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SPATIAL STOCHASTIC MODELING TO MAP INTRODUCTION AND SPREAD RISKS FOR INVASIVE SPECIES: CONCEPTS AND DATA NEEDS

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Risk

- Risk can be defined as the occurrence probability for an undesired event, along with some evaluation of the consequences of the event (Kaplan and Garrick 1981)
- Knight (1921):
  Risk is a probabilistically measurable uncertainty
- Risk in engineering:
  - the probability of event × losses per accident
- Risk in information security: A function of three variables:
  - the probability that there is a threat
  - the probability that there are any vulnerabilities
  - the potential impact

Invasive species case:

Our aim to include **both** the probability of invasive species occurrence and the impact

Here we're looking at probabilities of introduction, population establishment and host damage

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Our approach

Integrated spatial 2-D discrete modelling framework:

- **Entry model –** simulates species entries with marine imports
- **Spread model** – projects the path of the outbreak in space and time
- **Host resource distribution and growth** – specifies how much host resource, where, and how quickly it could regenerate
- **Impact model** - simulates establishments of new populations
  - evaluates the susceptibility of host resource

This study:

- A collaborative effort between the Canadian Forest Service, NC State University and Forest Health Technology Enterprise Team (USFS-FHTET)
- Uses *Sirex noctilio* as a example
- Uses the Forest Bioeconomic Model (CFS-FBM) to simulate entry, invasion and impact
- Generates integrated risk maps via multiple stochastic simulations of “entry-spread-establishment” events
- Integrates US and Canadian data (i.e., land base, ecoregions, ports of entry, host maps, growth and yield data)

Establishment and spread

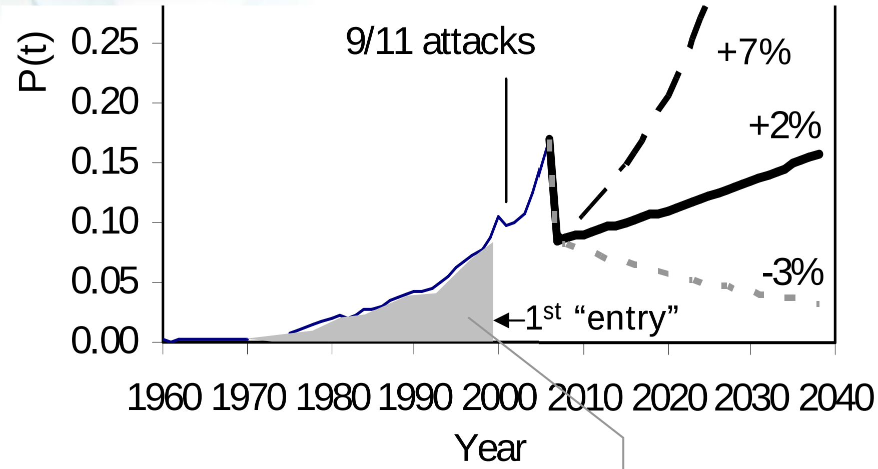
Travelling wave model – adapted from Sharov and Liebhold (1998)

- Population model – geometric growth rate with a maximum carrying capacity
- Dispersal kernel – $f(x) = p_0/(a + bx^c)$, for $x < x_{max}$ and $f(x) = 0$ for $x \geq x_{max}$
- Survival and establishment: age-dependent pine susceptibility model

Data assumptions

- Maximum spread rate – 50 km /year
- Pine susceptibility ratings – FHTET ranks (USFS FHTET 2007)
- Initial *Sirex noctilio* infestations: (1) 2006 CFS-CFIA-APHIS surveys
  (2) stochastic entry model outputs
- Pine volume map: CFS CanFI (Canada) and USFS FIA databases (US)
- Host mapping method: geostatistical (US), stochastic assignment (Canada)
- Pine growth assumptions: CFS Bernier and Ung model (Canada)
  USFS Forest Vegetation Simulator (FVS) model (US)

"Successful" entry



$$\int_{T_0}^{T_{entry}} P(t)dt = 1$$

$P(2006) \approx 0.172$
(for *S. noctilio* in US and Canada)

Proxy data used to define the probability of the successful **entry with establishment**, P(t):

International marine import stats:

- US Census trade statistics (1960-2006)
- StatsCan data (1971-2007)

P(t) can be found numerically - **IF** the date of the first entry is known

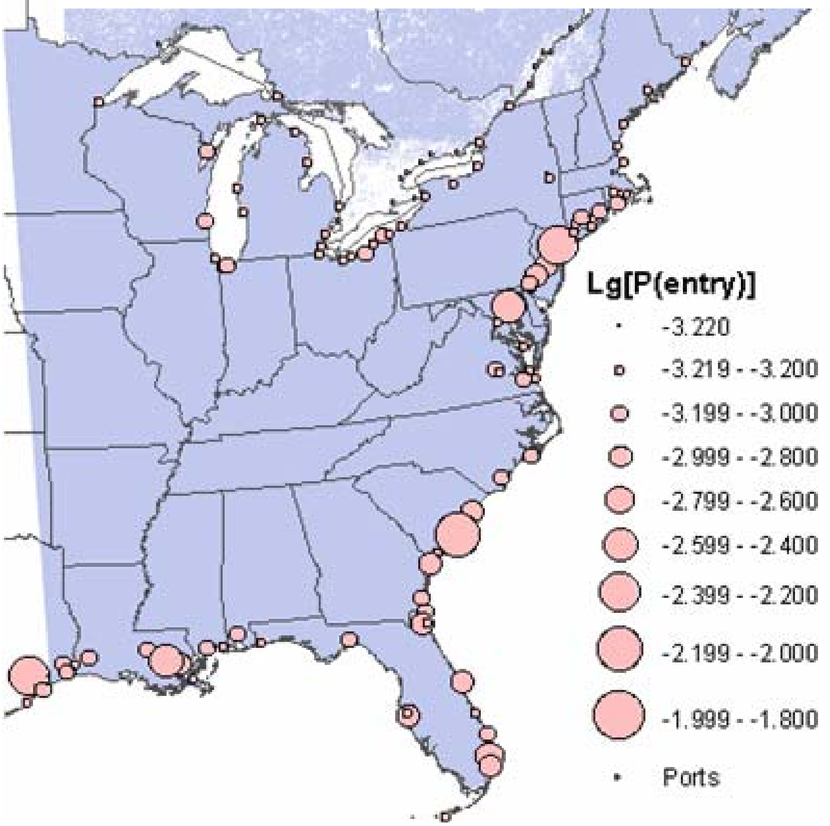
Impact of new wood packaging rules in ISPM-15 (FAO-IPPC 2006) after 2006:

- "High-risk" scenario: ΔP(t) = +7%/year
- "Medium" risk : ΔP(t) = +2%/year
- "Low" risk : P(t) = -3%/year

Δ

Local entry potential

High-risk scenario (ΔP(t) = 7%)



Partitioning P(t) for each port: $\sum_{x=1}^{N} W_{x(t)} = P(t)$

Calculating local entry potential, $W_{x(t)}$ from:

- US Army Corps of Engineers foreign cargo imports database
- StatsCan “Shipping in Canada” database
- Selecting only commodities and countries of origin that may have *S. noctilio*

Rescaling the original tonnage data, $v_{x(t)}$:

$$W_{x(t)} = 10^{-[k_1/(1+k_2 \cdot \exp[-k_3 \cdot \lg(V_{x(t)})])]}$$

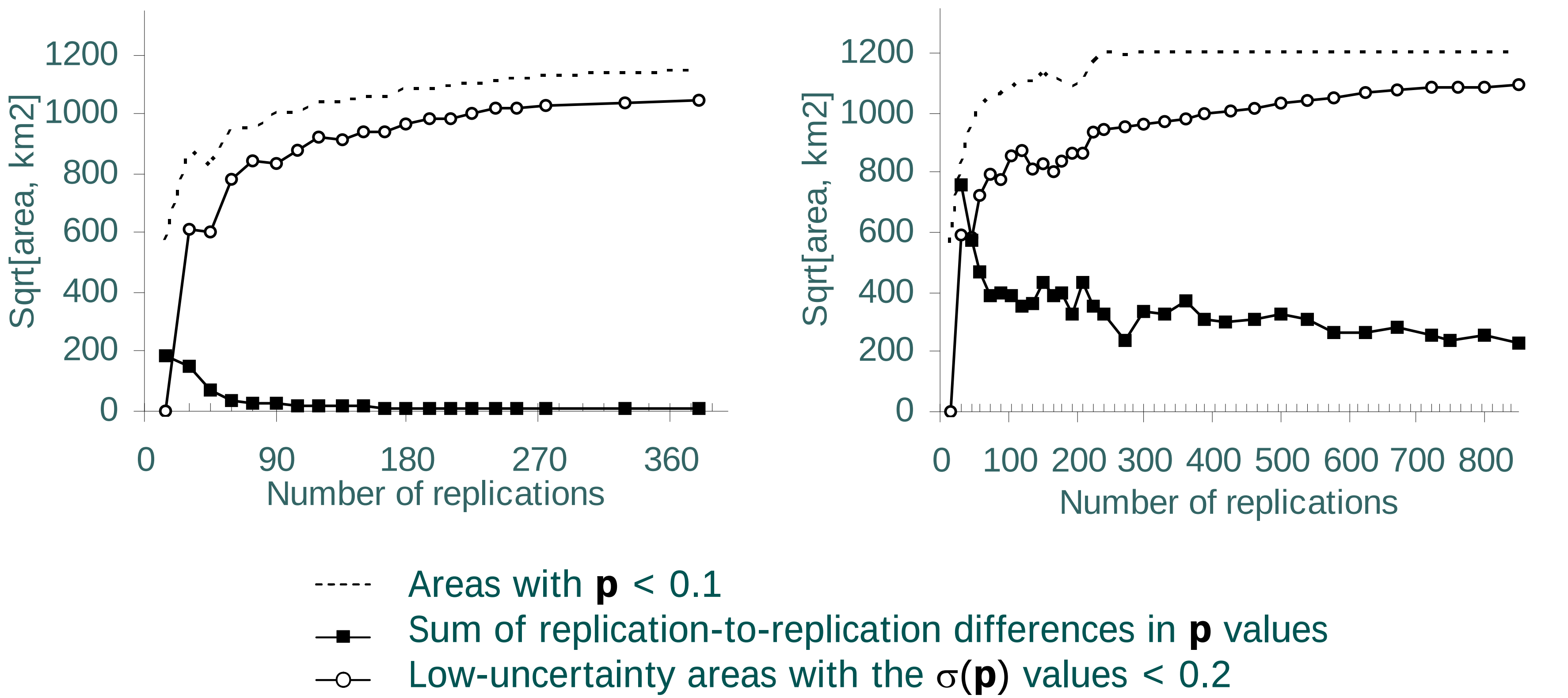
where $V_{x(t)} = v_{x(t)} / \sum_{x=1}^{N} v_{x(t)}$

$W_{x(t)}$ is then used to simulate entry events

Spatial extent and the number of replications

- Spatial extent - ~4 million 1-km^2 map cells with pine (eastern US and Canada)
- 300-900 replications per scenario - computationally intensive!
- Lower-probability scenarios = more replications

High-risk scenario (ΔP(t)=7%/yr.) **Low-risk scenario** (ΔP(t)= -3%/yr.)



Risk and uncertainty metrics

"Risk": The **probability** of *S. noctilio* establishment, **p**, in a minimum area, **i**, over a forecast horizon, **T**

- Fits to Kaplan and Garrick's (1981) definition
- Depends on the spatial resolution and the forecast horizon

"Uncertainty": **Standard deviation** of **p** , $\sigma(\mathbf{p})$

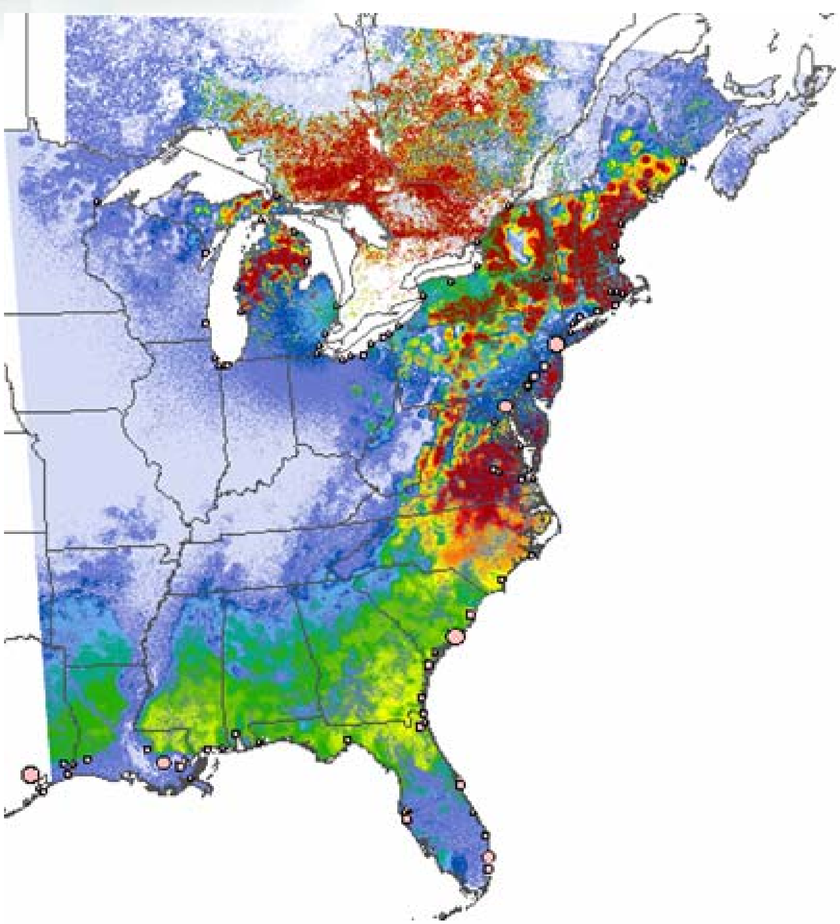
Binary entropy of **p**:

$$H(\mathbf{p}) = -\,\mathbf{p}\,\log_2 - (1-\mathbf{p})\,\log_2(1-\mathbf{p})$$

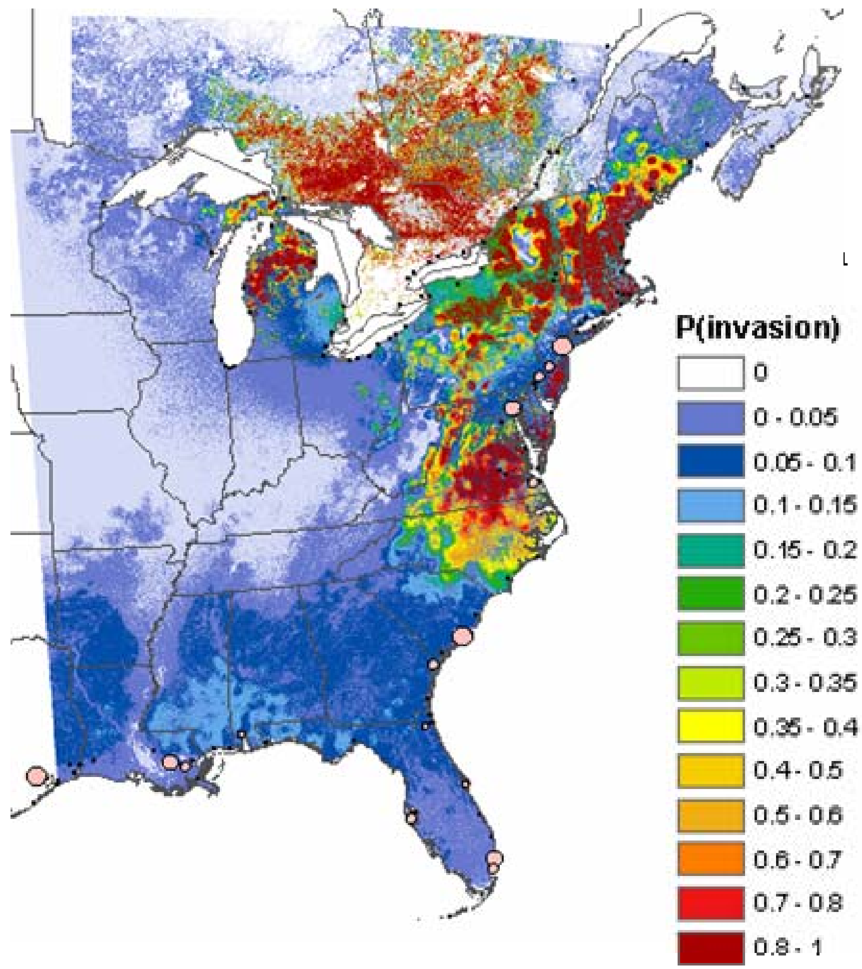
This study assesses only the risks of relatively large infestations (i.e., with populations covering 1 km^2 or larger)

Risk maps

High-risk scenario, $\Delta P(t) = 7\%$



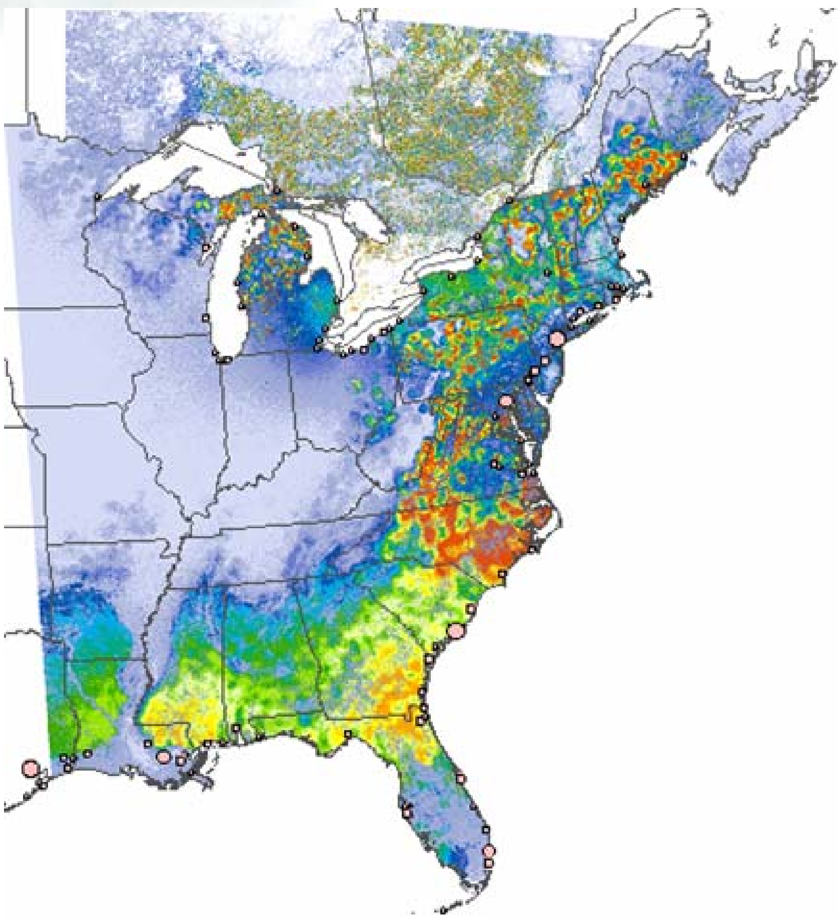
Low-risk scenario, $\Delta P(t) = -3\%$



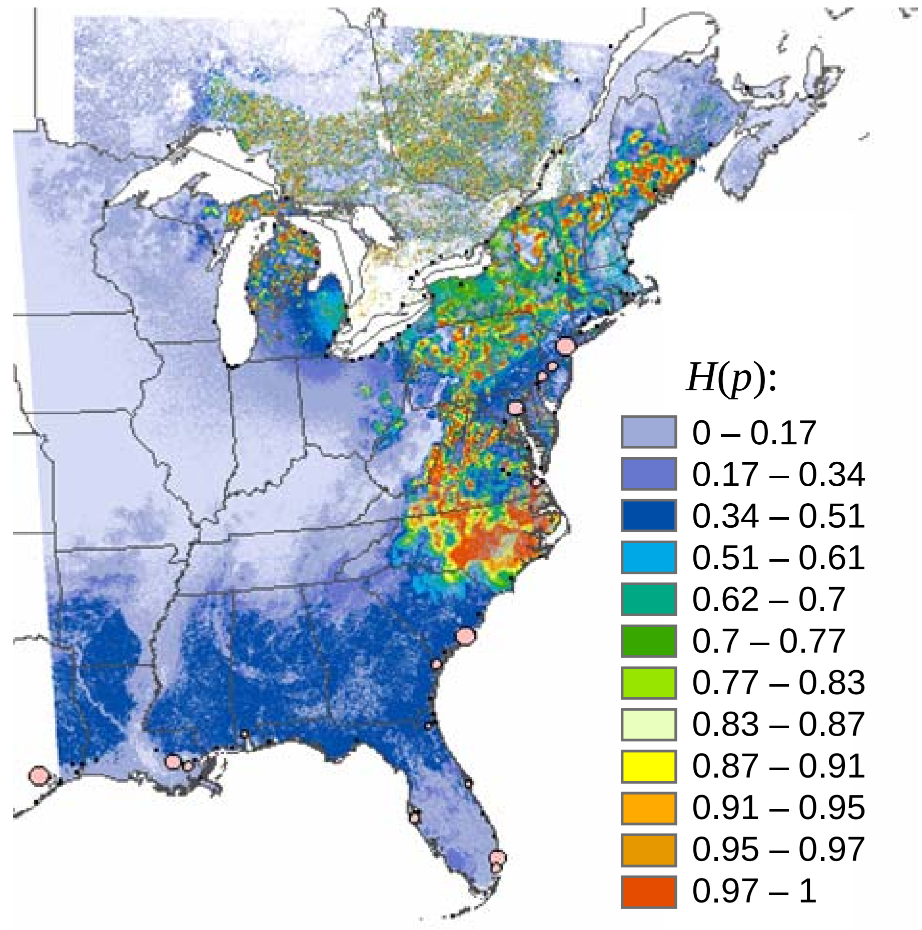
Risk of *S. noctilio* infestation, **p**, 30-year horizon

Uncertainty maps

High-risk scenario, ΔP(t) = 7%



Low-risk scenario, ΔP(t) = -3%



Binary entropy, H(**p**), 30-year horizon

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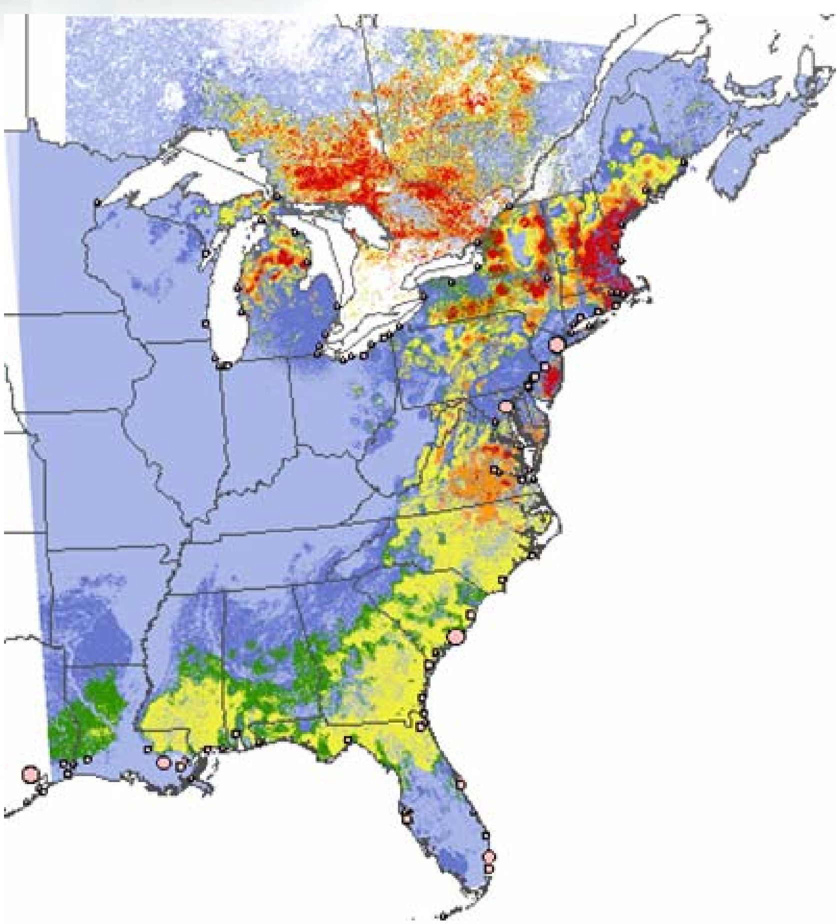
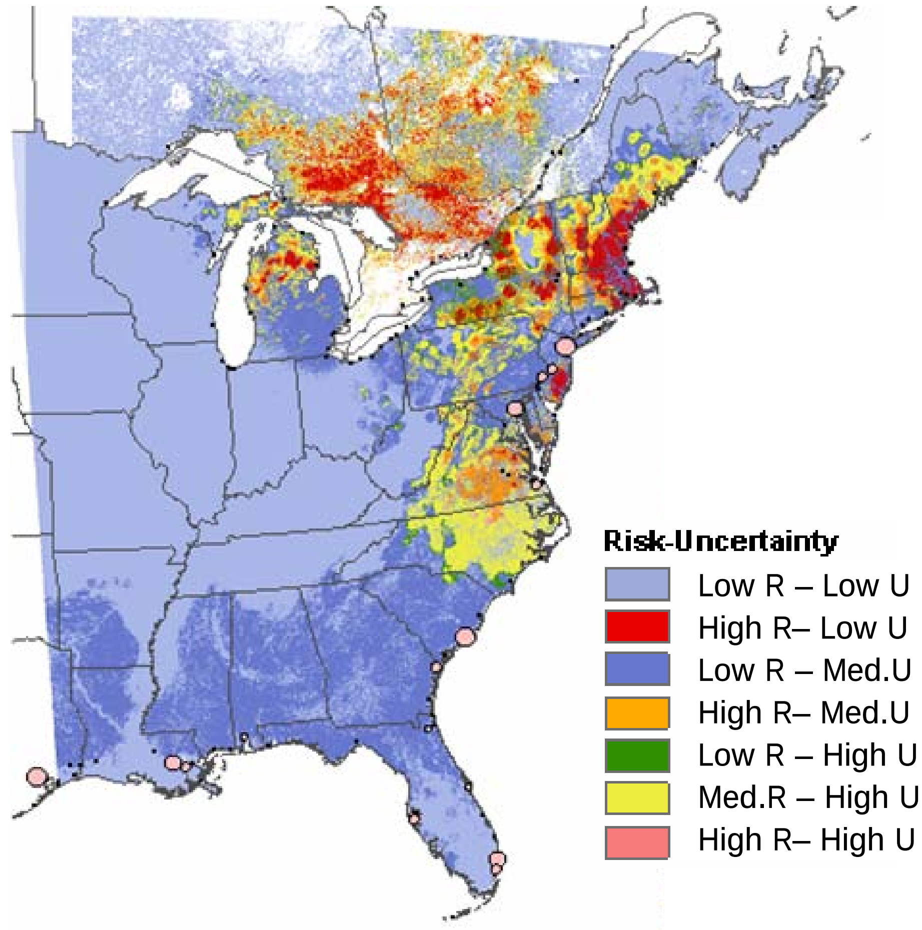
Risk - Uncertainty maps

High-risk scenario, ΔP(t) = 7%



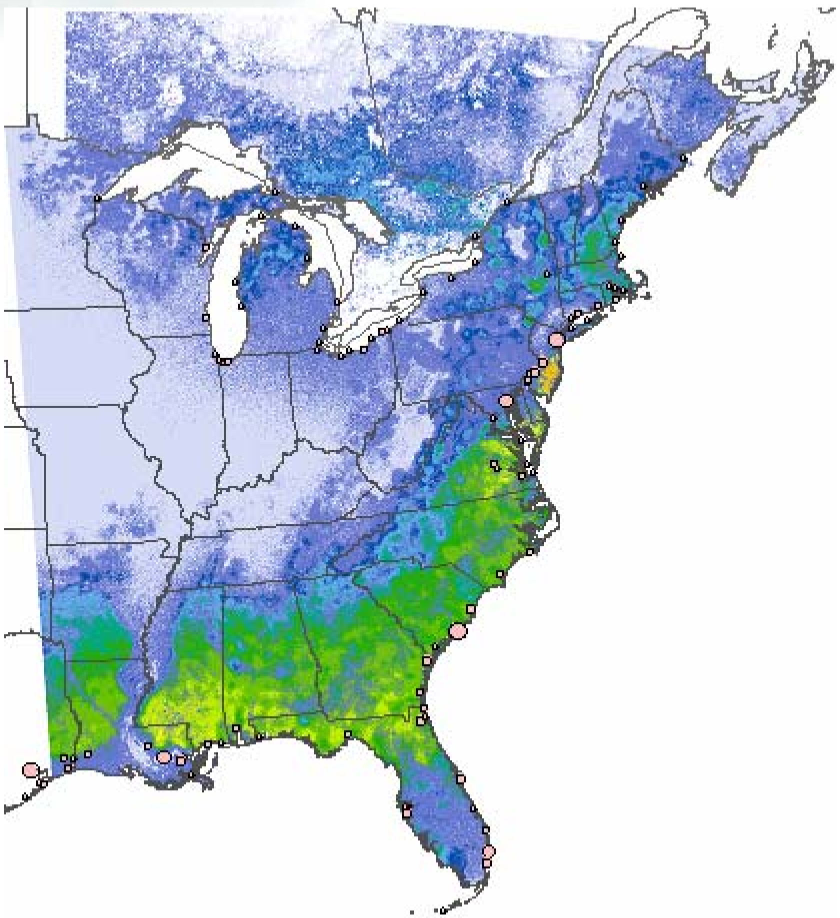
Low-risk scenario, ΔP(t) = -3%



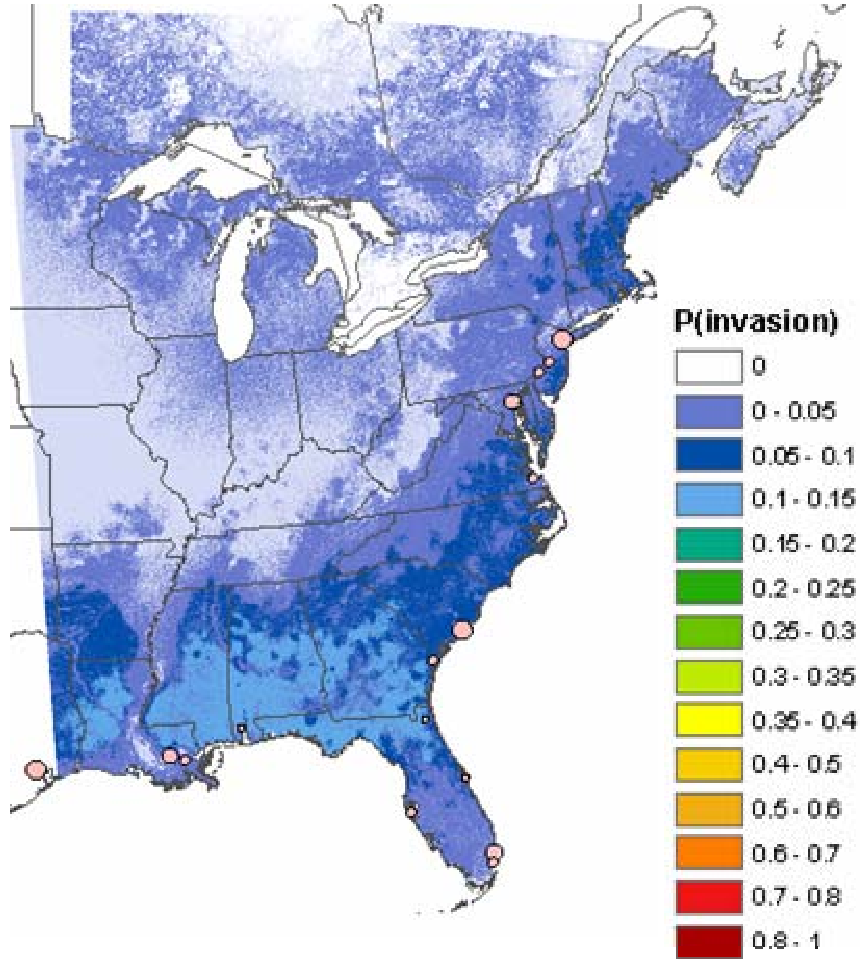
Risk – uncertainty classes, 30-year horizon

Risk maps: Ports only

High-risk scenario, $\Delta P(t)$ = 7%



Low-risk scenario, $\Delta P(t)$ = -3%



Risk of *S. noctilio* infestation, **p**, 30-year horizon

Conclusions

- A “single” product/depiction
- Attempts to quantify the uncertainties of the risk estimates
- Accounts for multiple entries and spatial dependencies
- Good potential to explore other entry models

  (i.e., network, transport pathways, in-land entries)

- Standardized outputs – easier to compare different species and scenarios

- Still a lot of work ahead:

  - Finding better proxies of the entry potential and the impact of the IPPC compliance standards (interceptions?)
  - Assessing entry potential from inland locations
  - Testing species of concern not yet detected in Canada and US
  - Standardizing US and Canadian data preparation approaches

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