Implications of vulnerability to hurricane damage for long-term survival of tropical tree species: a Bayesian hierarchical analysis

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Agenda

Introduction

- Hurricane
- Tree species

Field Study

Modeling Methods

- Single species
- Multi species + spatial variability

Results

- Model comparison and selection
- Species specific analysis
- Spatial correlation

Conclusion

- Strengths of the approach
- Limitations and future research

Introduction

- Caribbean Islands
  - Hurricanes
- Authors use Hurricane Hugo data
  - Sep 10-25, 1989
  - Max winds: 160 mph
- Test hypothesis
- Individual tree survives the post-hurricane recovery period
  - Taxonomy
  - Tree size and crowding
  - Influence of hurricane damage on tree survival
- Consider four species

Tree species

Caesaria arborea

Alchornea latifolia

Dacryodes excelsa

Manilkara bidentata

Field study

- 16-ha recovery plot in Puerto Rico
- Survey conducted for 4-5 months
  - Assess all trees >= 10 cm in diameter at breast height (DBH; ~ 1.3 m from ground) for degree of damage
  - Damage D = 0, 1, 2

  - After ~3.5 years another census
  - All trees >= 1 cm DBH
  - Survival S = 0,1

- Note: do not consider immediate mortality

Modeling

- Single species model
  - Likelihood functions

Damage Survival

$$L(D_i, S_i \mid \alpha, \beta, DBH_i, BA_i) =$$

$$L(D_i \mid \alpha, DBH_i) L(S_i \mid \beta, D_i, DBH_i, BA_i)$$

α = Defines relationship between DBH and prob. of tree receiving no, medium or heavy damage

β = prob. of remaining alive between surveys to tree size, crowding, and level of damage suffered by hurricanes

Marginal likelihood for damage

$$D_i \sim Multin(n, p_{0i}, p_{1i}, p_{2i} \mid \alpha, DBH_i)$$

n = 1 (individual tree)

$$\ln\left(\frac{p_{0i}}{p_{2i}}\right) = \alpha_1 + \alpha_2 . \frac{DBH_i}{100}$$

$$\ln\left(\frac{p_{1i}}{p_{2i}}\right) = \alpha_3 + \alpha_4 . \frac{DBH_i}{100}$$

Damage

None — Intermediate — Severe

$$p_{0i} + p_{1i} + p_{2i} = 1$$

1. Single species modeling…WinBUGS demonstration

1. Single species modeling…cont'd

Conditional likelihood for survival

$$S_i \sim Bern(p_{Ti} \mid \beta, D_i, DBH_i, BA_i)$$

p_{Ti} is the probability of tree surviving the entire census period, which depends on

p_{Si} which is the prob. of survival from one year to next

$$\ln\left(\frac{p_{Si}}{1-p_{Si}}\right) = \beta_1.\frac{DBH_i}{100} + \beta_2.100.BA_i + \beta_3.D_i(1) + \beta_4.D_i(2) + \beta_5.D_i(3)$$

size — crowding — different levels of damage

β = effect of

1. Single species modeling…WinBUGS demonstration

1. Single species: Posterior

- Goal is to estimate α and β
- The joint posterior density is proportional to likelihood, multiplied by the prior

$$P(\alpha, \beta \mid D, S, DBH, BA)$$

$$\propto \left(\prod_{i=1}^{N} L(D_i, S_i \mid \alpha, \beta, DBH_i, BA_i)\right)\pi(\alpha, \beta)$$

N = total number of trees,

π(α, β) is the prior density function for α and β, described by independent normal priors for α and β

α ~ No(0,100.I) and β ~ No(0,100.I)

2. Multispecies model

- Likelihood functions are the same, with the indices now referring to the i[th] tree of the j[th] species
- More differences in the posterior
  - Posterior densities for α, β and γ are proportional to likelihood multiplied by first-stage prior and hyperprior

$$P(\alpha_1,...,\alpha_J,\beta_1,...,\beta_J,\gamma \mid D,S,DBH,BA)$$

$$\alpha(\prod_{j=1}^{J}\prod_{i=1}^{N_j} L(D_{ij},S_{ij} \mid \alpha_j,\beta_j,\gamma,DBH_i,BA_i)\times$$

$$\pi(\alpha_1,...,\alpha_J,\beta_1,...,\beta_J \mid \gamma).\pi(\gamma)$$

  - J = total number of species and N_i is the number of trees identified as species j.

2. Multispecies model…cont'd

$$\gamma = (\mu_\alpha, \mu_\beta, \sigma_\alpha, \sigma_\beta)$$

$$\pi(\alpha_1, \ldots, \alpha_J, \beta_1, \ldots, \beta_J \mid \gamma)$$

is broken up to nine independent first-stage priors

$$\alpha_{1j} \sim No(\mu_{\alpha 1}, \sigma^2_{\alpha 1}), \ldots, \alpha_{4j} \sim No(\mu_{\alpha 4}, \sigma^2_{\alpha 4})$$

$$\beta_{1j} \sim No(\mu_{\beta 1}, \sigma^2_{\beta 1}), \ldots, \beta_{5j} \sim No(\mu_{\beta 5}, \sigma^2_{\beta 4}{}_5)$$

3. Multispecies model with spatial variability

- Likelihood functions are the same, but with one additional parameter for i[th] tree of the j[th] species growing in the k[th] quadrant.

$$L(D_{ijk}, S_{ijk} \mid \alpha_j, \beta_j, \varphi_k, DBH_i, BA_i) = L(D_{ijk} \mid \alpha_j, \varphi_k, DBH_i) \times$$
$$L(S_{ijk} \mid \beta_j, D_{ijk}, DBH_i, BA_i)$$

The marginal likelihood for damage is

$$D_{ijk} \sim Multin(n, p_{0ijk}, p_{1ijk}, p_{2ijk} \mid \alpha_j, DBH_i, \varphi_k)$$

$$\ln(\frac{p_{0ijk}}{p_{2ijk}}) = \alpha_{1j} + \alpha_{2j}.\frac{DBH_i}{100} + \varphi_{1k}$$

$$\ln(\frac{p_{1ijk}}{p_{2ijk}}) = \alpha_{3j} + \alpha_{4j}.\frac{DBH_i}{100} + \varphi_{2k}$$

2. Multispecies species modeling…WinBUGS demo

3. Posterior: Multispecies model with spatial variability

$$P(\alpha_1,...,\alpha_J,\beta_1,...,\beta_J,\varphi_1,...,\varphi_Q,\gamma,\tau \mid D,S,DBH,BA)$$

$$\alpha(\prod_{k=1}^{Q}\prod_{j=1}^{J}\prod_{i=1}^{N_{jk}} L(D_{ijk},S_{ijk} \mid \alpha_j,\beta_j,\varphi_k,\gamma,DBH_i,BA_i)\times$$

$$\pi(\alpha_1,...,\alpha_J,\beta_1,...,\beta_J \mid \gamma).\pi(\varphi_1,...,\varphi_Q \mid \tau).\pi(\gamma).\pi(\tau)$$

Where Q is the number of quadrats, and N_{jk} is the number of trees of species j in the quadrat k.

Results: Model comparison – damage probability I

Model 1:

Severe damage

$$\ln\left(\frac{p_{0i}}{p_{2i}}\right) = \alpha_1 + \alpha_2 \cdot \frac{\text{DBH}_i}{100}$$

Moderate damage

$$\ln\left(\frac{p_{1i}}{p_{2i}}\right) = \alpha_3 + \alpha_4 \cdot \frac{\text{DBH}_i}{100}$$

Model 2:

Hierarchical analysis

-> α_1, α_2, α_3, α_4 become tree specific

Model 3:

Spatial correlation with Gaussian CAR

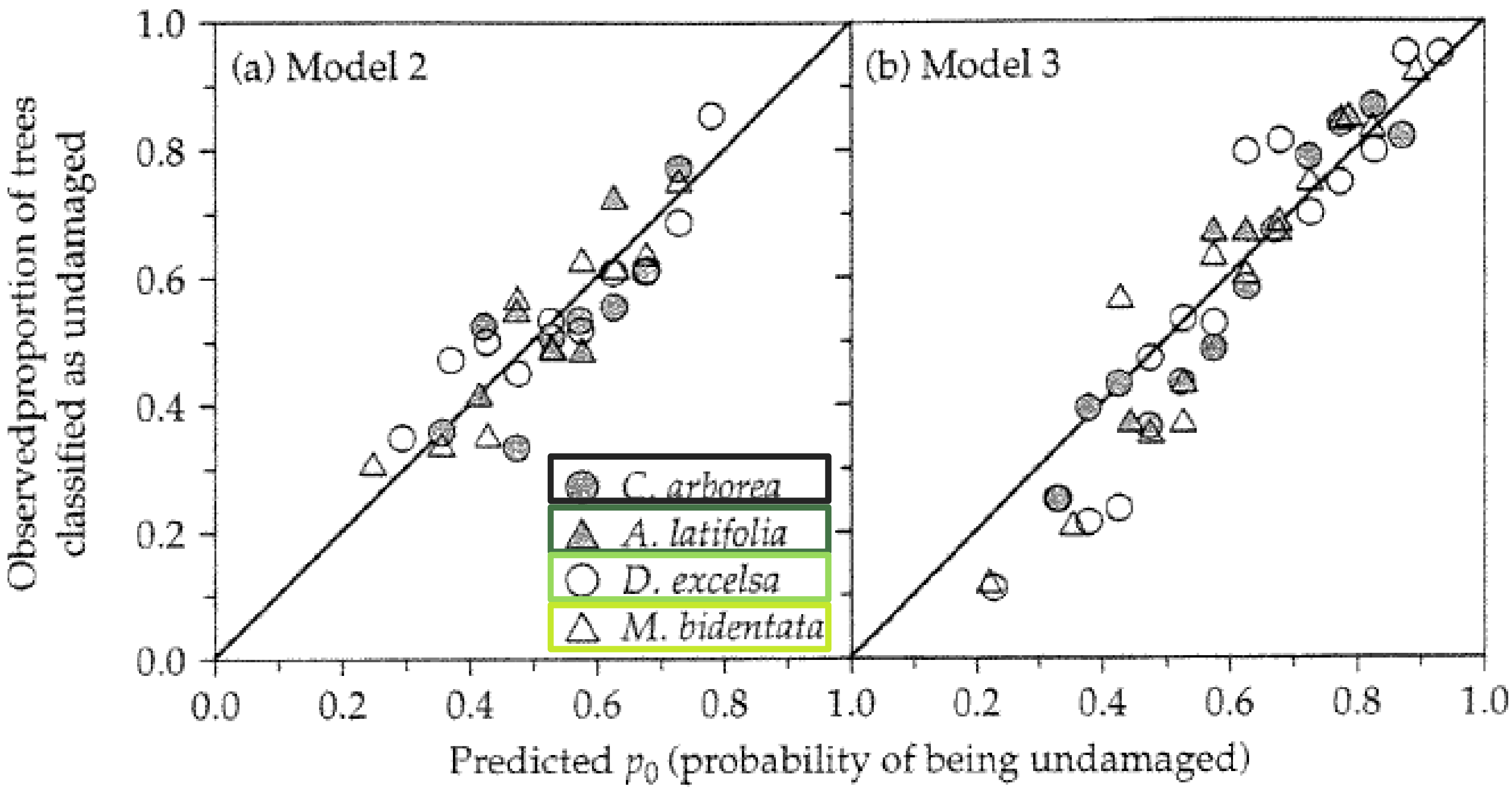
$$\ln\left(\frac{p_{0i}}{p_{2i}}\right) = \alpha_1 + \alpha_2 \cdot \frac{\text{DBH}_i}{100} + \varphi_1$$

$$\ln\left(\frac{p_{1i}}{p_{2i}}\right) = \alpha_3 + \alpha_4 \cdot \frac{\text{DBH}_i}{100} + \varphi_2$$

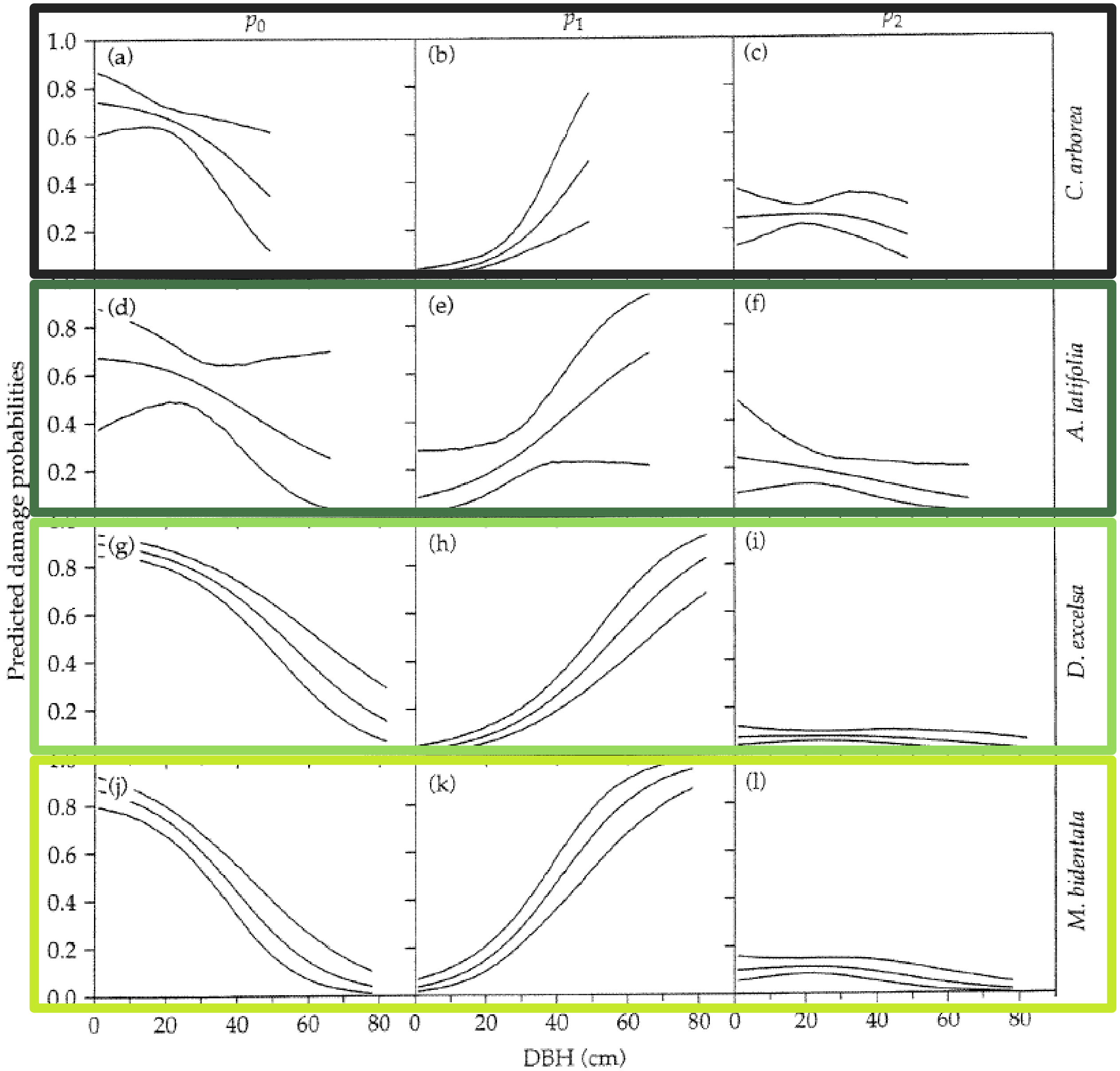
Results: Model comparison – damage probability II

Parameter	Model 1	Model 2	Model 3
α_1	**2.08**	**1.85**	**1.23**
+/- 95% int.	1.45, 2.69	1.30, 2.48	0.87, 1.63
α_2	**-7.03**	**-5.7**	**-1.29**
+/- 95% int.	-10.47, -3.54	-9.19, -2.31	-3.43, 0.69
α_3	**-2.09**	**-2.04**	**-3.07**
+/- 95% int.	-2.87, -1.34	-2.70, -1.47	-3.83, -2.37
α_4	**4.90**	**4.72**	**8.53**
+/- 95% int.	1.38, 8.47	2.07, 7.82	5.52, 12.00
DIC	n.a.	10‘391	9‘807

Results: Model comparison – damage probability III



Results: Model comparison – damage probability IV



Results: Model comparison – survival probability I

Model 1:

Survival probability

$$\ln\left(\frac{p_s}{(1-p_s)}\right) = \beta_1 \cdot \frac{\mathrm{DBH}_i}{100} + \beta_2 \cdot 100 \cdot \mathrm{BA} + \beta_3 \cdot \mathrm{D}(1) + \beta_4 \cdot \mathrm{D}(2) + \beta_5 \cdot \mathrm{D}(3)$$

Model 2:

Hierarchical analysis

-> β_1, β_2, β_3, β_4, β_5 become tree specific

Model 3:

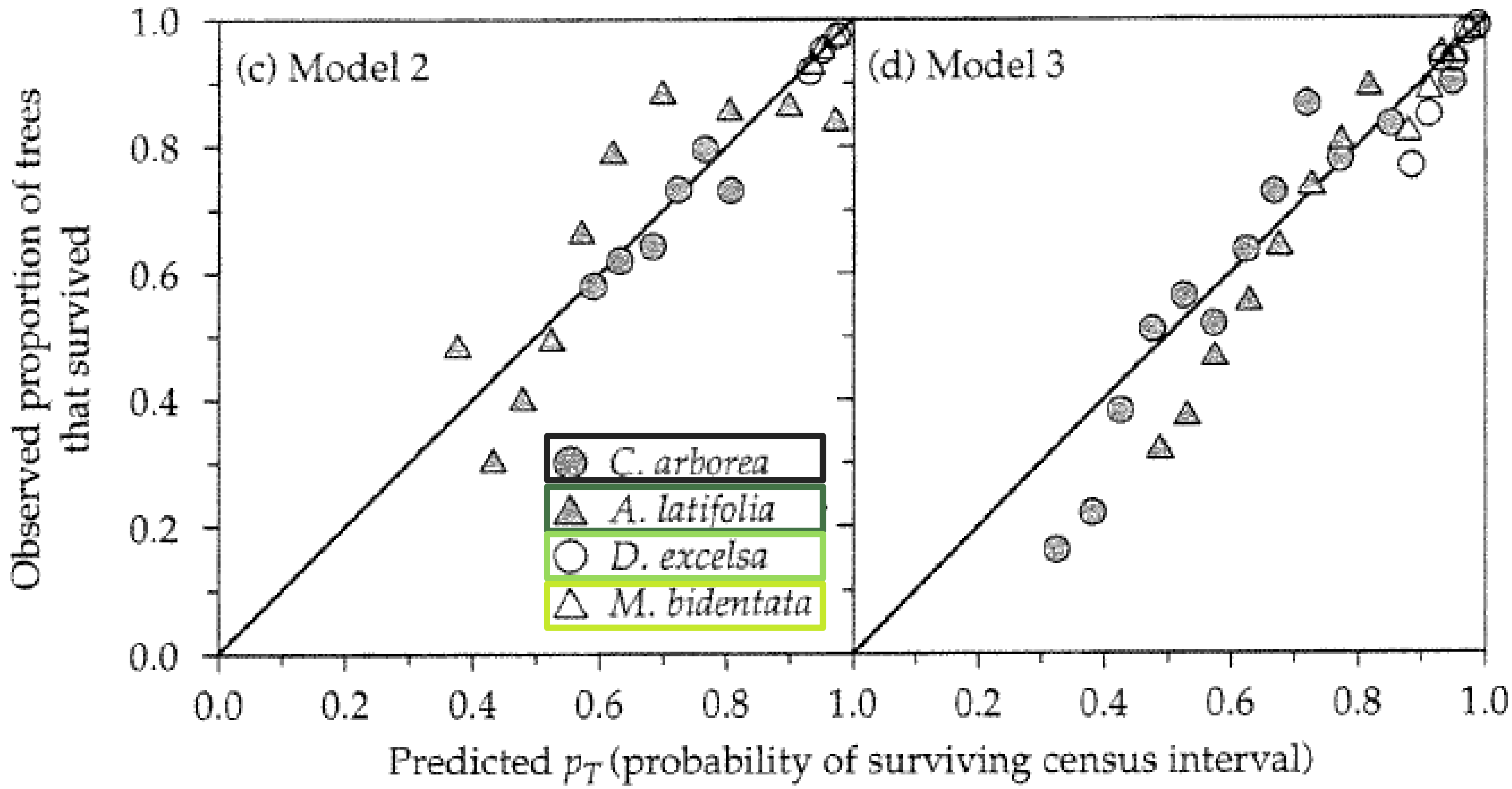
Spatial correlation with Gaussian CAR

-> φ_1, φ_2 (equal for all tree types)

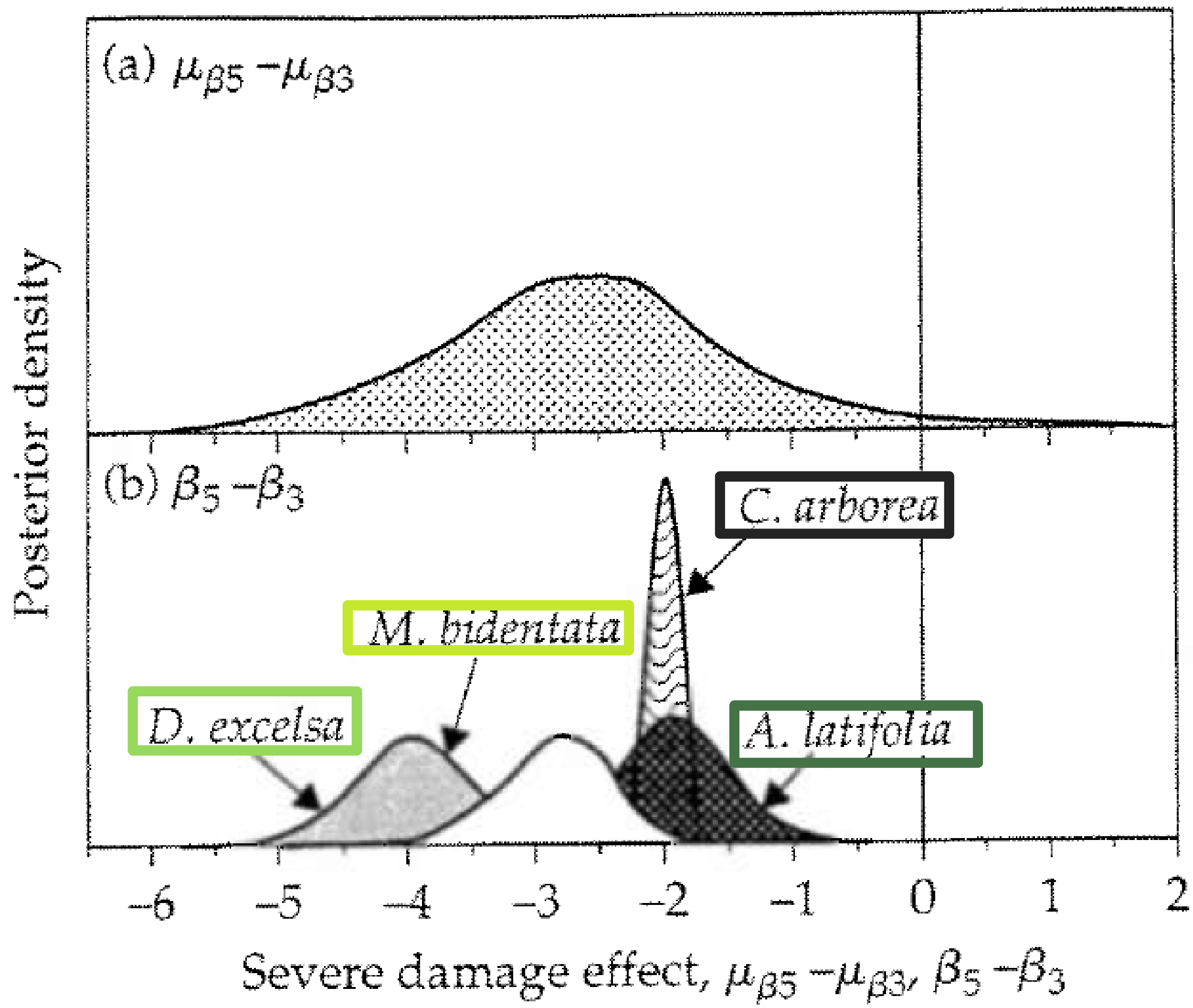
Results: Model comparison – survival probability II

Parameter	Model 1	Model 2	Model 3
β_1 (DBH)	**3.76**	**3.45**	**2.47**
+/- 95% int.	2.46, 5.01	2.51, 4.28	1.26, 3.71
β_2 (Crowding)	**1.64**	**1.6**	**1.95**
+/- 95% int.	0.92, 2.32	0.87, 2.32	1.19, 2.76
β_3 (no damage)	**1.73**	**1.8**	**2.06**
+/- 95% int.	1.44, 2.04	1.50, 2.12	1.74,2 .40
β_4 (partial damage)	**1.16**	**1.26**	**1.36**
+/- 95% int.	0.63, 1.709	0.72,1.81	0.83,1.93
β_4 (heavy damage)	**0.12**	**0.18**	**0.05**
+/- 95% int.	-0.25, 0.470	-0.18, 0.52	-0.31, 0.40

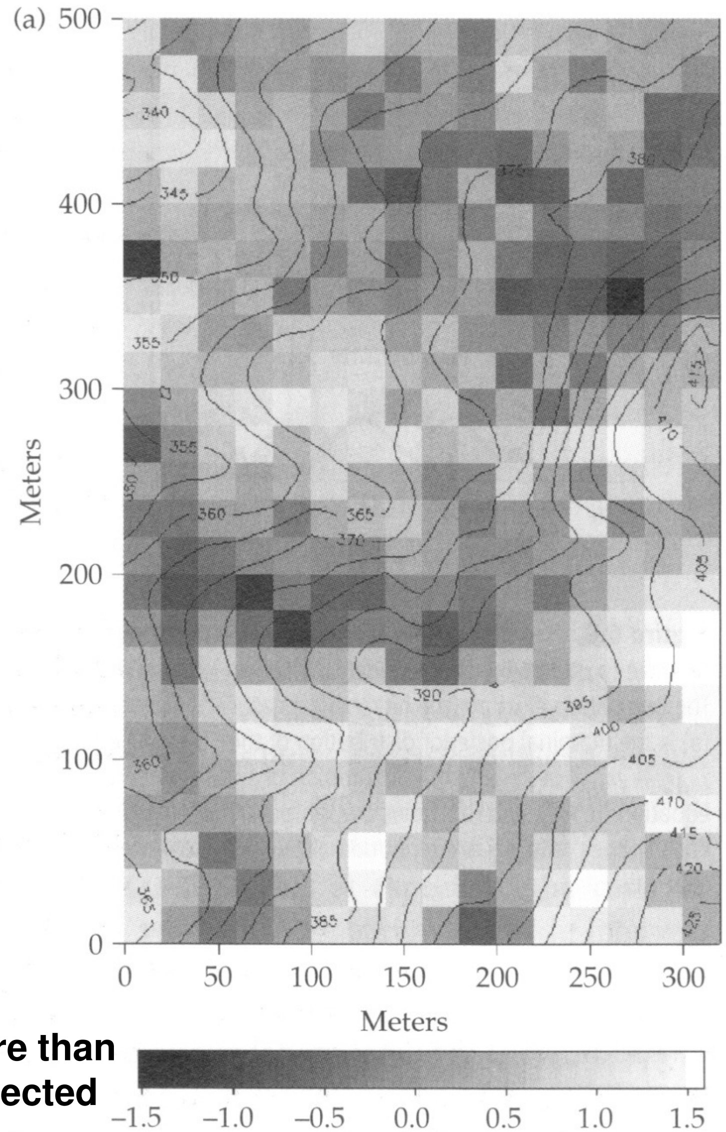
Results: Model comparison – survival probability III



Results: Model comparison – survival probability IV



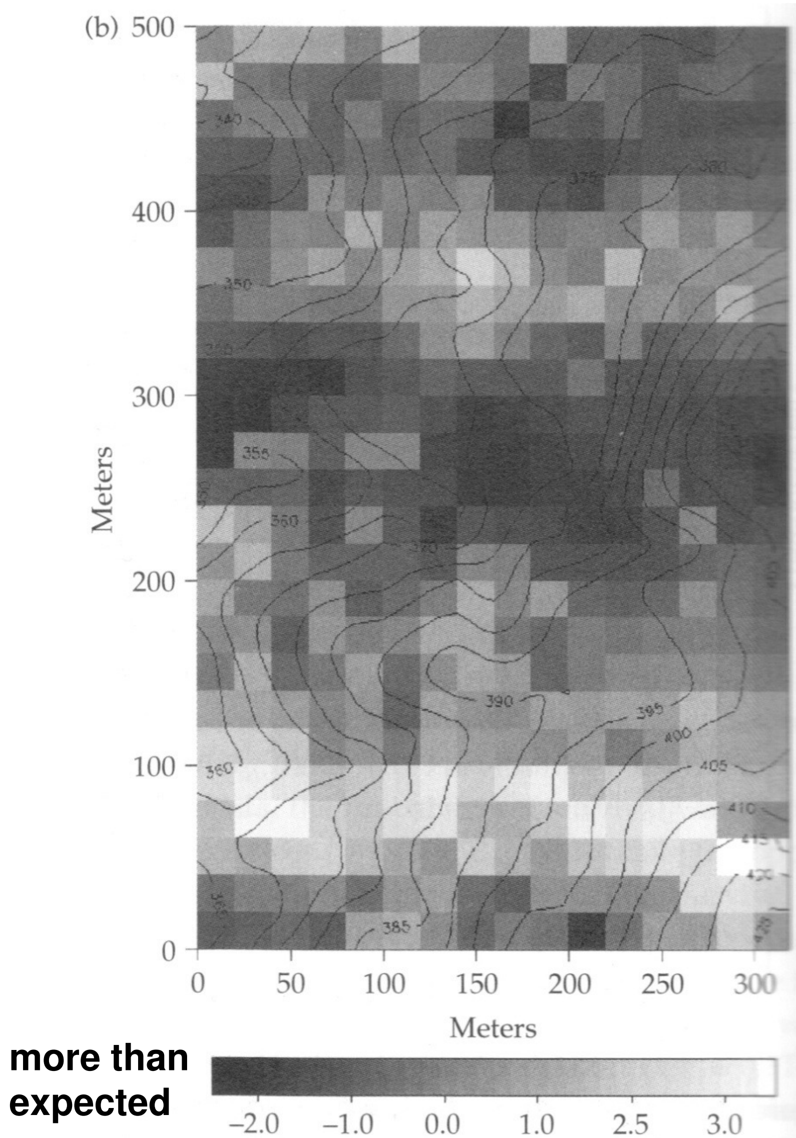
Results: Spatial correlation I – severe damage



more than expected

less than expected

Results: Spatial correlation II – moderate damage



Conclusion – Strengths of the approach

Species-specific parameters

- Small diameter -> less damage
- D. excelsa / M. bidentata with less damage than C. arborea / A. Latifolia
- Damage has more impact on survival for slow growing species but
- Slow growing species are less likely to be damaged

Spatial pattern

- Reflects storm directions, topology and former land use
- No assertion concerning interaction effects possible

Conclusion – Future directions

Inclusion of more species

Tree specific spatial correlation +
Inclusion of land-use history and topology

➔ hurricane intensity monitor

Data from multiple hurricane

➔ insights how storm regimes affect forest dynamics

Inclusion of interaction parameters