Laboratory of "Biometry – Evolutionary Biology"

Team "**Predictive Modelling and Ecotoxicology**"

University Claude Bernard Lyon 1

Use of Bayesian inference in ecotoxicology

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Ecotoxicology

- A scientific field at the bridge of chemistry, toxicology and ecology

"*The branch of toxicology concerned with the study of toxic effects, caused by natural or synthetic pollutants, to the constituents of ecosystems, animal (including human), vegetable and microbial, in an integral context*" [Truhaut, 1977]

"*Ecology in the presence of toxicants*" [Chapman, 2002]

- In ecotoxicology, the ecosystem answer to environmental perturbations (physical, chemical and/or biological) is studied in all compartments of the biosphere (air, soil and water) and at all levels of biological organization [Walker *et al*., 2006]

From one level to the next

Depending on the level of biological organization, answers may strongly differ [Clements 2000]:

Biochemical	Physiological	Individual	Population	Community	Ecosystem
• AchE • DNA damage	• Respiration • Metabolism	• Mortality • Growth • Reproduction	• Abundance • Stage structure	• Loss of sensitive species • Reduced species richness	• Nutrient cycling • Food web structure

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Individual
- Mortality
- Growth
- Reproduction

Population
- Abundance
- Stage structure

Community
- Loss of sensitive species
- Reduced species richness

Ecosystem
- Nutrient cycling
- Food web structure

Ecological relevance and spatio-temporal scale

From one level to the next

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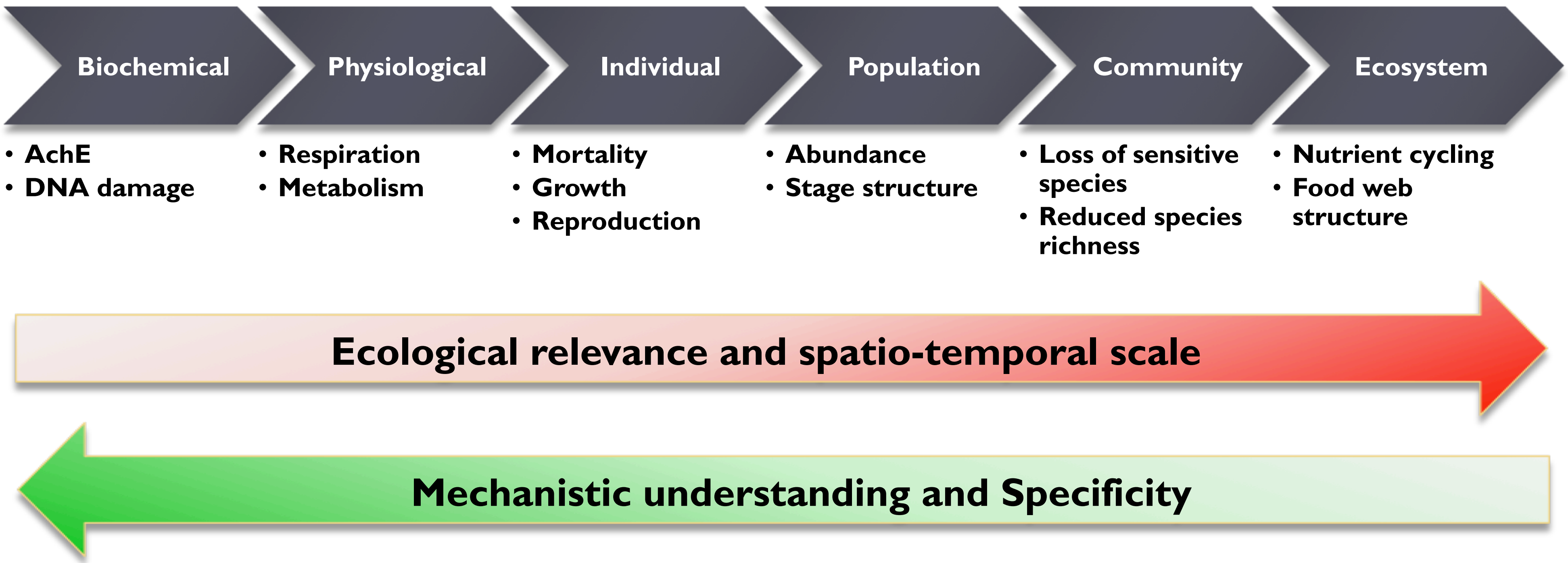


Beyond the "classical" analyses

- Monospecific standardized bioassays (ISO, OCDE norms) in laboratories:
  - Biomarker measures (molecular and cellular levels)
  - Life history trait measures at the individual level (survival, growth, reproduction)

- Toxicity thresholds [OCDE 2006] widely used but nevertheless much debated [Isnard *et al.*, 2001]:
  - LC_{50} : lethal concentration 50%
  - NOEC : No Observed Effect Concentration

➡ A crucial need of mechanistic effect models to understand underlying biological and ecological mechanisms [Preuss *et al.* 2009]

General framework

- **Quantitative Risk Assessment** in ecotoxicology

- **Dynamic modelling** in a cognitive and predictive purpose, and statistical inference for ecotoxicological risk assessment, by taking into account various sources of
  - **variability** (inter-individual, temporal, spatial variability,…)
  - **uncertainty** (gaps in knowledge on modelling)

➡ Evaluate effects, usually harmful, on environment and/or health, that are induced by the exposure to one or several contaminants.

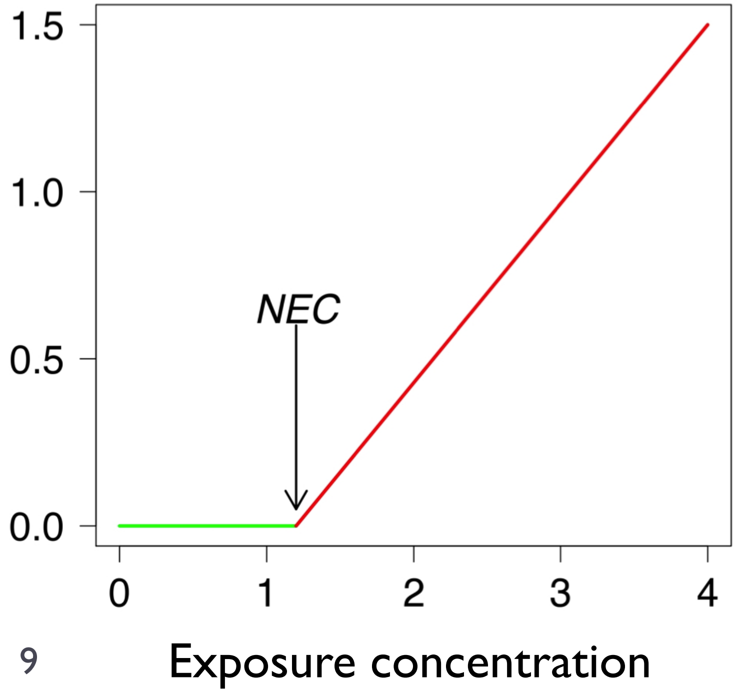
Modelling approach

3 steps

(1) Modelling of life history traits

- Effect models, mechanistic (Dynamic Energy Budget) or empirical
- Parameters with a clear biological meaning
- Hypotheses on the mode of action of contaminants

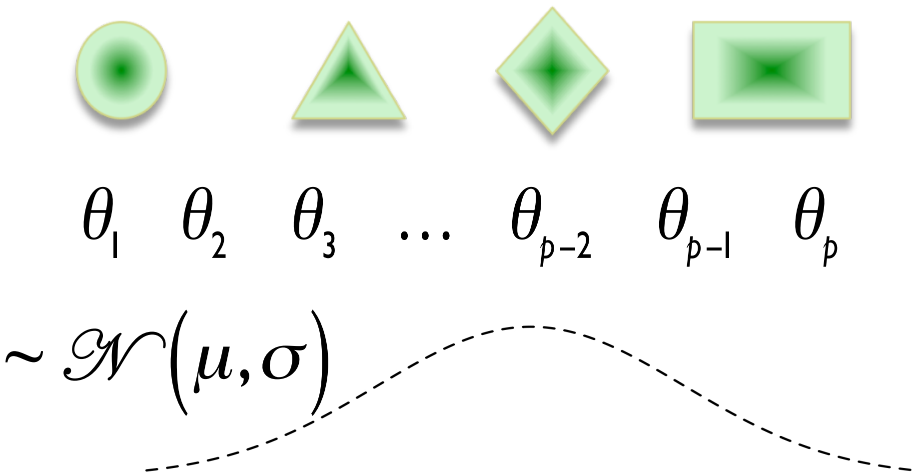
The stress function



NEC (*No Effect Concentration*)

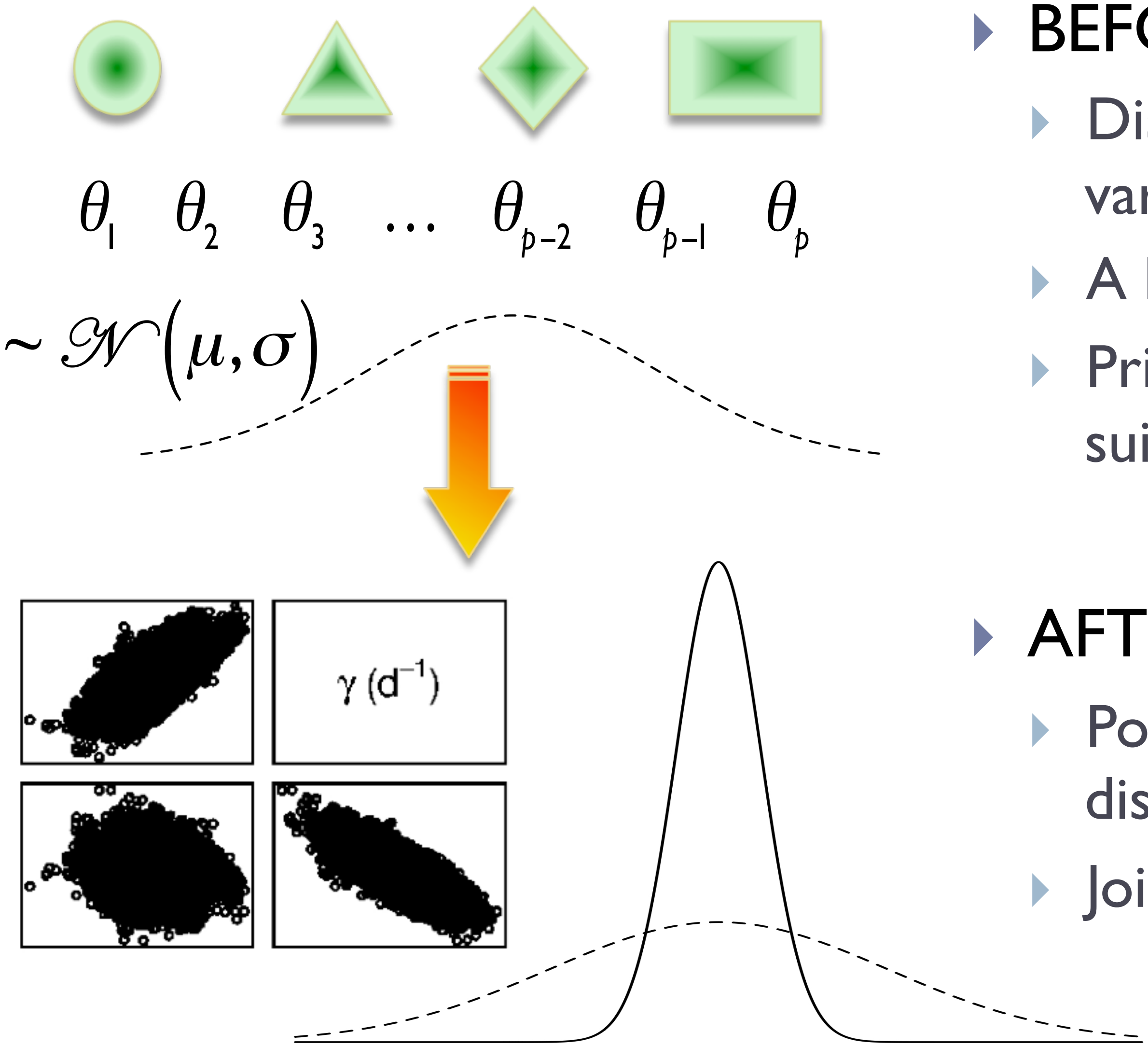
- A continuous value in the range of tested concentrations
- Not necessarily one of the tested concentrations
- Independent of the exposure duration

(2) **Bayesian** estimation of parameters



- BEFORE
  - Disparate data, latent variables
  - A lot of parameters
  - Prior information and suitable error models

(2) **Bayesian** estimation of parameters



- BEFORE
  - Disparate data, latent variables
  - A lot of parameters
  - Prior information and suitable error models
- AFTER
  - Posterior probability distributions
  - Joint probability distribution

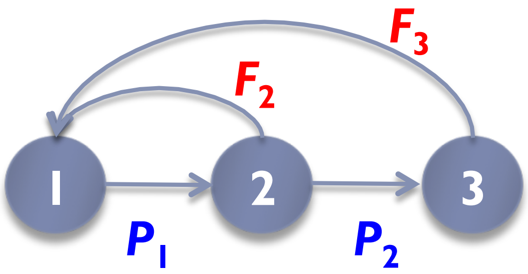
(3) Extrapolation at the population level

Population-level effects do not depend only on exposure and potential toxicity on life history traits, but also on important **ecological factors** [Grimm *et al.*, 2009]:

- life-cycle characteristics
- population and/or habitat structure
- density-dependence
- or environmental conditions

(3) Leslie matrix population models

[Caswell 2001]

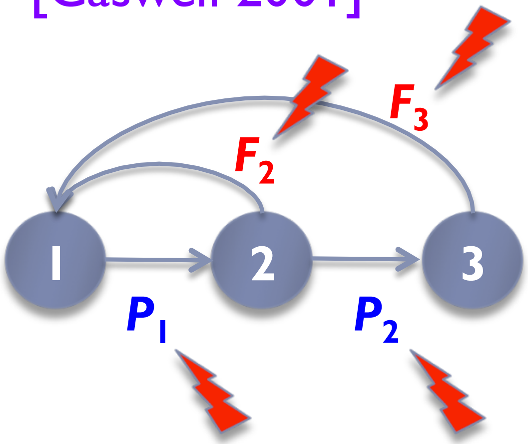


$$N_{t+1} = L \quad N_t$$

$$L = \begin{pmatrix} 0 & F_2 & F_3 \\ P_1 & 0 & 0 \\ 0 & P_2 & 0 \end{pmatrix}$$

(3) Leslie matrix population models

[Caswell 2001]



$$N_{t+1} = L(c)N_t$$

$$L(c) = \begin{pmatrix} 0 & F_2(c) & F_3(c) \\ P_1(c) & 0 & 0 \\ 0 & P_2(c) & 0 \end{pmatrix}$$

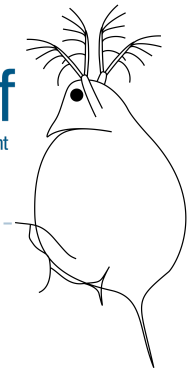
- Effect models on survival and reproduction lead to the calculation of vital rates $P_i(c)$ et $F_i(c)$ as continuous functions of the exposure concentration c.

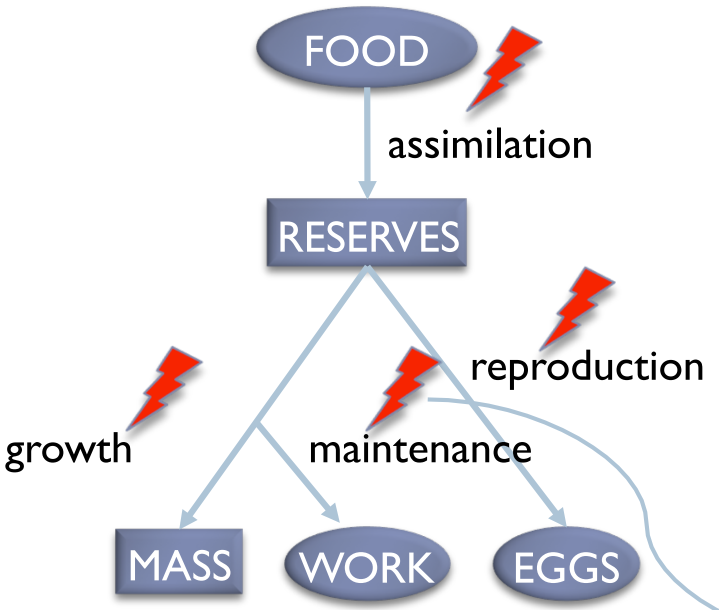
- The theory related to matrix population models thus provides the **asymptotic population growth rate $\lambda(c)$**

Example

Daphnia magna - Zinc

Modelling of life history traits

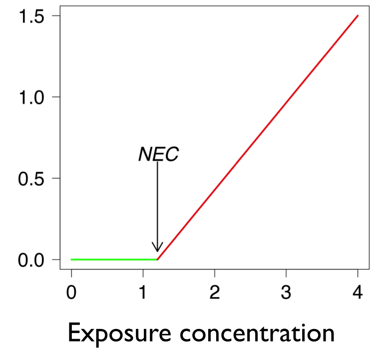




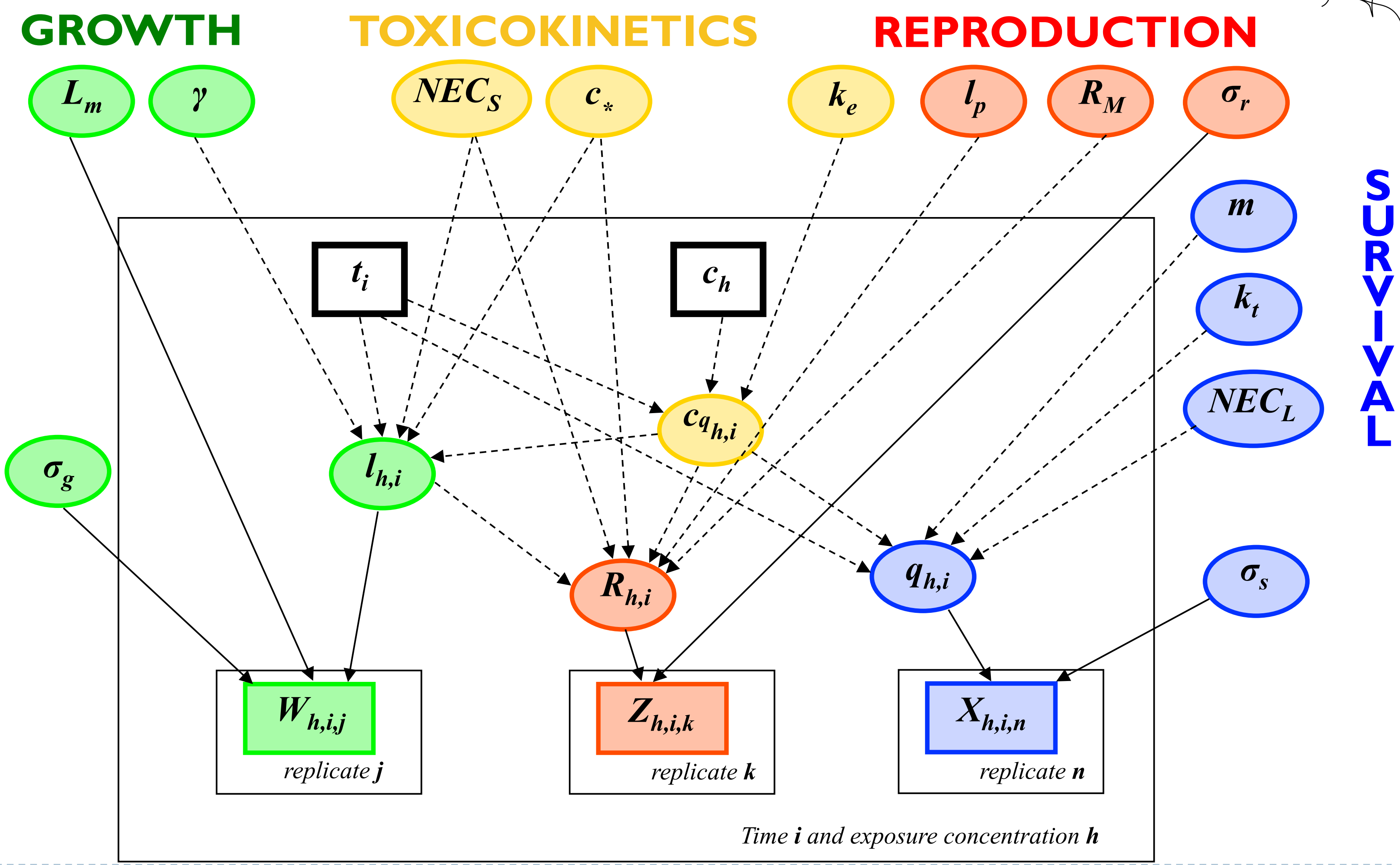
- DEB theory
  [Kooijman 2000]
- DEBtox effect models
  [Kooijman et Bedaux 1996 ; Billoir et al. 2008]

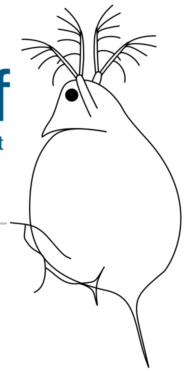
$$\frac{dR(t,c)}{dt} = \frac{R_M}{1-\ell_p^3}\left(1+\sigma(c)\right)\left[\ell(t,c)^2\,\frac{\left(1+\sigma(c)\right)^{-1}+\ell(t,c)}{2} - \ell_p^3\right]$$

$$\sigma(c) = k \times \max\left(0, c - NEC\right)$$



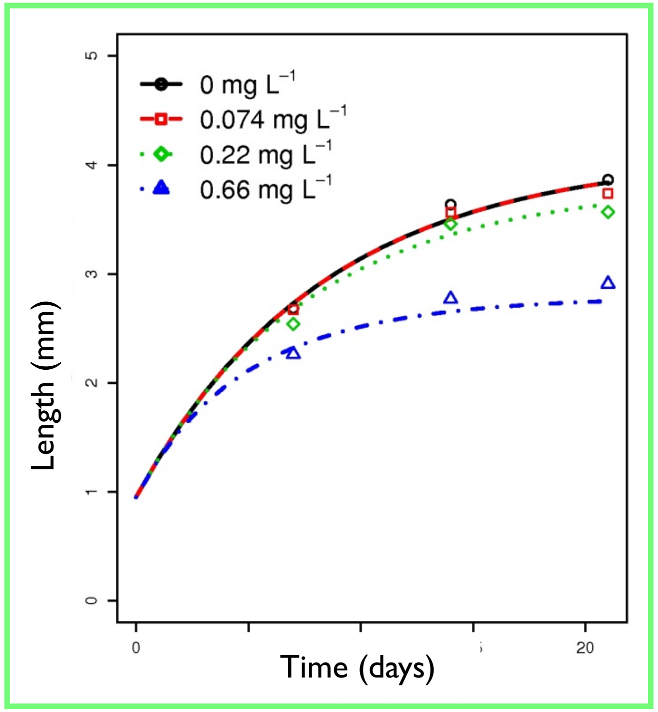
Directed Acyclique Graph (DAG)



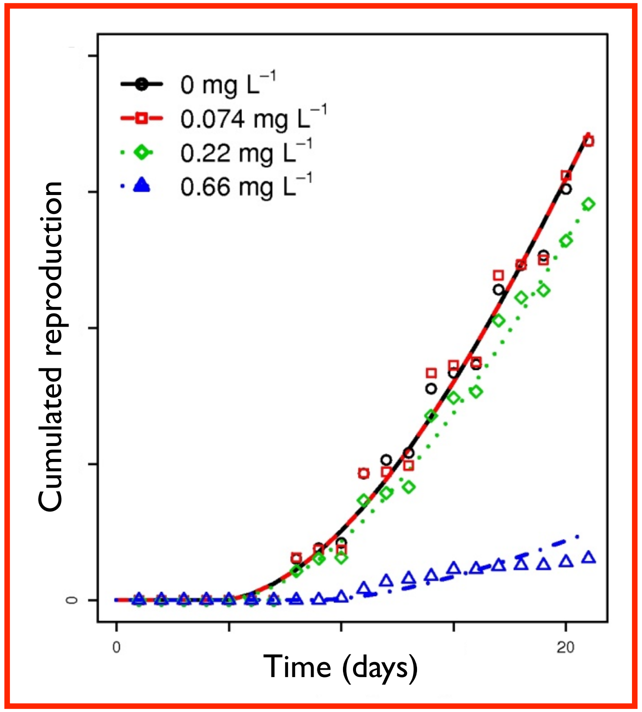


Fitting results

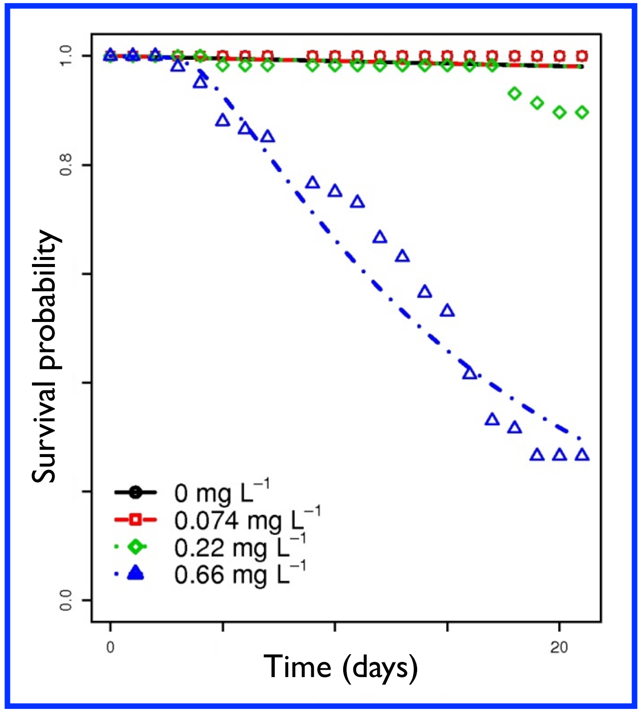
GROWTH



REPRODUCTION

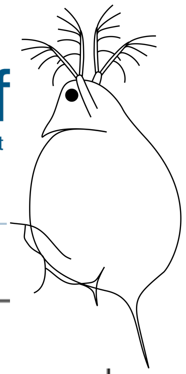


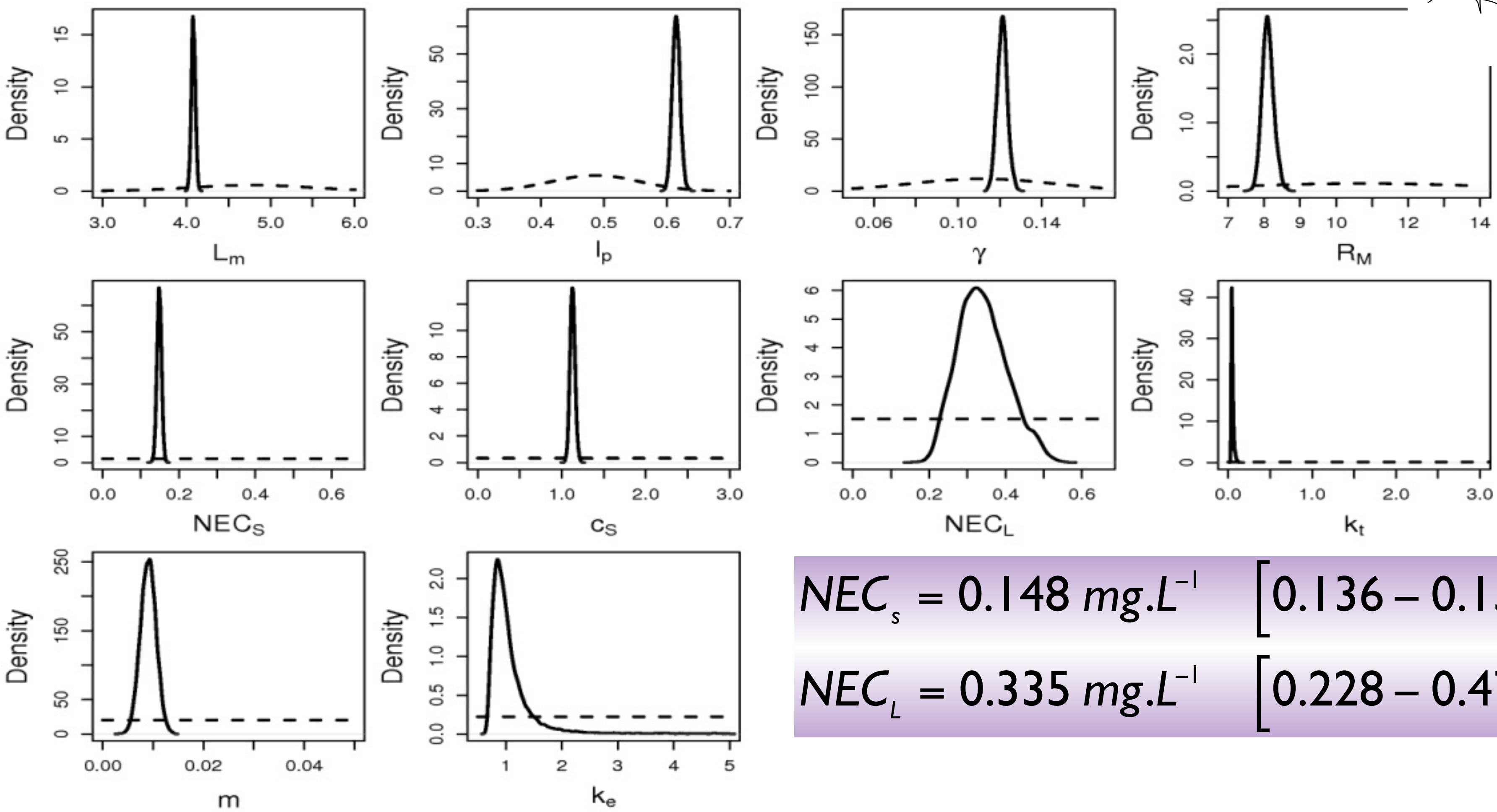
SURVIVAL



[Billoir *et al.* 2008a, 2008b ; Charles *et al.* 2009]

Parameter estimates and uncertainty





$$NEC_s = 0.148\ mg.L^{-1} \quad [0.136 - 0.159]$$

$$NEC_L = 0.335\ mg.L^{-1} \quad [0.228 - 0.479]$$

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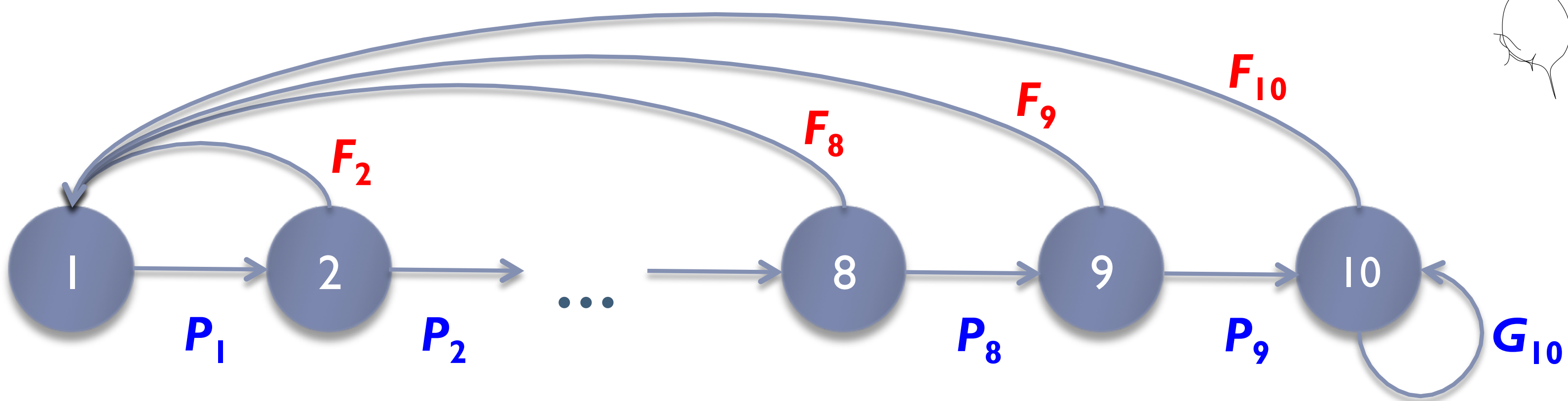
Modelling of population dynamics



$$L(c)=\begin{pmatrix} 0 & F_2(c) & \cdots & F_8(c) & F_9(c) & F_{10}(c) \\ P_1(c) & 0 & 0 & 0 & 0 & 0 \\ 0 & P_2(c) & 0 & 0 & \ddots & 0 \\ 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & \ddots & 0 & P_8(c) & 0 & 0 \\ 0 & 0 & 0 & 0 & P_9(c) & G_{10}(c) \end{pmatrix}$$

$$F_i(c)=\int_i^{i+1} R(t,c)\,dt$$

$$\lambda(c)$$

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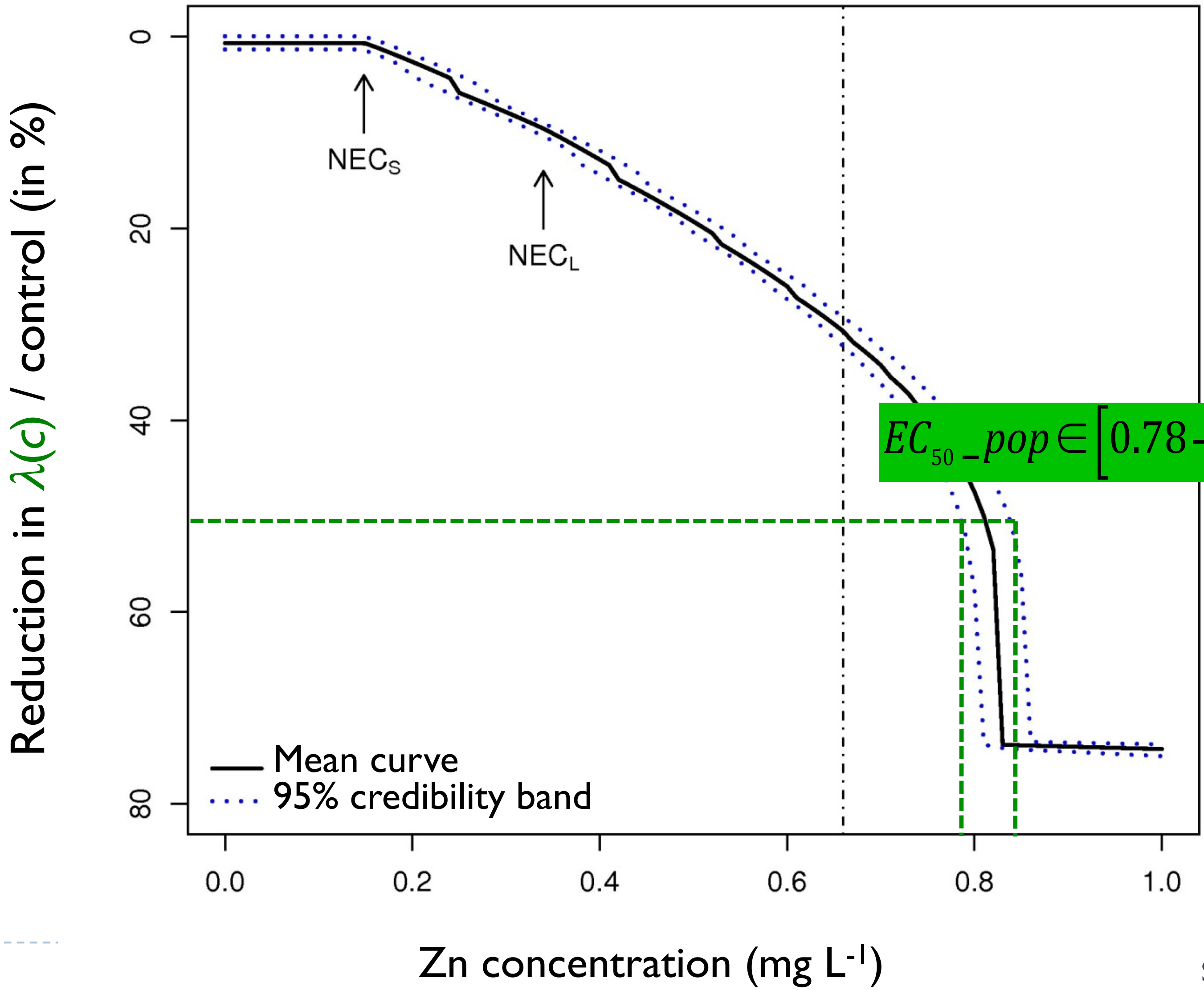

$$EC_{50}\_pop \in \left[0.78 - 0.83\right] mg\ L^{-1}$$

Conclusion

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Dynamic modelling and statistical inference

- Effect models at the *individual level*
- All parameters estimated through a *Bayesian approach*
- Integration of uncertainties and extrapolation at the *population level*

Conclusion - Perspectives

Dynamic modelling and statistical inference

- Effect models at the *individual level*
- All parameters estimated through a *Bayesian approach*
- Integration of uncertainties and extrapolation at the *population level*

- Taking into account of *internal kinetics* of contamination
- Taking into account of contaminant concentration *varying with time*
- Modelling at the *ecosystem level*


THANK YOU!