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Hierarchical Bayesian species distribution models with the **hSDM** R Package

Ghislain Vieilledent[⋆,1] Cory Merow[2] Jérôme Guélat[3]
Andrew M. Latimer[4] Marc Kéry[3]
Alan E. Gelfand[5] Adam M. Wilson[6] Frédéric Mortier[1]
and John A. Silander Jr.[2]

[1] **Cirad** France, [2] **University of Connecticut** USA, [3] **Swiss Ornithological Institute** Switzerland, [4] **University of California** USA, [5] **Duke University** USA, [6] **Yale University** USA

1. Introduction
   - Species distribution models
   - Issues : imperfect detection and spatial correlation
   - Available softwares
2. hSDM R package
   - Package main characteristics
   - Parameter inference
3. Examples
   - N-mixture iCAR model
   - Binomial iCAR model with large data-set
4. Recommendations
   - "statistical machismo" ?
   - hSDM and applied research in ecology

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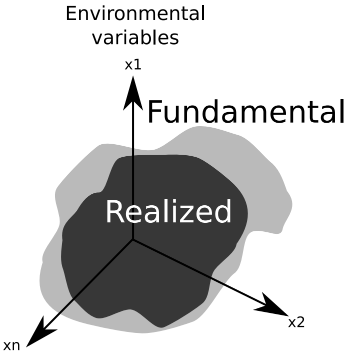
SDM definition

Objectives

- Identifying the suitable habitat for species persistence
- Reference : species niche (Hutchinson 1957)
- Representing this habitat spatially (maps)
- Applications : conservation biology

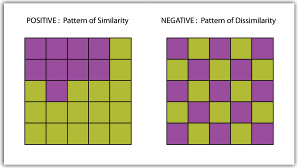


Imperfect detection

- Species is not observed perfectly (“Now you see me, now you don’t”)
- Detection probability < 1
- Treating observations as the “true” species distribution might lead to completely wrong habitat models
- See **Lahoz-Monfort et al.** 2014 *Global Ecology and Biogeography*

Spatial autocorrelation

- Most species present geographical patchiness
- Positive spatial correlation
- Causes :
  - Exogeneous environmental factors (climate, soil)
  - Endogeneous biotic processes (dispersal, migration)
- Ignoring spatial correlation may lead to biased conclusions about ecological relationships
- See **Lichstein et al.** 2002 *Ecological Monographs*



Site-occupancy and N-mixture models

Site-occupancy model (occurrence data)

Ecological process :

$Z_i \sim \mathcal{B}ernoulli(\theta_i)$

$\text{logit}(\theta_i) = X_i\beta$

Observation process :

$y_{it} \sim \mathcal{B}ernoulli(\delta_{it} \times Z_i)$

$\text{logit}(\delta_{it}) = W_{it}\gamma$

N-mixture model (count data)

Ecological process :

$N_i \sim \mathcal{P}oisson(\lambda_i)$

$\log(\lambda_i) = X_i\beta$

Observation process :

$y_{it} \sim \mathcal{B}inomial(N_i, \delta_{it})$

$\text{logit}(\delta_{it}) = W_{it}\gamma$

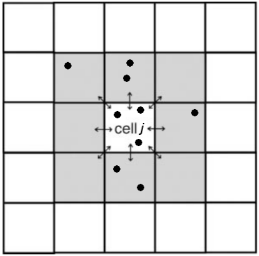
Repeated observations at particular sites (multiple visits)

CAR process

intrinsic CAR

$p(\rho_j|\rho_{j'}) \sim \mathcal{N}ormal(\mu_j, V_\rho/n_j)$

μ_j : mean of $\rho_{j'}$ in the neighborhood of j.
V_ρ : variance of the spatial random effects.
n_j : number of neighbors for cell j.



CAR process

Site-occupancy model (occurrence data)

Ecological process :
$Z_i \sim \mathcal{B}ernoulli(\theta_i)$
$\text{logit}(\theta_i) = X_i\beta + \rho_{j(i)}$

Observation process :
$y_{it} \sim \mathcal{B}ernoulli(\delta_{it} \times Z_i)$
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N-mixture model (count data)

Ecological process :
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Available softwares

Softwares for mixture models

PRESENCE, **MARK**, **E-SURGE**, **unmarked**, **stocc**, **JAGS**, **stan**, **WinBUGS**, **OpenBUGS**

Softwares for spatial autocorrelation

OpenBUGS, **WinBUGS**, **BayesX**, **stocc**, **CARBayes**, **R-INLA**, **spatcounts**, **OpenBUGS**, **spdep**, **CARramps**, **spBayes**

Mixture models + spatial autocorrelation

Very few softwares available and limitations : **OpenBUGS**, **WinBUGS** (might be slow), **stocc** (probit and binary data only).

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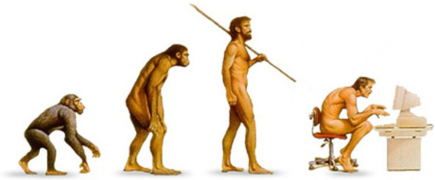
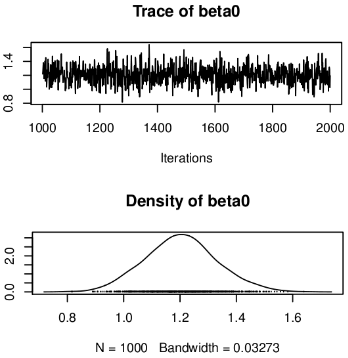
Package main characteristics

- **hSDM** : R "user-friendly" package
- Mixture models : **site-occupancy**, **N-mixture**, but also **ZIB** and **ZIP** models
- Including a spatial autocorrelation process (**iCAR**)
- Web-site : `https://ecology.ghislainv.fr/hSDM`
- Vignette with several examples on simulated and real data-sets



Parameter inference

- hierarchical Bayesian models
- MCMC methods (no approximation of the posterior)
- adaptive Metropolis within Gibbs (**“efficient”**)
- written in pure **C** code (**“fast”**)
- source code available through `git` on Sourceforge



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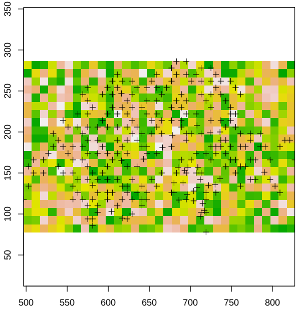
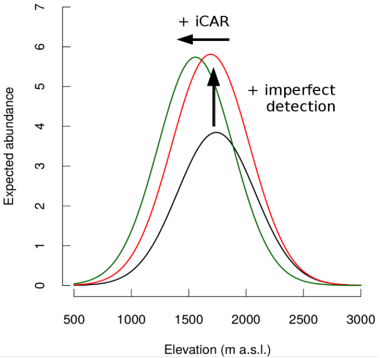
N-mixture iCAR model

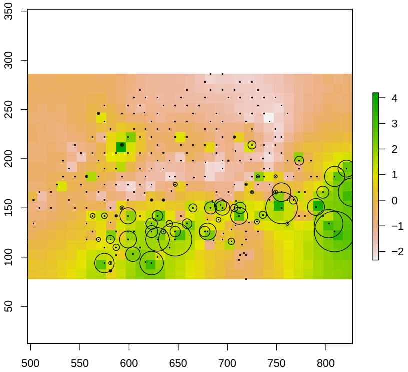
- **Kéry & Royle** 2010, *Journal of Animal Ecology*
- Abundance of the Willow tit (*Poecile montanus*)
- Switzerland
- 264 sites with 2 or 3 visits
- 10×10 km cells



N-mixture iCAR model

- Models of increasing complexity
- (1) Poisson, (2) N-mixture and (3) N-mixture + iCAR

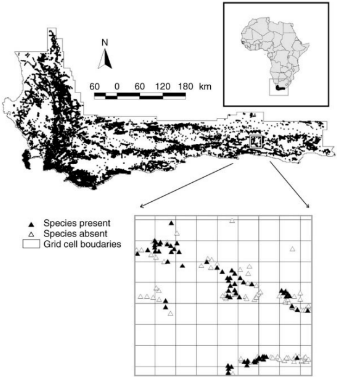




Spatial random effects (raster) and observed abundance (circles)

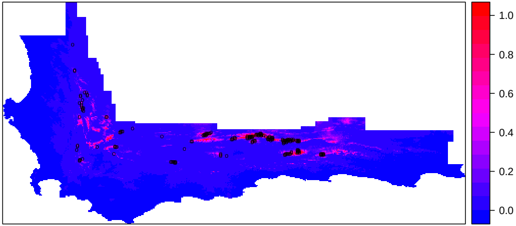
Binomial iCAR model with large data-set

- **Latimer et al.** 2006, *Ecological Applications*
- Occurrence of *Protea punctata*
- Cap Floristic Region (South Africa)
- 36909 1'×1' grid cells
- Too many data to use ⋆**BUGS** programs

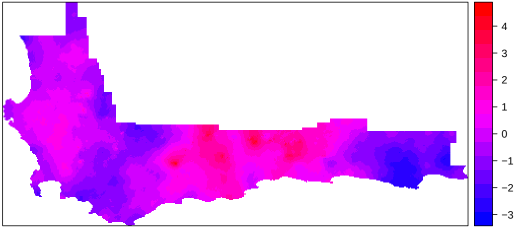


Binomial iCAR model with large data-set

Probability of presence



Spatial random effects



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"statistical machismo" ?

Following **Brian McGill**'s post

- Bonferroni corrections
- Phylogenetic corrections
- Spatial regression
- Detection error
- Bayesian methods

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Can we be accused of "statistical machismo" ?

hSDM and applied research in ecology

Some recommendations

- Complex models need **appropriate data** (quantity + structure).
- Beware of over-parametrization and identifiability problems.

Complex models and applied research

- It is true that in some cases, complex models do not significantly improve our ecological knowledge of the species.
- Conservation planning : we need to identify the level of **model complexity** we need to reach in order to take good decisions.

When complex models are necessary ?

hSDM : tool to investigate the situations (species, place) where imperfect detection and spatial correlation lead to significant different results that impact decisions.

... Thank you for attention ...