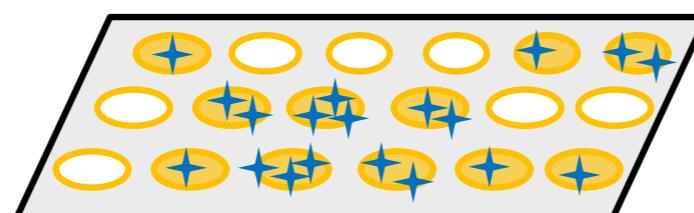
*Ecology*, 100(9), 2019, e02777  
© 2019 by the Ecological Society of America

Incorporating citizen science data in spatially explicit integrated population models

CATHERINE C. SUN,<sup>1,4</sup> J. ANDREW ROYLE,<sup>2</sup> AND ANGELA K. FULLER<sup>3</sup>



Combined  
model



# 3 WHERE DO WE GO FROM THERE

WHAT DO YOU SEE  
YOURSELF DOING IN  
10 YEARS?,



New technologies produce new and more data

# New technologies produce new and more data drones

esa

ECOSPHERE

METHODS, TOOLS, AND TECHNOLOGIES

Remotely piloted aircraft improve precision of  
capture–mark–resight population estimates of Australian fur seals

KARINA J. SORRELL <sup>1,2</sup>† ROHAN H. CLARKE <sup>1</sup> ROSS HOLMBERG,<sup>2</sup> AND REBECCA R. MCINTOSH<sup>2</sup>

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e-DNA

*Journal of Applied Ecology* 2016, 53, 1148–1157

doi: 10.1111/1365-

**Quantifying relative fish abundance with eDNA: a  
promising tool for fisheries management**

Anaïs Lacoursière-Roussel<sup>1\*</sup>, Guillaume Côté<sup>1</sup>, Véronique Leclerc<sup>2</sup> and  
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PIT-tags

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Received: 2 May 2019 | Revised: 2 July 2019 | Accepted: 5 July 2019

DOI: 10.1002/ece3.5482

ORIGINAL RESEARCH

*Ecology and Evolution* Open Access

WILEY

**High detectability with low impact: Optimizing large PIT tracking systems for cave-dwelling bats**

Emmi van Harten<sup>1</sup>  | Terry Reardon<sup>2</sup> | Lindy F. Lumsden<sup>3</sup> | Noel Meyers<sup>4</sup> |

Thomas A. A. Prowse<sup>5</sup> | John Weyland<sup>6</sup> | Ruth Lawrence<sup>4</sup>

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acoustic

Received: 30 January 2018 | Accepted: 31 May 2018

DOI: 10.1111/2041-210X.13040

RESEARCH ARTICLE

Methods in Ecology and Evolution 

Modelling sound attenuation in heterogeneous environments for improved bioacoustic sampling of wildlife populations

J. Andrew Royle 

# Survey design



« An applied statistician knowledgeable in capture-recapture should often be consulted for both the design and analysis of capture-recapture or capture-resighting studies, especially if the population issues are complex. »

Lebreton et al. (1992)  
Ecological Monographs 62, 67-118



# Survey design

Received: 20 March 2019 | Accepted: 22 July 2019

DOI: 10.1111/2041-210X.13279

**REVIEW ARTICLE**

Methods in Ecology and Evolution 

## Sampling and analysis frameworks for inference in ecology

Byron K. Williams  | Eleanor D. Brown 

# From population to community ecology



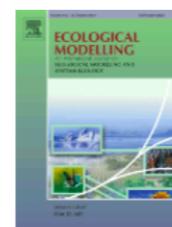
# From population to community ecology



Ecological Modelling

Available online 18 August 2019, 108713

In Press, Corrected Proof



Integrating multiple data sources to fit matrix population models for interacting species

Frédéric Barraquand <sup>a, b</sup> , Olivier Gimenez <sup>c</sup>



# spatial capture-recapture



to boldly go where no ecologist has gone before

# spatial capture-recapture



## ECOGRAPHY

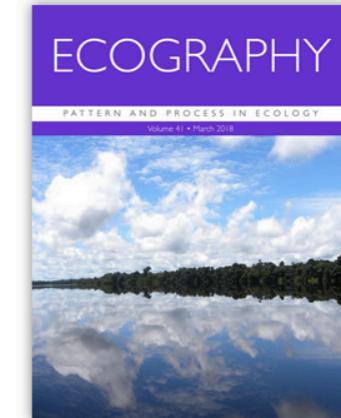
A JOURNAL OF SPACE  
AND TIME IN ECOLOGY

Review & synthesis

Free Access

### Unifying population and landscape ecology with spatial capture–recapture

J. Andrew Royle , Angela K. Fuller, Christopher Sutherland



[Volume 41, Issue 3](#)

March 2018

Pages 444-456

Advertisement

to boldly go where no ecologist has gone before

# Combination of (even more) information

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*Methods in Ecology and Evolution* 2014, **5**, 592–597

doi: 10.1111/2041-210X.12191

## APPLICATION

### Fitting occupancy models with E-SURGE: hidden Markov modelling of presence–absence data

Olivier Gimenez<sup>1\*</sup>, Laetitia Blanc<sup>1</sup>, Aurélien Besnard<sup>1</sup>, Roger Pradel<sup>1</sup>, Paul F. Doherty Jr<sup>2</sup>, Eric Marboutin<sup>3</sup> and Rémi Choquet<sup>1</sup>

# Combination of (even more) information

*Ecology*, 93(11), 2012, pp. 2336–2342  
© 2012 by the Ecological Society of America

## Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions

ROLAND LANGROCK,<sup>1,5</sup> RUTH KING,<sup>1</sup> JASON MATTHIOPoulos,<sup>2</sup> LEN THOMAS,<sup>1</sup> DANIEL FORTIN,<sup>3</sup> AND  
JUAN M. MORALES<sup>4</sup>

*Methods in Ecology and Evolution* 2014, **5**, 592–597

doi: 10.1111/2041-210X.12191

### APPLICATION

## Fitting occupancy models with E-SURGE: hidden Markov modelling of presence-absence data

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Eric Marboutin<sup>3</sup> and Rémi Choquet<sup>1</sup>

# Combination of (even more) information

Received: 4 September 2017 | Accepted: 24 April 2019

DOI: 10.1111/biom.13078

**BIOMETRIC PRACTICE**

**Biometrics** WILEY  
A JOURNAL OF THE INTERNATIONAL BIOMETRIC SOCIETY

## Open population maximum likelihood spatial capture-recapture

Richard Glennie<sup>1</sup>  | David L. Borchers<sup>1</sup> | Matthew Murchie<sup>1</sup> | Bart J. Harmsen<sup>2,3</sup> |  
Rebecca J. Foster<sup>2,3</sup>

### Abstract

Open population capture-recapture models are widely used to estimate population demographics and abundance over time. Bayesian methods exist to incorporate open population modeling with spatial capture-recapture (SCR), allowing for estimation of the effective area sampled and population density. Here, open population SCR is formulated as a hidden Markov model (HMM),

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*Methods in Ecology and Evolution* 2014, **5**, 592–597

doi: 10.1111/2041-210X.12191

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# Combination of (even more) information

BIOMETRICS 73, 1321–1331  
December 2017

DOI: 10.1111/biom.12701

## Hidden Markov Models for Extended Batch Data

Laura L. E. Cowen,<sup>1\*</sup> Panagiotis Besbeas,<sup>2,3,\*\*</sup> Byron J.  
and Carl J. Schwarz<sup>4,\*\*\*\*</sup>

Received: 4 September 2017 | Accepted: 24 April 2019

DOI: 10.1111/biom.13078

### BIOMETRIC PRACTICE



## Open population maximum likelihood spatial capture-recapture

Richard Glennie<sup>1</sup> | David L. Borchers<sup>1</sup> | Matthew Murchie<sup>1</sup> | Bart J. Harmsen<sup>2,3</sup> |  
Rebecca J. Foster<sup>2,3</sup>

Ecology, 93(11), 2012, pp. 2336–2342  
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## Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions

ROLAND LANGROCK,<sup>1,5</sup> RUTH KING,<sup>1</sup> JASON MATTHIOPoulos,<sup>2</sup> LEN THOMAS,<sup>1</sup> DANIEL FORTIN,<sup>3</sup> AND  
JUAN M. MORALES<sup>4</sup>

### Abstract

Open population capture-recapture models are widely used to estimate population demographics and abundance over time. Bayesian methods exist to incorporate open population modeling with spatial capture-recapture (SCR), allowing for estimation of the effective area sampled and population density. Here, open population SCR is formulated as a hidden Markov model (HMM),

Methods in Ecology and Evolution 2014, 5, 592–597

doi: 10.1111/2041-210X.12191

### APPLICATION

## Fitting occupancy models with E-SURGE: hidden Markov modelling of presence-absence data

Olivier Gimenez<sup>1\*</sup>, Laetitia Blanc<sup>1</sup>, Aurélien Besnard<sup>1</sup>, Roger Pradel<sup>1</sup>, Paul F. Doherty Jr<sup>2</sup>,  
Eric Marboutin<sup>3</sup> and Rémi Choquet<sup>1</sup>

# Combination of (even more) information

BIOMETRICS 73, 1321–1331  
December 2017

DOI: 10.1111/biom.12701

## Hidden Markov Models for Extended Batch Data

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and Carl J. Schwarz<sup>4,\*\*\*\*</sup>

Received: 4 September 2017 | Accepted: 24 April 2019

DOI: 10.1111/biom.13078

### BIOMETRIC PRACTICE



## Open population maximum likelihood spatial capture-recapture

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Rebecca J. Foster<sup>2,3</sup>

Ecology, 93(11), 2012, pp. 2336–2342  
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Combination of (even more) information  
Hidden Markov models as a unifying framework?

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Received: 27 February 2018

Accepted: 6 December 2018

DOI: 10.1111/biom.13045

**ORIGINAL ARTICLE**

**WILEY**  **Biometrics**  
Since 1947 A JOURNAL OF THE INTERNATIONAL BIOMETRIC SOCIETY

## Exact inference for integrated population modelling

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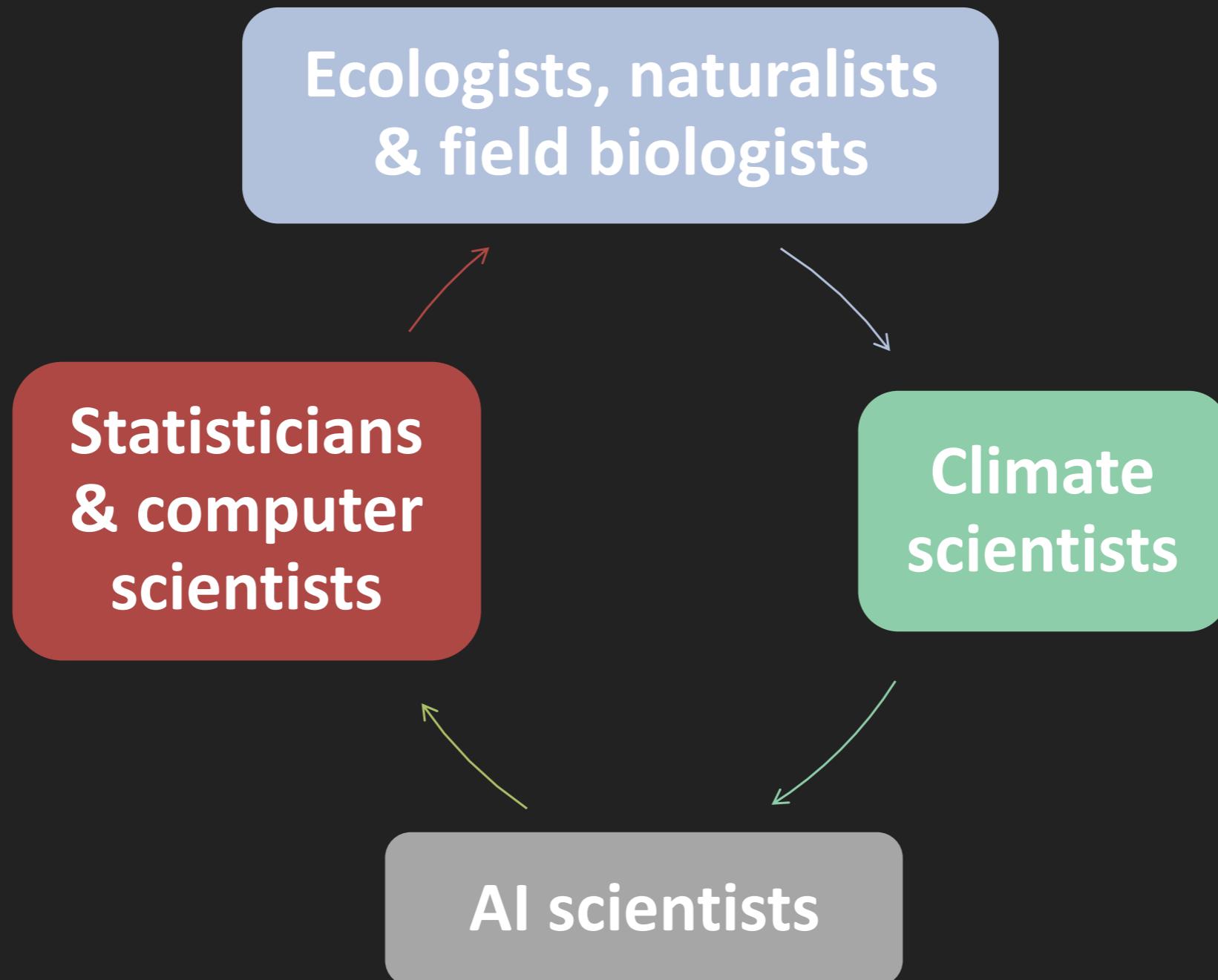
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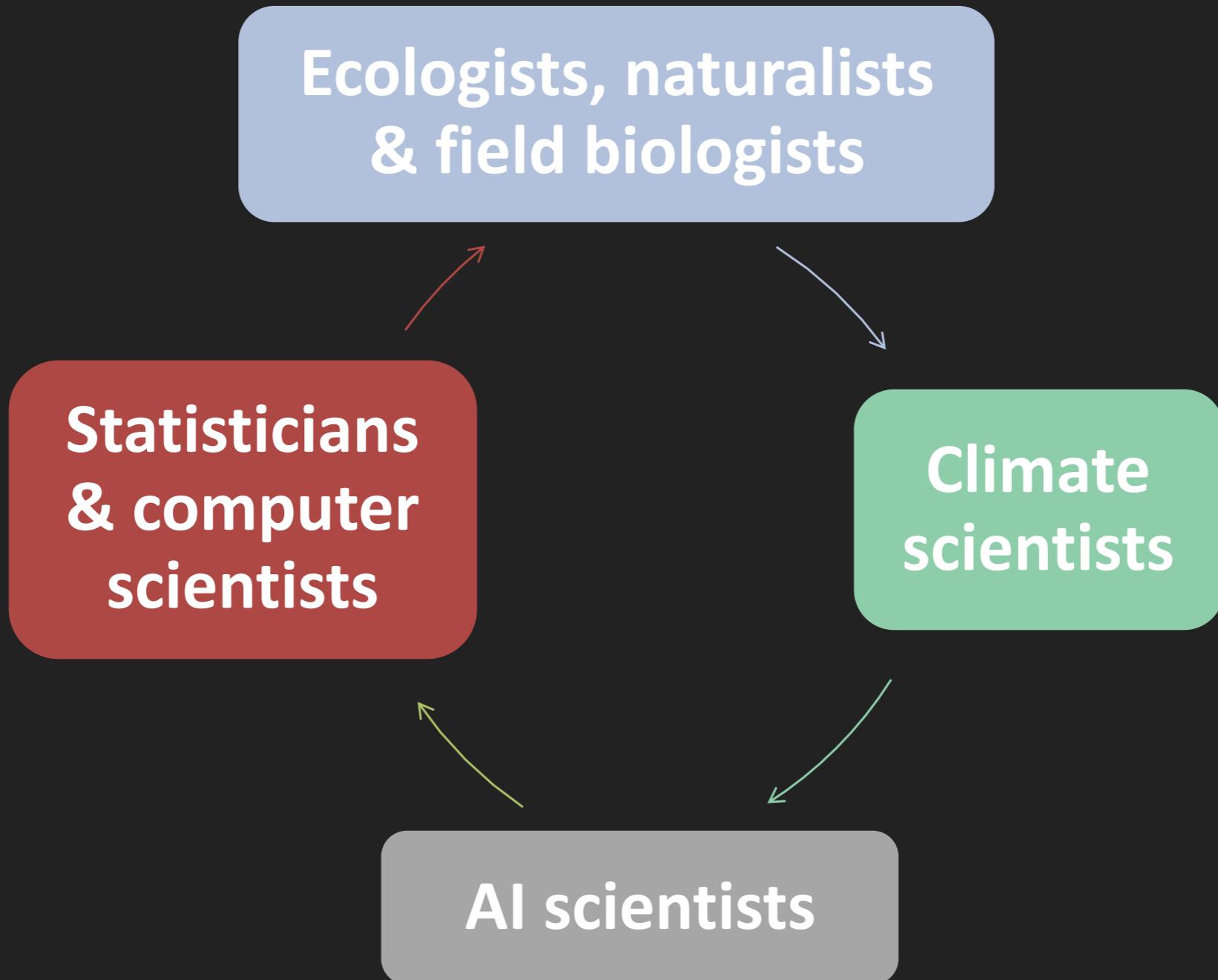
### Abstract

Integrated population modelling is widely used in statistical ecology. It allows data from population time series and independent surveys to be analysed simultaneously. In classical analysis the time-series likelihood component can be conveniently approximated using Kalman filter methodology. However, the natural way to model systems which have a discrete state space is to use hidden Markov models (HMMs).

# Cross-fertilization between disciplines



# Cross-fertilization between disciplines



Workshops: Disseminate methods and software, build inclusive & friendly community

Olivier Gimenez

WRC2019, Berlin



# CAPTURE-RECAPTURE

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## ECOLOGICAL QUESTIONS, METHODS

Slides, analyses, data & codes: <https://tinyurl.com/y5npsk5r>

# We ignored books, for convenience

