MODELS FOR ANALYZING PLANT HEALTH RISK

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Risk

A future event that may have negative consequences
Risk of biological invasion

Risk that an harmful organism present in an area A enters in an area B (where the pest is absent) and has some impacts
Chrysomèle du maïs (*Diabrotica virgifera*)
First report of *Xylella fastidiosa* in the EPPO region

- Special Alert -

Octobre 2013

Symptoms of quick decline (complesso del disseccamento rapido dell’olivo) observed in Puglia on olive trees.

All pictures of symptoms on olive trees were kindly provided by Donato Bosca, Istituto di Virologia Vegetale del CNR, UOS, Bari (IT)
Franco Nigro, Dipartimento di Scienze del Suolo, della Pianta e degli Alimenti, Università degli Studi di Bari (IT)
Antonio Guarlo, Plant Protection Service, Regione Puglia (IT)

*Xyphon fulgida.*
J. Clark - University of California, Berkeley (US)

*Draeculacephala minerva.*
J. Clark - University of California, Berkeley (US)

*Graphocephala atropunctata.*
A.H. Purcell University of California, Berkeley (US)
Biological invasion results from a succession of events

• Entry of a pest in a given area

• Establishment of a pest in a given area

• Spread of a pest in a given area

• Impact of a pest on some hosts or on the environment
Pest risk analysis aims at analyzing these events

- Currently done by national and international agencies
- ANSES in France, USDA in USA, EFSA and EPPO in Europe
- Results of these analyses are used to define official regulations concerning the movements of plant materials
  - Prohibition
  - Test of presence in imported commodities
  - Treatment of commodities
Why could models be useful?

• Computing probability of pest entry in a geographical area

• Computing probability of pest establishment in a geographical area

• Predicting the spread of a pest in a geographical area

• Predicting the impact of a pest on a crop

• Assessing the effectiveness of different methods of pest controls
A great diversity of approaches for assessing risk of invasion

- **Qualitative approaches**
  Require risk assessors to choose from categorical ratings *e.g.* very low, low, moderate, high, very high

- **Quantitative approaches**
  Can be used by risk assessors to obtain numerical quantities (*e.g.*, probabilities)
Qualitative approaches

- Risk rating methods
- Widely used
- Issues related to definition and combination of ratings
**Availability of suitable hosts or suitable habitats, alternate hosts and vectors in the risk assessment area**

1.16. Estimate the number of host plant species or suitable habitats in the risk assessment area (see question 6).

<table>
<thead>
<tr>
<th>Level of uncertainty:</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
</table>

1.17. How widespread are the host plants or suitable habitats in the risk assessment area? (specify)

<table>
<thead>
<tr>
<th>Level of uncertainty:</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
</table>
# USDA Guidelines for Pest Risk Assessments

<table>
<thead>
<tr>
<th>Sub-elements</th>
<th>Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity imported annually</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
<tr>
<td>Survive post harvest treatment</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
<tr>
<td>Survive shipment</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
<tr>
<td>Not detected at port or entry</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
<tr>
<td>Moved to suitable habitat</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
<tr>
<td>Contact with host material</td>
<td>Low, Med., High 1, 2, 3</td>
</tr>
</tbody>
</table>
Problems related to qualitative approaches

- Ratings not always clearly defined.
- No consensus on method for combining ratings.
Examples of definitions of ratings

Quantity of commodity imported annually
Low (1 point): < 10 containers/year
Medium (2 points): 10 - 100 containers/year
High (3 points): > 100 containers/year

from USDA Guidelines
Examples of definitions of ratings

- Negligible = 0 (no potential to survive)
- Low = 1 (potential to survive on a third or less of the range of hosts in the PRA area)
- Medium = 2 (potential to survive on a third to two thirds of the range of hosts in the PRA area)
- High = 3 (potential to survive throughout most or all of the range of hosts in the PRA area)

from Canadian Food Inspection Agency: establishment potential rating guidelines (2002)
Difficult to make generic definitions

Appropriate definitions may depend on pests and areas
No consensus on methods for combining scores
## USDA Guidelines for Pest Risk Assessments

<table>
<thead>
<tr>
<th>Sub-element</th>
<th>Ratings</th>
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<tbody>
<tr>
<td>Quantity imported annually</td>
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<td></td>
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<td>Low, Med., High</td>
</tr>
<tr>
<td></td>
<td>1, 2, 3</td>
</tr>
</tbody>
</table>

### Cumulative risk rating

- **6-9** → Low
- **10-14** → Med.
- **15-18** → High
### Table 8.4 Matrix of rules for combining descriptive likelihoods — Biosecurity Australia

<table>
<thead>
<tr>
<th>Likelihood 1</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Very (V) low</th>
<th>Extremely (E) low</th>
<th>Negligible</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>V low</td>
<td>E low</td>
<td>Negligible</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>V low</td>
<td>E low</td>
<td>Negligible</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>V low</td>
<td>V low</td>
<td>E low</td>
<td>Negligible</td>
</tr>
<tr>
<td>Very low</td>
<td>V low</td>
<td>V low</td>
<td>V low</td>
<td>E low</td>
<td>E low</td>
<td>Negligible</td>
</tr>
<tr>
<td>E. low</td>
<td>E low</td>
<td>E low</td>
<td>E low</td>
<td>E low</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
What is the best method for combining scores?

from Hennen (2007)

<table>
<thead>
<tr>
<th>Combining scores</th>
<th>Simple</th>
<th>Programming effort</th>
<th>Robust</th>
<th>Objective</th>
<th>Dealing with uncertainty</th>
<th>Relevant (for EPO)</th>
<th>Sensitive</th>
<th>Match knowledge</th>
<th>Complete</th>
<th>Laborious</th>
<th>Reliable</th>
<th>Maintenance</th>
<th>Flexible</th>
<th>Required expert knowledge</th>
<th>Weighted overall score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sum of scores</td>
<td>2 Arithmetic mean</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>0/+</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3 Weighted average/sum</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4 Maximum</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>5 Cross the Threshold</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6a Mandatory</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>6b Optional</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>7 Differentiated scores (Imagine)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>8 Fuzzy combinations</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>9 Rule-based Experts Systems</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>10 Holt (Bayesian)</td>
<td>-</td>
<td>0</td>
<td>-/+</td>
<td>0</td>
<td>-</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
A great diversity of approaches for assessing risk of invasion

- **Qualitative approaches**
  Require risk assessors to choose from categorical ratings *e.g.* very low, low, moderate, high, very high.

- **Quantitative approaches**
  Can be used by risk assessors to obtain numerical quantities (*e.g.*, probabilities).
Quantitative approaches

- Many types of models
- Issues related to
  - model choice
  - parameter estimation
  - transparency of complex models
  - uncertainty of the model outputs
A great diversity of models.

- Statistical models (Poisson, binomial, logistic…)
- Machine learning
- Climate-based systems (NAPPFAST, CLIMEX)
- Pathway models
- Population ecology model (Leslie matrix…)
**Important types of generalized linear models**

<table>
<thead>
<tr>
<th>Type</th>
<th>Deterministic part</th>
<th>Stochastic part</th>
<th>R function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binomial logit</td>
<td>logit link</td>
<td>Binomial distribution</td>
<td><code>glm(Y~X, family=binomial(link = &quot;logit&quot;))</code></td>
</tr>
<tr>
<td>Poisson log linear</td>
<td>log link</td>
<td>Poisson distribution</td>
<td><code>glm(Y~X, poisson(link = &quot;log&quot;))</code></td>
</tr>
<tr>
<td>Gaussian linear</td>
<td>Identity link</td>
<td>Gaussian distribution</td>
<td><code>glm(Y~X, gaussian(link = &quot;identity&quot;))</code></td>
</tr>
</tbody>
</table>
Consider the experiment of Myers et al. (2009) on the effect of heat treatment on the insect species *Agrilus planipennis*, a pest of ash (a tree species).

Ash wood were treated at five different temperatures (45, 50, 55, 60, 65°C) during 30 min.

The number of surviving insects were counted after each heat treatments.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Nb of insects (for 1 m2 of wood)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>51</td>
</tr>
<tr>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>55</td>
<td>12</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>65</td>
<td>0</td>
</tr>
</tbody>
</table>
Number of surviving insects (for 1 m²)
**Wetness model** (Magarey et al., 2005)

\[ W = \text{leaf wetness duration requirement for successful fungal infection (h)} \]

\[ T = \text{average temperature (°C)} \]
\[ W = \frac{W_{\text{min}}}{f(T)} \text{, and } W \leq W_{\text{max}} \]

\[ f(T) = \left( \frac{T_{\text{max}} - T}{T_{\text{max}} - T_{\text{opt}}} \right) \left( \frac{T - T_{\text{min}}}{T_{\text{opt}} - T_{\text{min}}} \right)^{(T_{\text{opt}} - T_{\text{min}})/(T_{\text{max}} - T_{\text{opt}})} \]

Five parameters: \( T_{\text{min}}, T_{\text{opt}}, T_{\text{max}}, W_{\text{min}}, W_{\text{max}} \)
Scientific name:
*Guignardia citricarpa*
Order: Dothideales, Family: Botryosphaeriaceae
Common Name: Citrus black spot *Guignardia citricarpa* Kiely
Parameter values estimated for pycnidiospores of *Guignardia citricarpa* Kiely, and associated response of $W$ to temperature (from EFSA, 2008)

$$T_{\text{min}} = 10 \, ^\circ\text{C}, \quad T_{\text{opt}} = 25 \, ^\circ\text{C}, \quad T_{\text{max}} = 35 \, ^\circ\text{C}, \quad W_{\text{min}} = 12 \, \text{h}, \quad W_{\text{max}} = 35 \, \text{h}$$
CLIMEX index of establishment suitability for *Phytophthora ramorum*
Estimated probability of establishment of the western corn rootworm (*Diabrotica virgifera virgifera*)
Table 2. Nine models for predicting distribution of the western corn rootworm.

<table>
<thead>
<tr>
<th>Name</th>
<th>Class of method</th>
<th>Data</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOCLIM</td>
<td>Envelope model</td>
<td>P</td>
<td>DIVA-GIS v5.2</td>
</tr>
<tr>
<td>Envelope Score (ES)</td>
<td>Envelope model</td>
<td>P</td>
<td>openModeller v1.0.9</td>
</tr>
<tr>
<td>DOMAIN</td>
<td>Multivariate distance</td>
<td>P</td>
<td>DIVA-GIS v5.2</td>
</tr>
<tr>
<td>Environmental Distance (ED)</td>
<td>Multivariate distance</td>
<td>P</td>
<td>openModeller v1.0.9</td>
</tr>
<tr>
<td>Climate Space Model (CSM)</td>
<td>Principal components analysis</td>
<td>P</td>
<td>openModeller v1.0.9</td>
</tr>
<tr>
<td>DKGARP</td>
<td>Genetic Algorithm for Rule Set Production, desktop version, with the best subset procedure</td>
<td>ppa</td>
<td>openModeller v1.0.9</td>
</tr>
<tr>
<td>OMGARP</td>
<td>Genetic Algorithm for Rule Set Production, openModeller version, with the best subset procedure</td>
<td>ppa</td>
<td>openModeller v1.0.9</td>
</tr>
<tr>
<td>MAXENT</td>
<td>Maximum Entropy</td>
<td>ppa</td>
<td>Maxent v3.3.1</td>
</tr>
<tr>
<td>Support Vector Machine (SVM)</td>
<td>Support Vector Machine</td>
<td>ppa</td>
<td>openModeller v1.0.9</td>
</tr>
</tbody>
</table>

Data needed for model calibration are presence data (p) or both presence and pseudo-absence data (ppa).
doi:10.1371/journal.pone.0020957.t002

Dupin et al. (2011)
Pathway model for estimating probability of entry from Stansbury et al., 2002

Number of successful entry of *Tilletia indica* in Australia

![Graph showing the probability of Tilletia indica entry in Australia](graph.png)
Population ecology model for estimating the probability of establishment of the Asian longhorned beetle (*Anoplophora glabripennis*)

from Bartell & Nair (2003).
Major problems related to the use of quantitative models

- Model choice
- Parameter estimation
- Transparency of complex models
- Uncertainty of the model outputs
Model choice

- **Difficulties** in comparing models as:
  - Deep involvement needed to learn how to use all the models and associated softwares
  - Model performance depends on the estimated parameter values
  - Several quantitative criteria could be computed, but each one has its own limitations
  - Need of large amount of reliable data, difficult to find
Evaluation des erreurs de 16 modèles prédissant l’incidence du piétin échaudage du blé

RMSEP (%)

Ennaïfar, Makowski, Meynard, Lucas. 2007.
Major problems related to the use of quantitative models

- Model choice
- Parameter estimation
- Transparency of complex models
- Uncertainty of the model outputs
Parameter estimation

• Numerous methods
  - Expert knowledge
  - Manual adjustment
  - Frequentist methods
  - Bayesian methods

• Influence of experts and of data on model outputs
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DV0</td>
<td>Lower temperature threshold for growth</td>
<td>5°C</td>
</tr>
<tr>
<td>DV1</td>
<td>Lower optimum temperature</td>
<td>15°C</td>
</tr>
<tr>
<td>DV2</td>
<td>Upper optimum temperature</td>
<td>25°C</td>
</tr>
<tr>
<td>DV3</td>
<td>Upper temperature threshold for growth</td>
<td>28°C</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM0</td>
<td>Lower soil moisture threshold for growth</td>
<td>0.2</td>
</tr>
<tr>
<td>SM1</td>
<td>Lower optimum soil moisture</td>
<td>0.4</td>
</tr>
<tr>
<td>SM2</td>
<td>Upper optimum soil moisture</td>
<td>0.8</td>
</tr>
<tr>
<td>SM3</td>
<td>Upper soil moisture threshold for growth</td>
<td>1.3</td>
</tr>
<tr>
<td>Heat stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTHS</td>
<td>Temperature threshold for heat stress</td>
<td>28°C</td>
</tr>
<tr>
<td>THHS</td>
<td>Heat stress accumulation rate</td>
<td>0.0005 week(^{-1})</td>
</tr>
<tr>
<td>Wet stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMWS</td>
<td>Soil moisture threshold for wet stress</td>
<td>1.3</td>
</tr>
<tr>
<td>HWS</td>
<td>Wet stress accumulation rate</td>
<td>0.007 week(^{-1})</td>
</tr>
<tr>
<td>Hot–wet stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTHW</td>
<td>Temperature threshold for hot-wet stress</td>
<td>23°C</td>
</tr>
<tr>
<td>MTHW</td>
<td>Soil moisture threshold for hot-wet stress</td>
<td>0.2</td>
</tr>
<tr>
<td>PHW(^b)</td>
<td>Hot-wet stress accumulation rate</td>
<td>0.0101 week(^{-1})</td>
</tr>
<tr>
<td>PDD</td>
<td>Number of degree-days above DV0 necessary to complete one generation</td>
<td>1,100 degree-days</td>
</tr>
</tbody>
</table>

\(^a\) Yonow et al., 2004
Estimation of fecundity rate

Prob. density

\[ \theta \text{ (eggs/adult/month)} \]

from Bartell & Nair (2003).
Expert elicitation: the MATCH tool

http://optics.eee.nottingham.ac.uk/match/uncertainty.php#

David E. Morris, Jeremy E. Oakley, John A. Crowe, A web-based tool for eliciting probability distributions from experts, Environmental Modelling & Software, Volume 52, February 2014, Pages 1-4
Total number of placed chips = 28

Log Normal distribution: $\mu = 3.860918; \sigma = 0.2698408$;
Probability of establishment of *Diabrotica virgifera virgifera*  
Model ES fitted to **1955 presence data**
Probability of establishment of *Diabrotica virgifera virgifera*
Model ES fitted to **1980 presence data**
Major problems related to the use of quantitative models

- Model choice
- Parameter estimation
- Transparency of complex models
- Uncertainty of the model outputs
Analysis of uncertainty
Ten Most Important Accomplishments in Risk Analysis, 1980–2010

Michael Greenberg, Charles Haas, Anthony Cox, Jr., Karen Lowrie, Katherine McComas, and Warner North

As part of the celebration of the 30th anniversary of the Society for Risk Analysis and Risk Analysis, An International Journal, a group of our editors engaged in a process to select the 10 most important accomplishments in risk analysis. The article that follows is the product of this process.

Some preliminary decisions were that we would reach out to the full membership for nominations, focus on the period 1980 to 2010, and accept nominations for contributions to theory, methods, and applications. Also, we focused on accomplishments that address health, safety, and the environment, which has been our tradition.\(^1\) All the accomplishments have contributed to answering at least one of the six following risk analysis questions:\(^2–5\)

1. What can go wrong?
2. What are the chances that something with serious consequences will go wrong?
3. What are the consequences if something does go wrong?

TEN MOST IMPORTANT ACCOMPLISHMENTS IN RISK ANALYSIS, 1980–2010

Theory

1. Understanding how affect and trust influence risk perception and behavior
2. Recognizing that personal decisions reflect different processes for valuing and combining anticipated and actual losses, gains, delays, and surprises.
3. Developing an environmental justice ethic and frameworks

Methods

4. Using formal uncertainty analysis in risk assessment
Parameter values estimated for pycnidiospores of *Guignardia citricarpa* Kiely, and associated response of $W$ to temperature (from EFSA, 2008)

$T_{\text{min}} = 10 \, ^{\circ}\text{C}$, $T_{\text{opt}} = 25 \, ^{\circ}\text{C}$, $T_{\text{max}} = 35 \, ^{\circ}\text{C}$, $W_{\text{min}} = 12 \, \text{h}$, $W_{\text{max}} = 35 \, \text{h}$
Figure 3B. The probability of more than 15 days suitable for *Guignardia citricapnia* pycnidiosporic infection by continent. (Legend lower left).
Uncertainty about the model parameters

Guignardia citricarpa Kiely

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{min}}$ (°C)</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>$T_{\text{max}}$ (°C)</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td>$T_{\text{opt}}$ (°C)</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>$W_{\text{min}}$ (h)</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>$W_{\text{max}}$ (h)</td>
<td>35</td>
<td>48</td>
</tr>
</tbody>
</table>

Panel on Plant Health, from EFSA (2008)
Uncertainty analysis

Its purpose is to answer the following question:

« What is the uncertainty about \( y(z) \) resulting from the uncertainty about \( z \)? »

We have

\[
\begin{align*}
\text{We have} & \\
& \\
& \\
& \\
\end{align*}
\]

and

\[
\begin{align*}
\text{We have} & \\
& \\
& \\
& \\
\end{align*}
\]

We want to compute

\[
\begin{align*}
& \\
& \\
& \\
\end{align*}
\]
How to choose between qualitative and quantitative approaches?

- Advantages and disadvantages of each approach for the assessor, decision makers and stakeholders.

- How to assess the accuracy of different pest risk assessment methods?
Qualitative approaches

- Easy to understand.

- A qualitative PRA can be done quickly.

- Problems of consistency due to
  - inaccurate definitions of ratings,
  - methods used for combining scores.

- Explicit definitions needed.

- Training workshops could be organized to improve the consistency of the assessments made by experts.

- Another option: provide evidences only (no ranking).
Quantitative approaches

- Time and resources can be problematic.
- Model choice is difficult
- Complex models are not transparent
- Data not sufficient. Expert knowledge often required for estimating parameters.
- Uncertainty can be taken into account using probability distributions.
- Models can be used to combine probability of entry and probability of establishment.