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Data collection and information sharing in plant health
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Selection and organization of life-history data for PRA: a mechanistic perspective

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1. Introduction

- Damage caused by alien species is related to a set of conditions that are knowable in advance (Leung et al., 2012).
  - This is the motivation for using Risk Assessment

- It derives
  - The importance of tools to select and organize (i.e., represent) the information and then generate knowledge
  - These tool influence
    - The way in which we can know in advance the future states of a system (probability of entrance, establishment and spread)
    - The efficiency and costs of the processes of data acquisition, organization and knowledge extraction

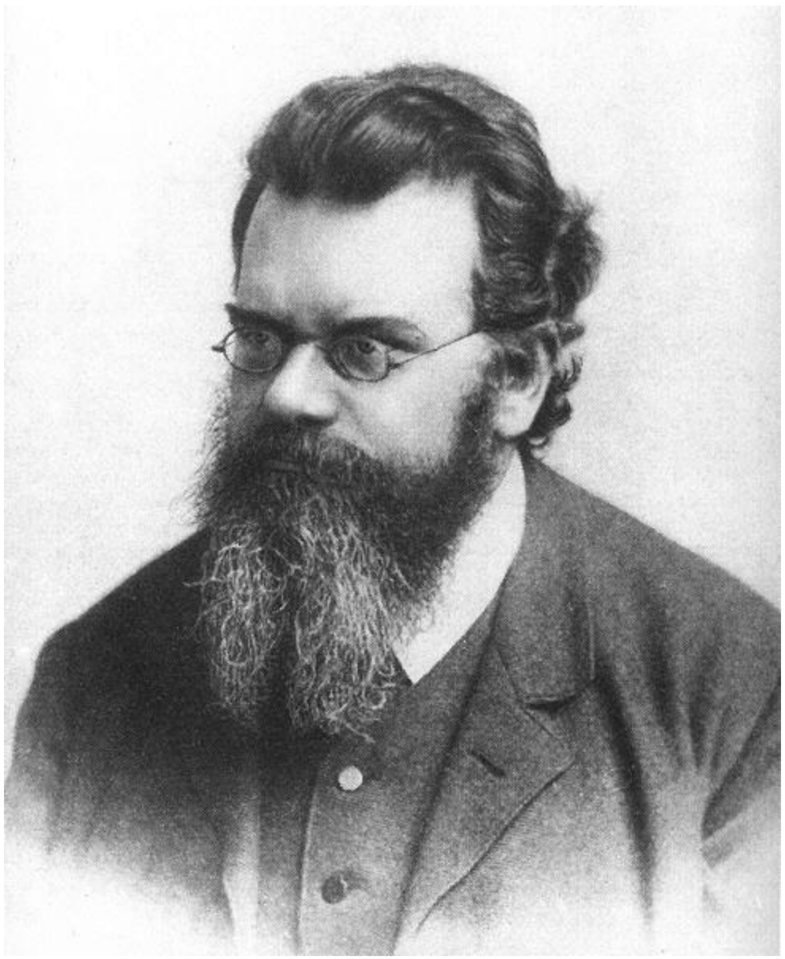
- Two additional key aspects
  - Necessity to establish a scientifically-based procedure for the PRA, and then
    - Make extensive reference to the biological and ecological disciplines to learn more about the species and the processes
    - Make the Risk Assessment a quantitative procedure
  - Try to make the procedure of PRA increasingly standardized by
    - The standard definition of the entities or modules ("objects") on which operate (e.g., what is a biological cycle and how to represent it?)
    - The definition of rules of combination and/or transformation of these modules to obtain information and knowledge required (e.g., how can I connect the biological cycle with the potential establishment of a species?)

- The present contribution explores possibilities
  - To link risk assessment to basic ecology → theory of LHS
    - Tools for data organization and knowledge extraction
  - For standardization
    - How to use standard information and information processing to generate new knowledge

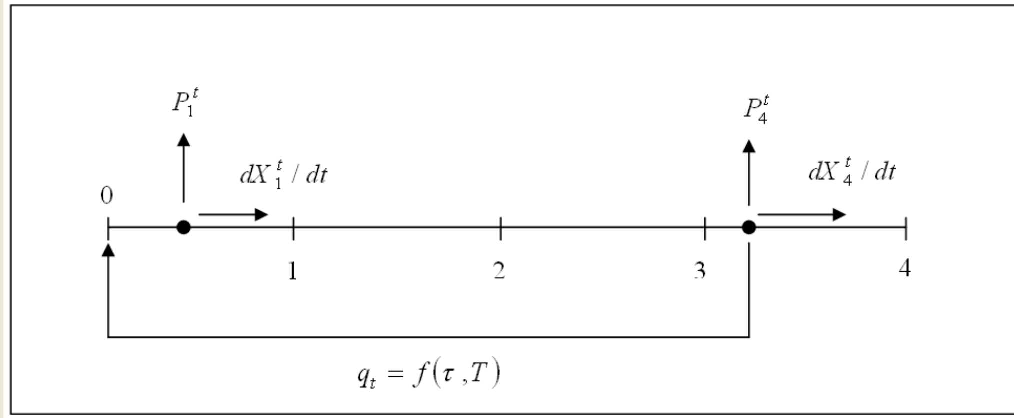
- The objective
  - Propose a method for data selection and organization based on the definition and use of BioDemographic Functions (BDF)
  - Examine some properties of BDF as a candidate tool for data organization and knowledge extraction for PRA standardization

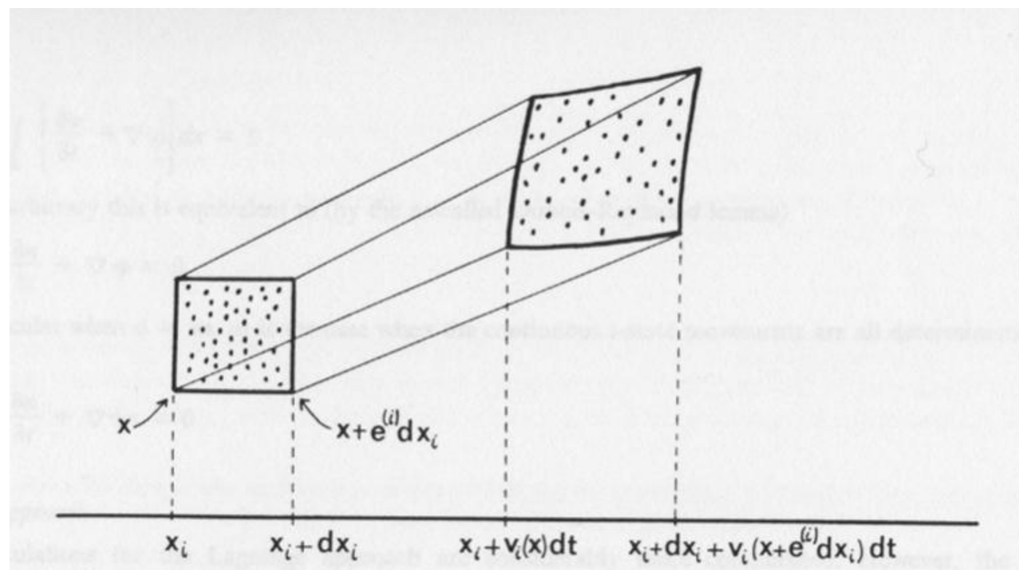
2. A mechanistic method based on biodemographic functions

- Mechanistic approach: from *i*-state to *p*-state

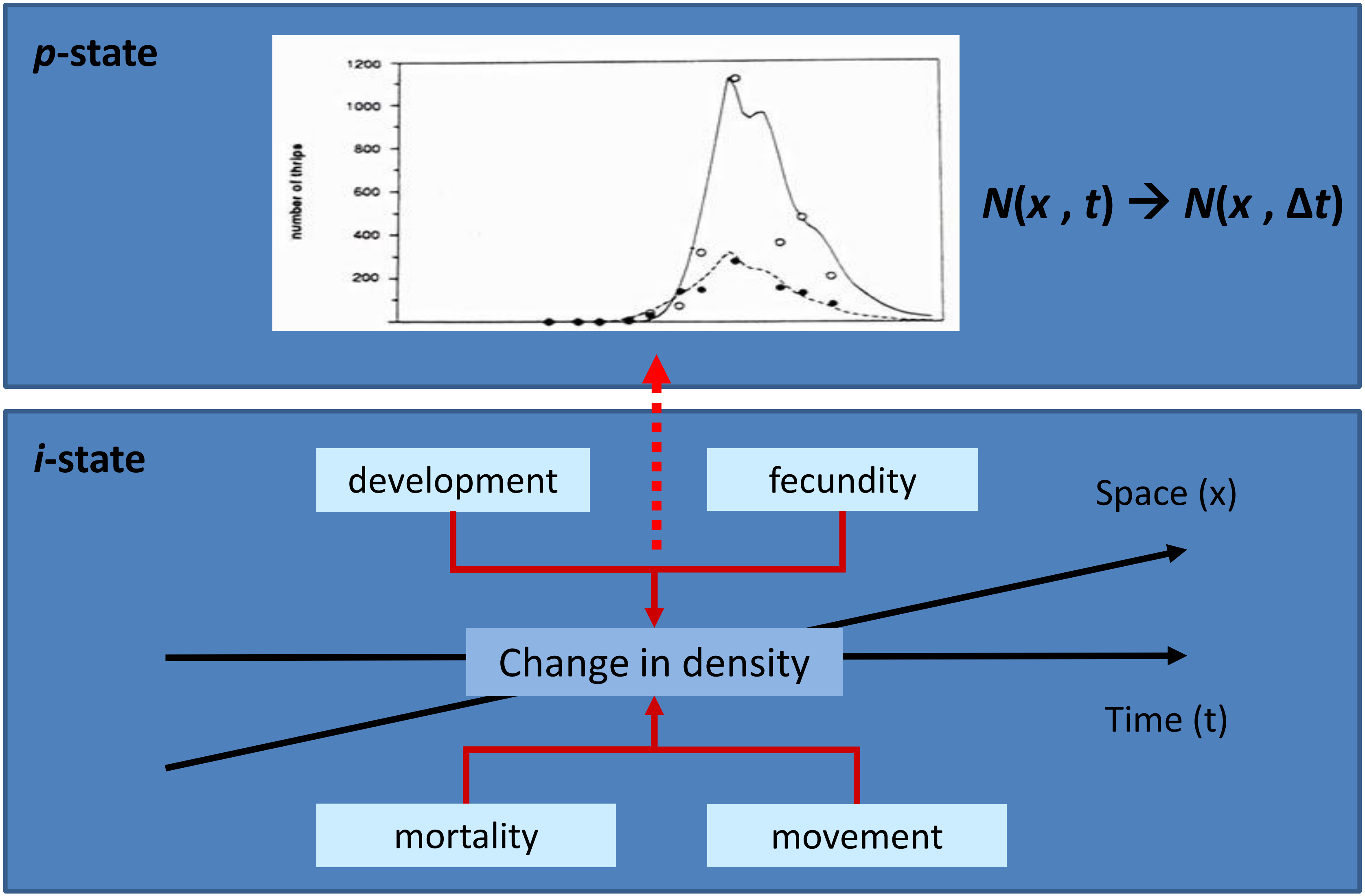


Ludwig Boltzmann (1844-1906)





- From individuals to population dynamics



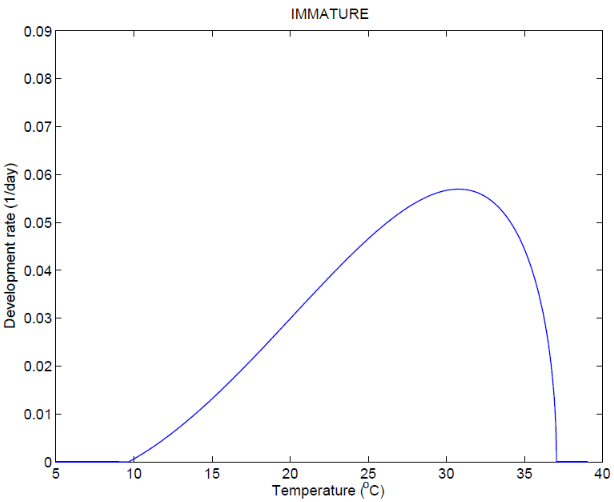
• Data at individual level: minimal selection and organization (knowledge extraction?)

Biological parameters	*B. tabaci* species (geographical origin)	Host plants	Range of temperatures (°C)					References
			15–17	19–21	25–26	28–30	31–35	
Mean development time (days), egg to adult stage	MEAM1 (Turkey)	Cucumber Cantaloupe Squash Watermelon		33.5 36.5 37.2 38.9	19.3 20.8 20.1 23.8	16.8 19.6 19.8 21.9		Bayhan et al. 2006a
	MEAM1 (Japan)	Cabbage Cucumber Tomato Egg-plant Bell pepper Kidney beans			23.2 22.6 23.7 21.3 22.5 0-26.5			Iida et al. 2009
	Med (Japan)	Cabbage Cucumber Tomato Egg-plant Bell pepper Kidney beans			28.8 24.6 28 28.4 35.2 24.1-28			Iida et al. 2009
	MEAM1 (Japan)	Tomato Cucumber		39.8 38.7	21.6 19.8	18.1 15.8	23 26.7	Tsueda and Tsuchida 2011
	Med (Japan)	Tomato Cucumber		42.9 37.1	21.9 19.8	19.2 16	- 25.5	Tsueda and Tsuchida 2011
	MEAM1 (China)	Bean Soybean Cowpea			27.8 18.2 22.7			Musa and Ren 2005
	MEAM1 (China)	Cotton Tobacco Cabbage Squash Kidney bean				23 .5 22.5 23.6 21.4 19.2		Zang et al. 2006
	Asia II (China)	Cotton Tobacco Cabbage Squash Kidney bean				21.5 - - 22.9 -		Zang et al. 2006
	MEAM1 (USA - Georgia)	Cotton *Deltapine 50* Cotton *Stoneville 453*		37.8 37.9	21.3 21.5	16.3 18.3	23.1 18.9	Nava-Camberos et al. 2001
		Cantaloupe *Tam Sun* Cantaloupe *Gold Rush*		36.0 35.9	20.7 21.4	14.8 14.6	19.5 19.4	
	MEAM1 (south of Spain)	Sweet pepper	45.3	36.6	21.5	18	16.8-19.8	Muñiz and Nombela 2001
	Med (south of Spain)	Sweet pepper	42.7	34.1	20.7	16.2	16-18.1	Muñiz and Nombela 2001
	MEAM1 (Spain)	*Solanum nigrum* *Datura stramonium*			21.8 23.4			Muñiz 2000a
	Med (Spain)	*Solanum nigrum* *Datura stramonium*			20.2 21.9			Muñiz 2000a
	Med (south of France)	Tomato	55.8	39.6	25.6	20.2	20.5	Bonato et al. 2007
	Italy (Italy)	*Euphorbia characias*	77.5	48.1	35.4	29.7	35.7	Demichelis et al. 2005
Survival (%), egg to adult stage	MEAM1 (Turkey)	Cucumber Cantaloupe Squash Watermelon		73.2 72.9 52.1 37.6	83.2 84.9 76.1 64.8	72.9 75.6 57.1 40.1		Bayhan et al. 2006a
	MEAM1 (Japan)	Cabbage Cucumber Tomato Egg-plant Bell pepper Kidney beans			76.4 77.9 94.3 93.2 6.1 0-41.3			Iida et al. 2009
	Med (Japan)	Cabbage Cucumber Tomato Egg-plant Bell pepper Kidney beans			62.1 90.6 64.9 96.3 73 71-83.9			Iida et al. 2009
	MEAM1 (China)	Bean Soybean Cowpea			77.1 64.3 70.1			Musa and Ren 2005
	MEAM1 (China)	Cotton Tobacco Cabbage Squash Kidney bean				86.2 55.2 79 62 64.6		Zang et al. 2006
	Asia II (China)	Cotton Tobacco Cabbage Squash Kidney bean				77.8 0 0 26 0		Zang et al. 2006
	MEAM1 (USA - Georgia)	Cotton *Deltapine 50* Cotton *Stoneville 453*		37.3 64.4	41.3 39.0	55.9 38.2	42.5 56.7	Nava-Camberos et al. 2001
		Cantaloupe *Tam Sun* Cantaloupe *Gold Rush* Pepper *Jalapa* Pepper *Jupiter*		100 78.1 0 0	91.3 85.9 0 8.3	98.1 76.5 0 0	84.0 88.5 0 0	
	Med (south of France)	Tomato	48	83	85	82	63	Bonato et al. 2007
	MEAM1 (Spain)	*Malva parviflora* *Capsella bursa-pastoris* *Brassica kaber* *Lactuca serriola*			75.7 63.6 34.8 26.5			Muñiz 2000a
	Med (Spain)	*Malva parviflora* *C. bursa-pastoris* *Brassica kaber* *Lactuca serriola*			86.9 57 45.3 28.9			Muñiz 2000a
Adult longevity (days)	Med (south of France)	Tomato	39.6	27.3	21.9	14.6	8.5	Bonato et al. 2007
	MEAM1 females (China)	Bean Soybean Cowpea			9.8 12.3 11.7			Musa and Ren 2005
	MEAM1 (China)	Cotton Tobacco Cabbage Squash Kidney bean				20.3 2.2 14.6 6.1 6		Zang et al. 2006
	Asia II (China)	Cotton Tobacco Cabbage Squash Kidney bean				11.2 1.7 1.2 2.2 2.1		Zang et al. 2006
	MEAM1 (Japan)	Tomato Cucumber		24.1 26.7		11.4 11.9		Tsueda and Tsuchida 2011
	Med (Japan)	Tomato Cucumber		21.4 23.7		11.4 11.6		Tsueda and Tsuchida 2011
Fecundity (total number of eggs per female)	Med (south of France)	Tomato	49.5	105.3	94.2	58.6	41	Bonato et al. 2007
	MEAM1 females (China)	Bean Soybean Cowpea			98 160.9 153.1			Musa and Ren 2005
	MEAM1 (Japan)	Tomato Cucumber		105.8 162.1		127.9 135.8		Tsueda and Tsuchida 2011
	Med (Japan)	Tomato Cucumber		67.9 149.3		68 81.8		Tsueda and Tsuchida 2011

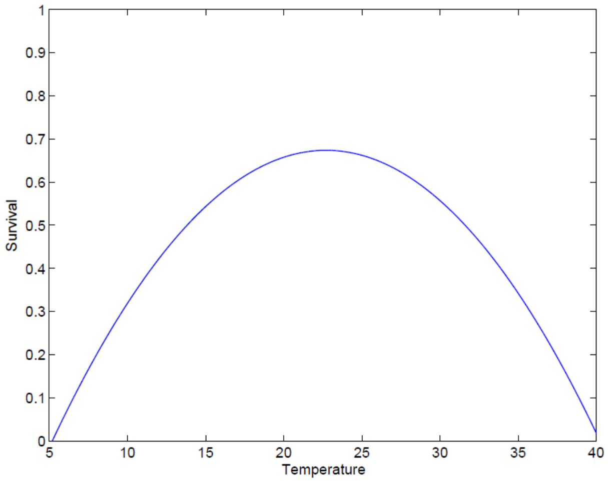
1. Data for parameter estimation

Parameters in the biodemographic functions have been estimated on the basis of experimental data on life history traits collected at individual level and available in literature. Many references consider the dependence of life history traits on temperature as well as on host plant. However, most of them do not report any information on the biotype or species of the tested population. The necessity to differentiate the biodemographic responses of MEAM1 and Med species (formerly known as B and Q biotypes) limited the papers to be considered to those in which the taxonomic identity of the experimental population is clearly determined and reported. The following papers were taken into account for parameter estimation: Bayan et al. (2006a); Bonato et al. (2007); Brewster et al. (1997); Chen et al. (2003); Crowder et al. (2006); De Barro et al. (2006); Oriani de Godoy et al. (2011); Delatte et al. (2009); Deschamps and Bonato (2011); Elbaz et al. (2011); Gergis (1994); Gonzalez-Zamora and Moreno (2011); Guo et al. (2012); Iida et al. (2009); Kakimoto et al. (2007); Li et al. (2012b); Mansaray and Sundufu (2009); Muñiz and Nombela (2001); Musa and Ren (2005); Nava-Camberos et al. (2001); Naranjo and Ellsworth (2005); Naranjo and Ellsworth (2009); Naranjo et al. (2010); Pascual and Callejas (2004); Qiu et al. (2004); Tsai and Wang (1996; Tsueda and Tsuchida (2011); Wagner (1995); Walker et al. (2010); Yang and Chi (2006); Xie et al. (2011); Zang and Liu (2007).

- The alternative? The fantastic four

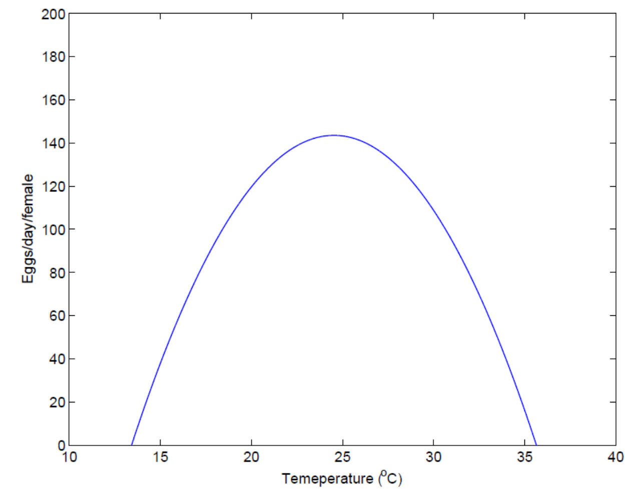


Development rate function

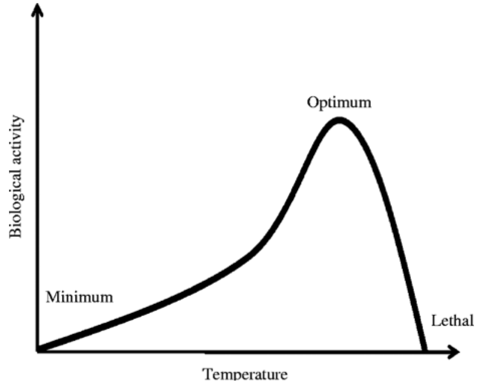


Survival rate function

Activity rate function



Fecundity rate function



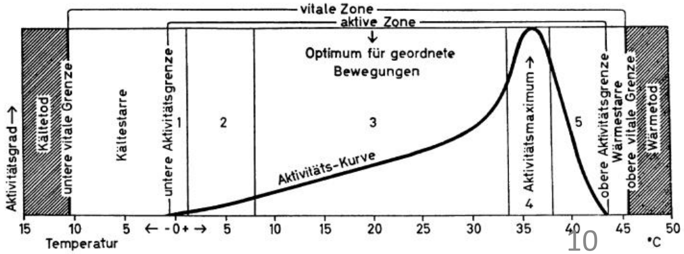


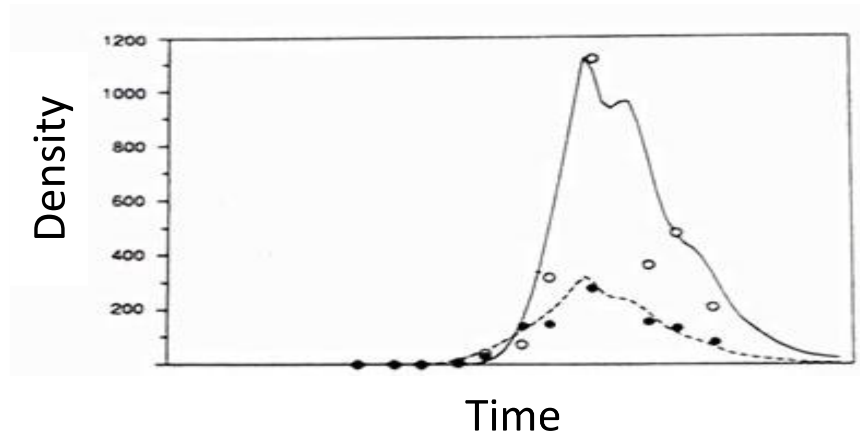
ABB. 35. Aktivitätsstufen und Aktivitätskurve der Eiraupe von *Lymantria monacha* in Abhängigkeit von der Temperatur. Nach v. ARNIM 1936.

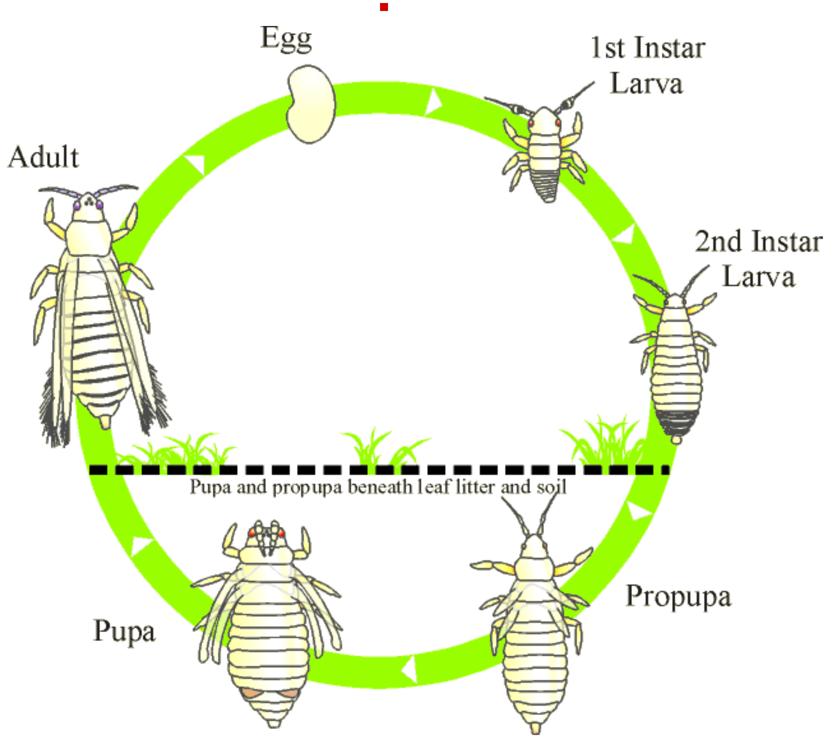
- Development (for poikilotherm organisms)

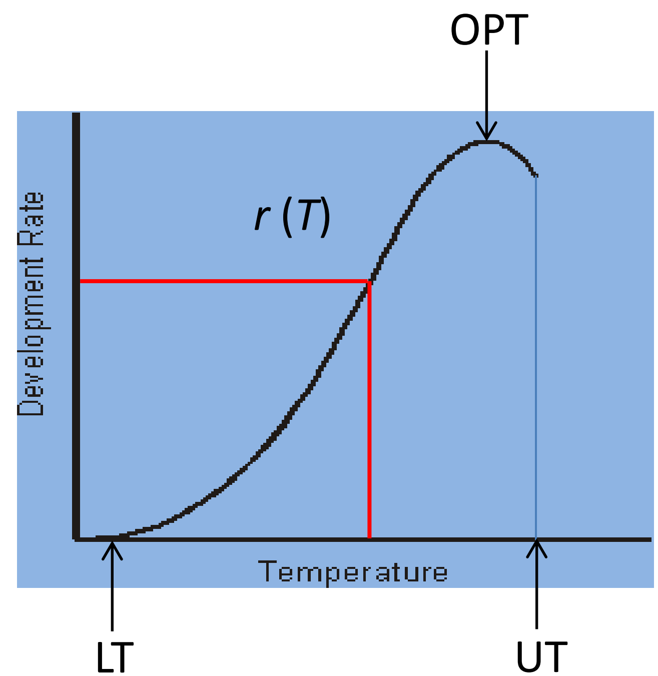
development

duration D[d], rate r [1/d]

egg → nymph → adult

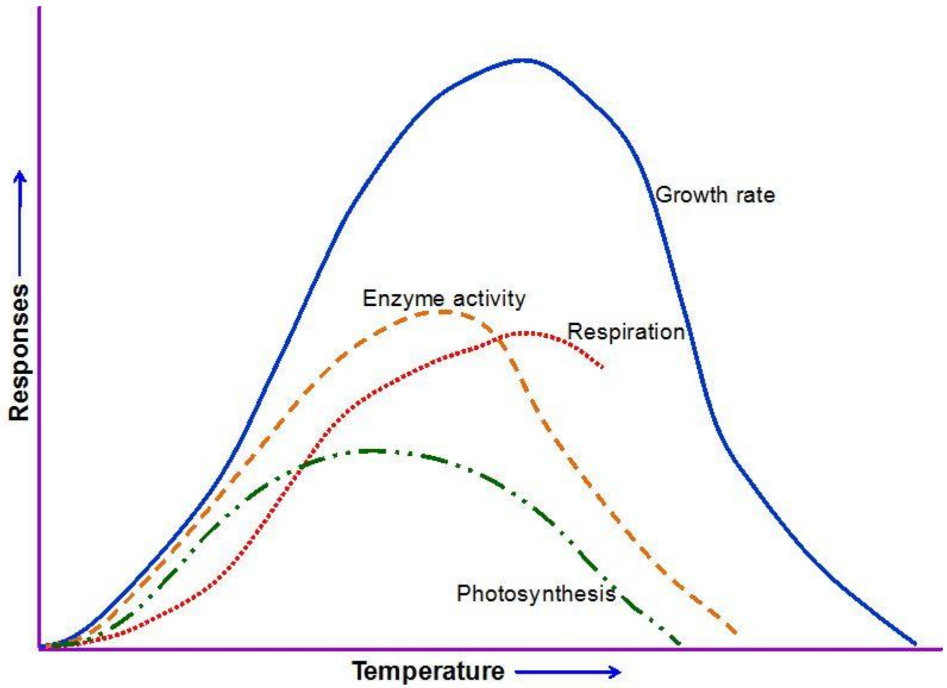


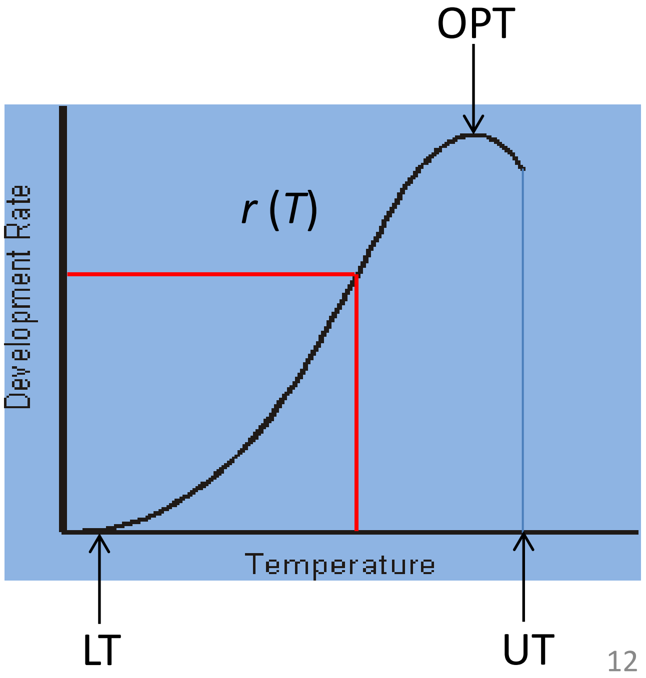




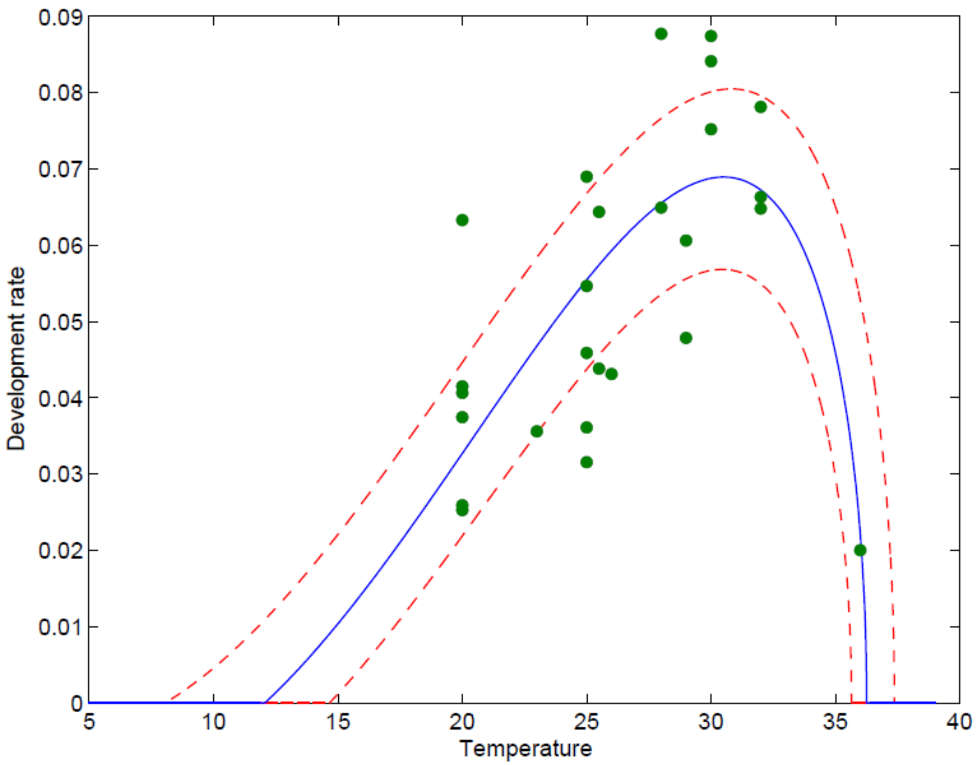
Development rate function

- Which information is required (indication for data selection)
  - <u>Shape of the curves</u> are derived from responses of physiological processes to forcing variables
  - <u>Three key elements</u>
    - Shape
    - Thresholds (Lower and Upper)
    - The maximum (Optimum)





- How to estimate biodemographic rate functions?



(i) From experiments

(ii) From field data (combining data and modelling)

(iii) Combining data and expert judgement

- Which functional form for a rate function?

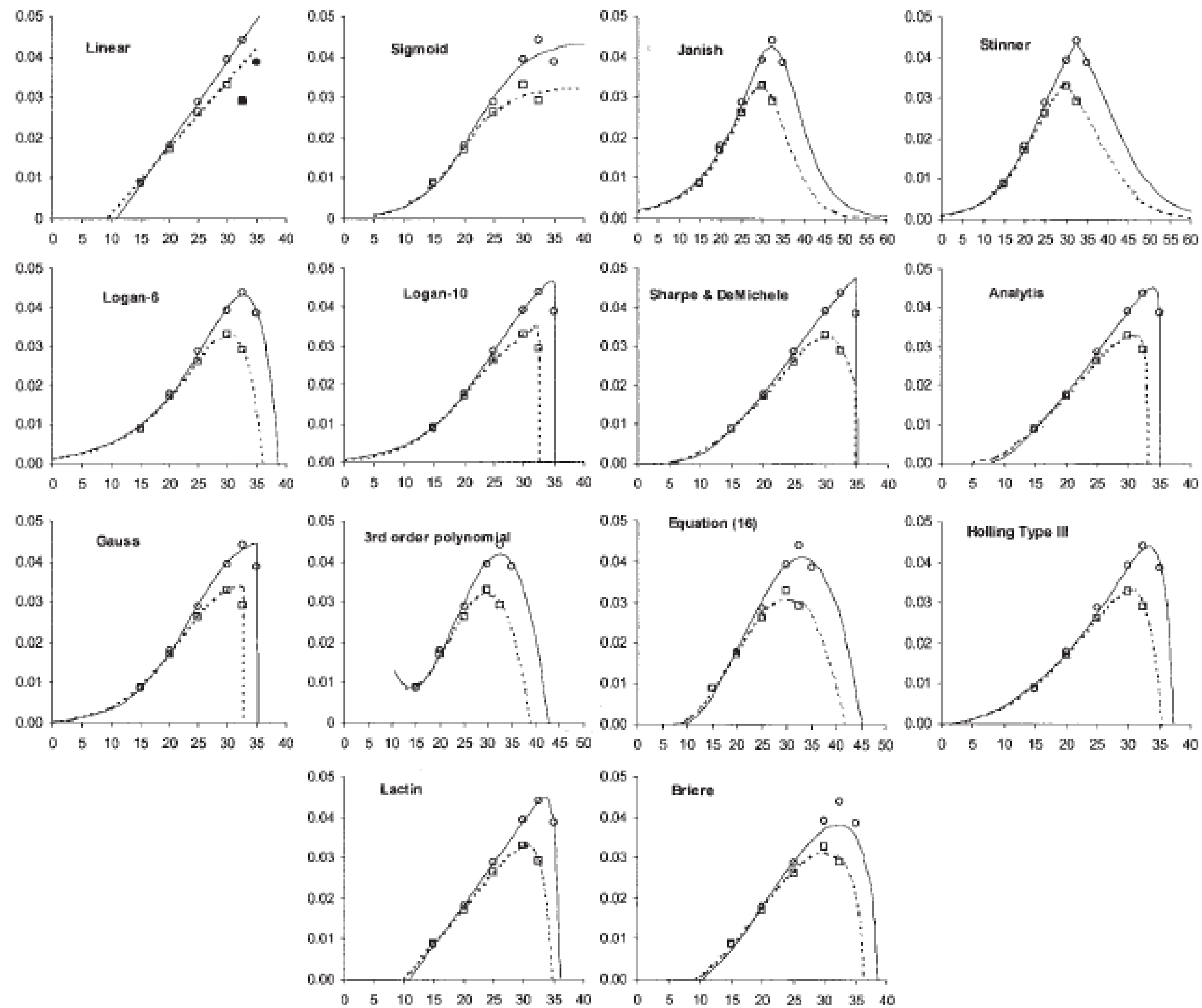
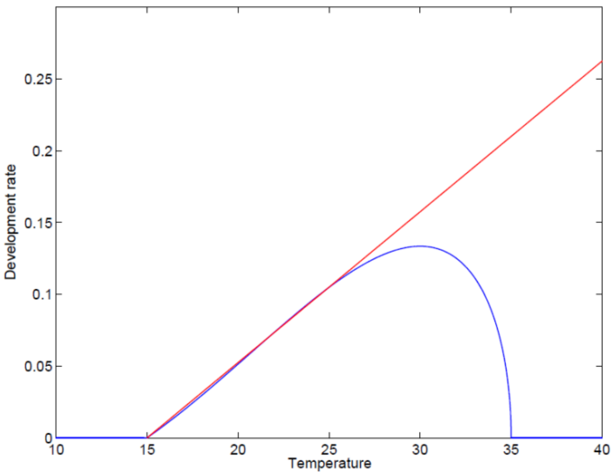


Fig. 1. Fitting of equations of Table 1 on data of Table 2 for the total biological cycle of *N. includens* (solid line) and *N. bisignatus* (dotted line). In all charts, the ordinate is the rate of development (1/D, in days^{-1}), and the abscissa is the temperature (in °C). In the linear regression, the last data values have been omitted because of deviation from the straight line.

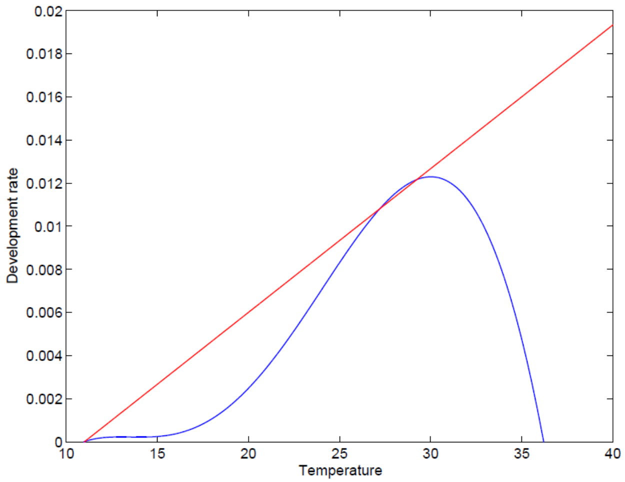
3. Meaning and use of the biodemographic functions

3.1. Non-linearity in physiological responses

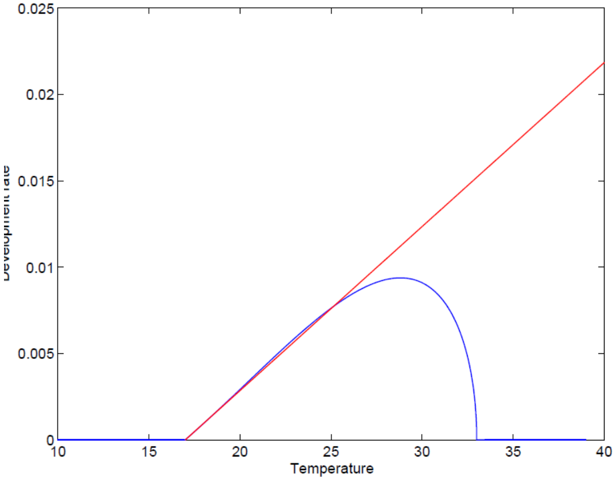
- The problem
  - Many approaches consider linear physiological responses to environmental forcing variables
  - Non-linearity in physiological responses is more realistic and the implications of non-linearity in the transition from *i*-state to *p*-state are not adequately considered
- The example
  - The effect on population dynamics of non-linearity in development rate function is investigated considering a population dynamics model for the invasive apple snail *Pomacea canaliculata*



Egg Developmental rate function

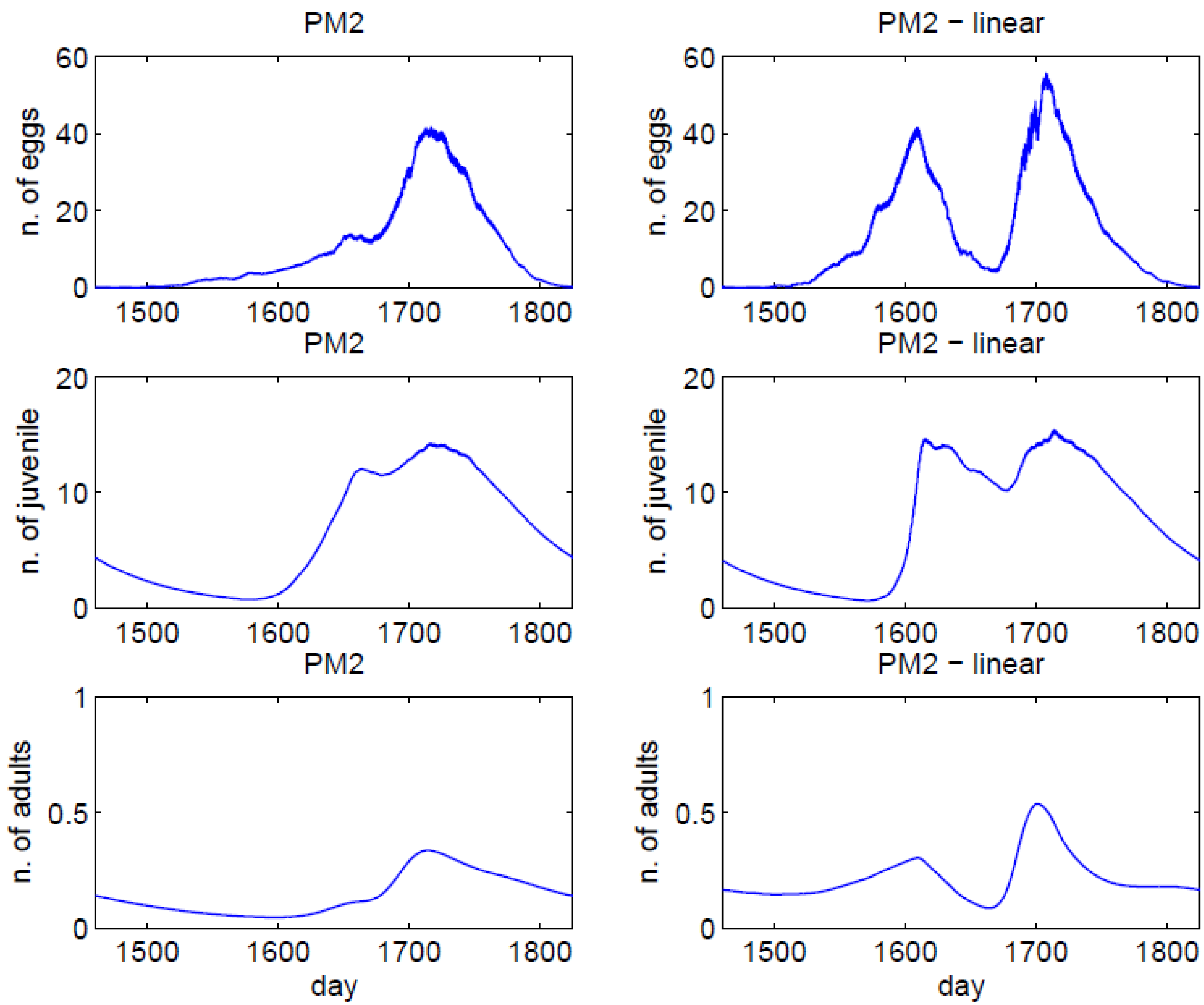


Juvenile Developmental rate function



Adult Developmental rate function

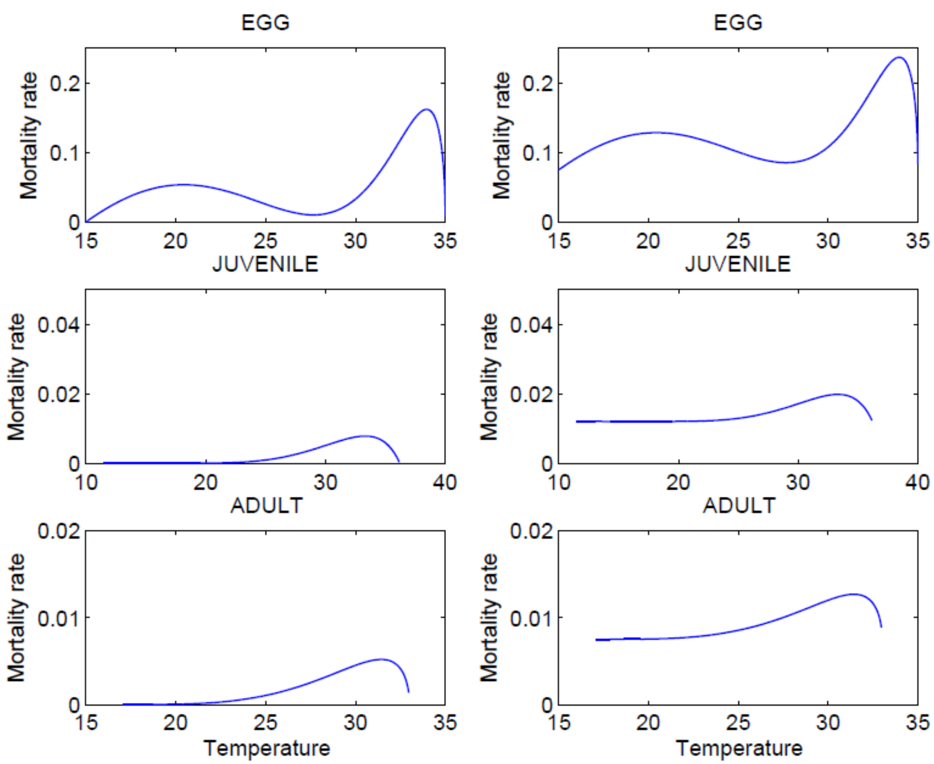
- Implications of non-linearity on long-term population dynamics of the apple snail *Pomacea canaliculata*



3.2. Dependence of physiological responses from two variables

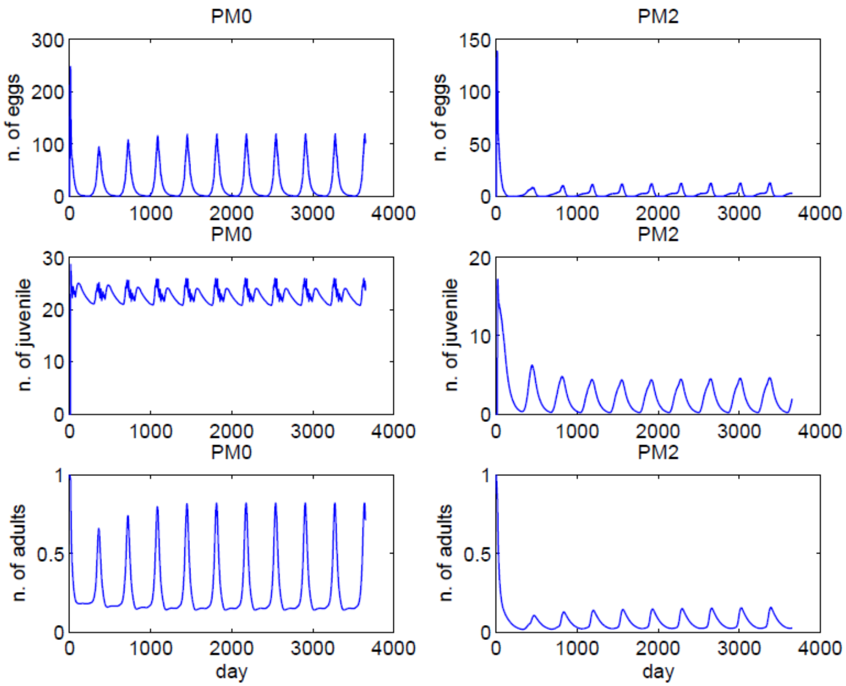
- The problem
  - Physiological responses can be dependent from more than one environmental variable
- The example
  - The effect of adding a temperature-independent and density-dependent mortality factor to the temperature-dependent mortality rate in *Pomacea canaliculata*

Temperature-dependent (intrinsic) mortality rate (lab experiments)

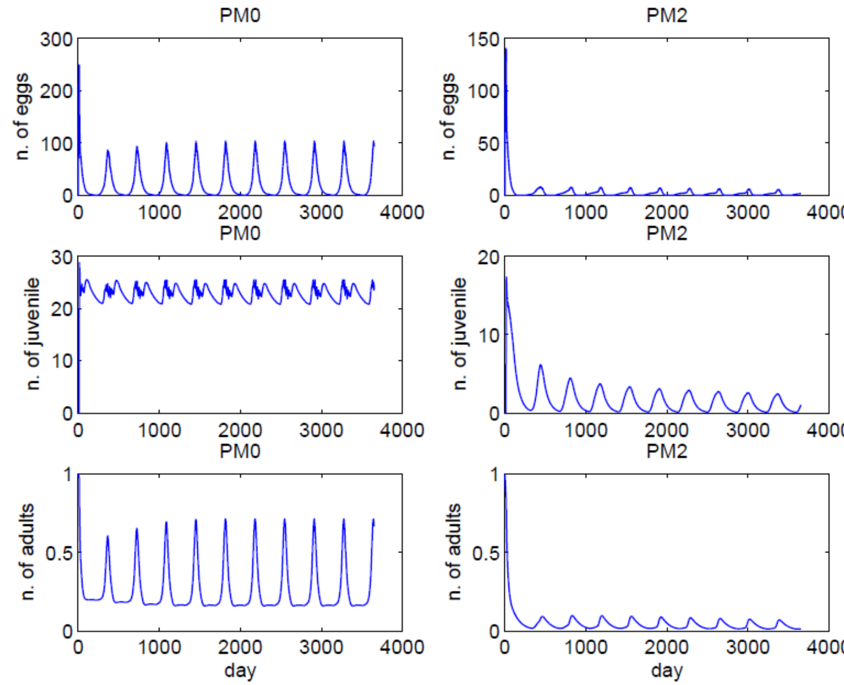


T-dependent + Density-dependent mortality rate (extrinsic) (after model calibration)

- A model calibration procedure for the estimation of the additional mortality factor

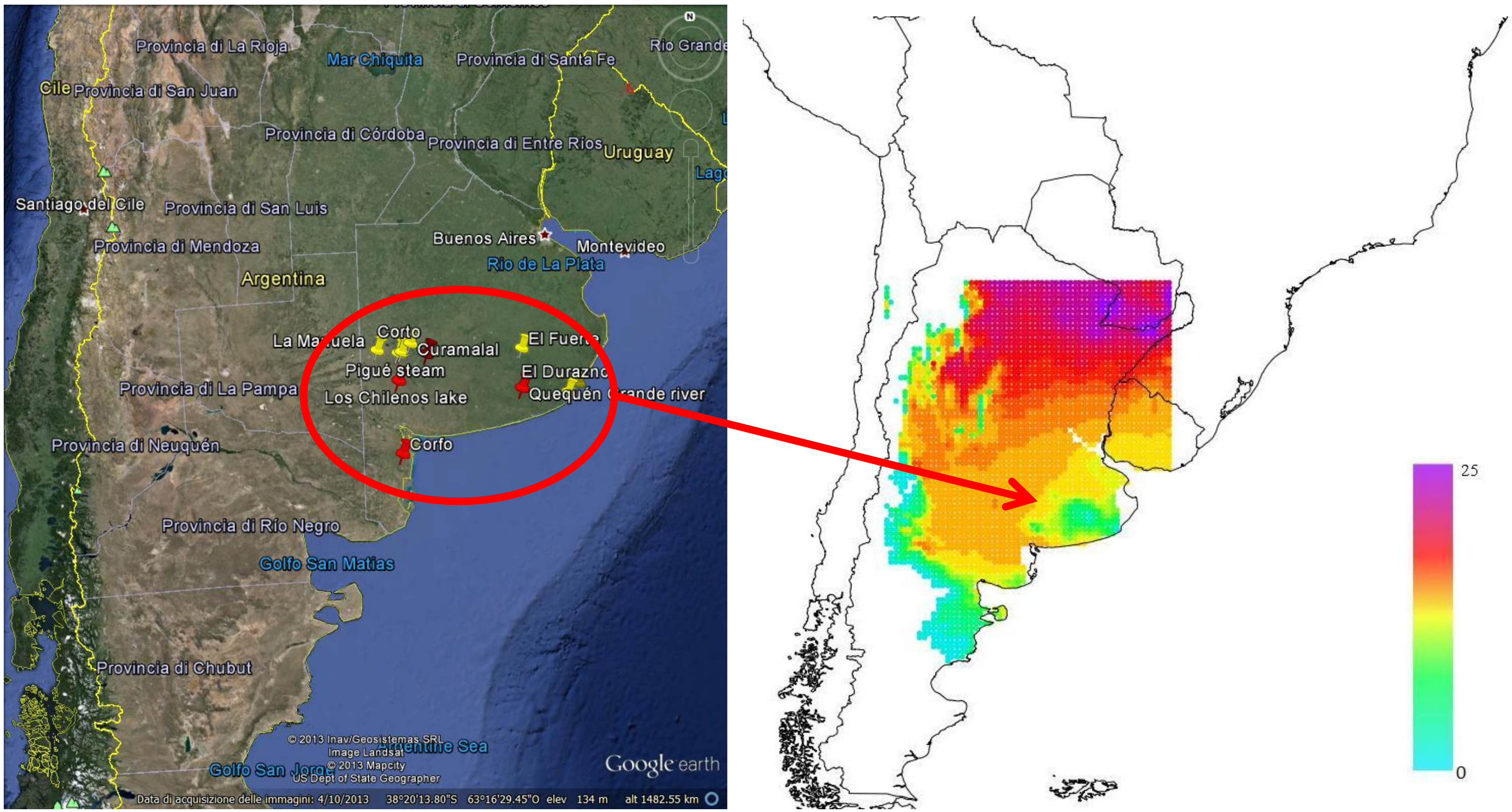


P. canaliculata, Paso de las Piedras Argentina



P. canaliculata, los Chilenios Argentina

- Implications: Only the consideration of an additional mortality factor allows to interpret the southernmost distribution in South America

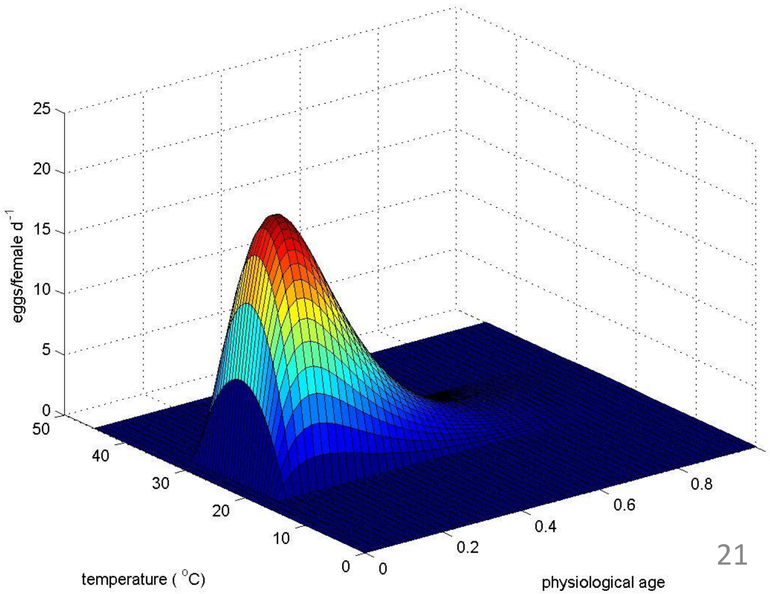


3.3. Dependence of physiological responses from three variables

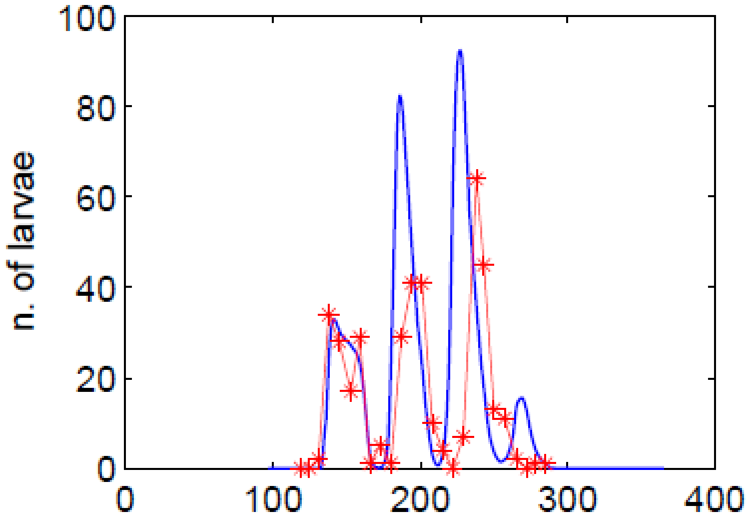
- The problem
  - Physiological responses <u>depend on different types of variables</u> (i) individual status (age), (ii) abiotic environmental factors (e.g., temperature), (iii) biotic environmental factors (e.g., food availability and quality)
- The example
  - <u>Fecundity rate function of grape berry moth</u> (*Lobesia botrana*) depend on temperature, physiological age of the insect and plant phenology

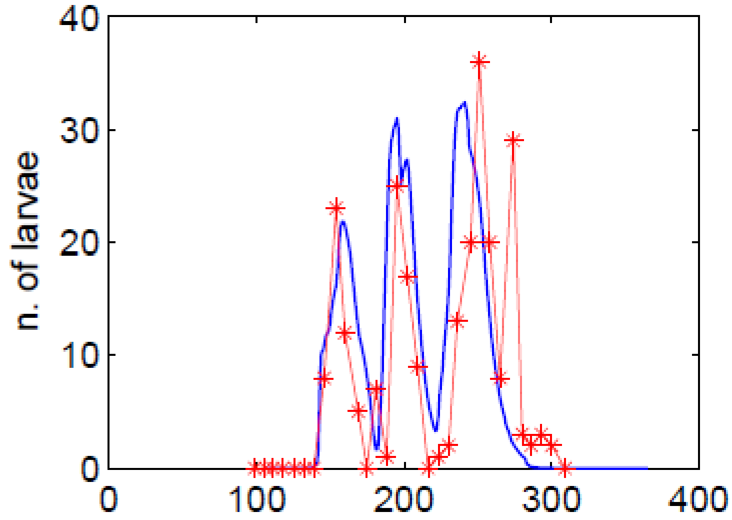
<u>Three functions</u>:

f1(BBCH) for inflorescence
f2(BBCH) for green berries
f3(BBCH) for maturing fruits



- Implication: fitting of natural population





Larval stage population dynamics
Colognola, Verona, Italy
CV. Garganega, 2009

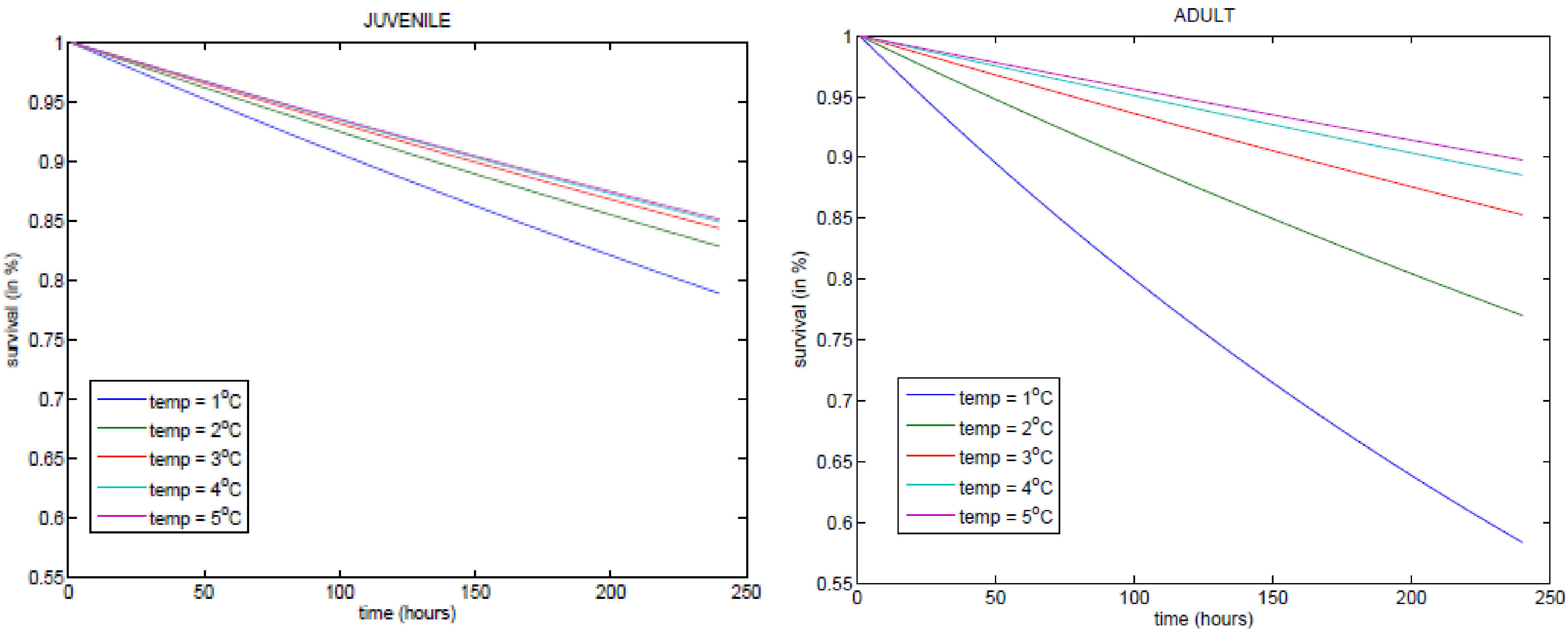
Initial conditions: first 3-4 adult weekly catches (at the beginning of the season)

Larval stage population dynamics
Colognola, Verona, Italy
CV. Garganega, 2010

Initial conditions: first 3-4 adult weekly catches (at the beginning of the season)

3.4. Stress effects

- The problem
  - Establishment of an IAS depends on the biological performances under stressing condition (e.g., survival at the extremes of the range of temperature)
  - Stress is a matter of time exposure and level of the stressing factor
- The example
  - Sensitivity to cold stress of the invasive apple snail *P. canaliculata*

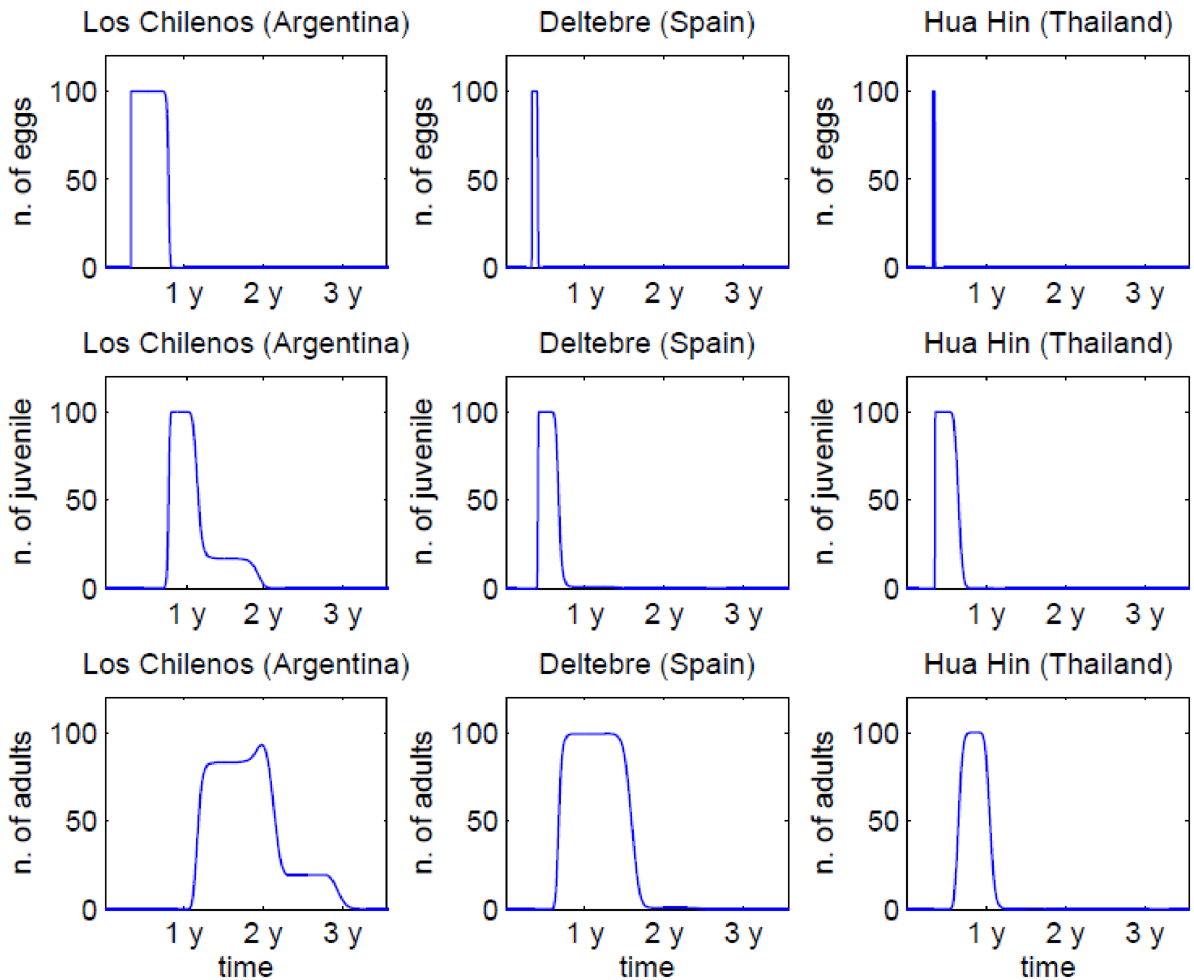


3.5. Adaptive capacity

- The problem
  - Biodemographic functions are shaped and tested by the evolution and constrained in their change
  - Their non-linearity, physiological basis and stability allow a single function to account for different adaptive responses to different environmental conditions (e.g., climate)
  - We do not need to change the parameters and we can fully rely on a single function (*i*-state) to describe variation in the population dynamics

- The example
  - A single development-rate function account for *Pomacea canaliculata* plasticity in response to different climates

- Implications: Different realistic patterns of *Pomacea canaliculata* phenology in response to different climates

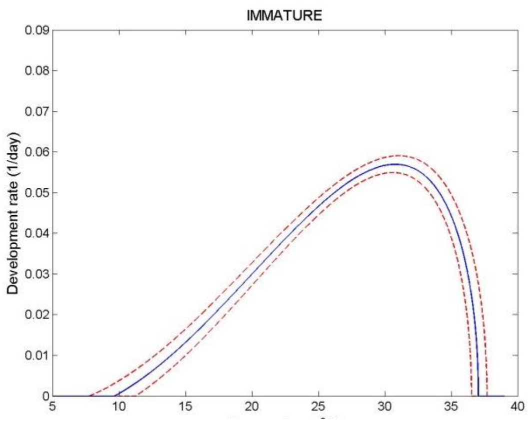


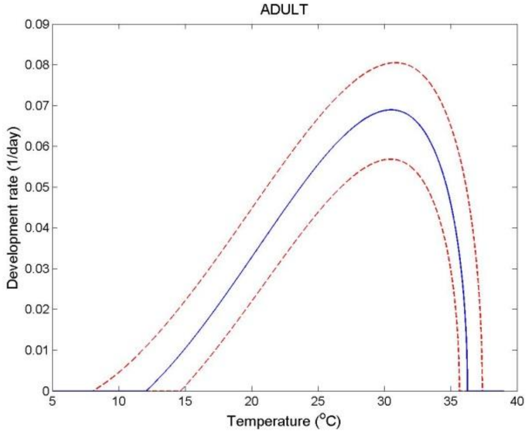
3.6. Biological variability

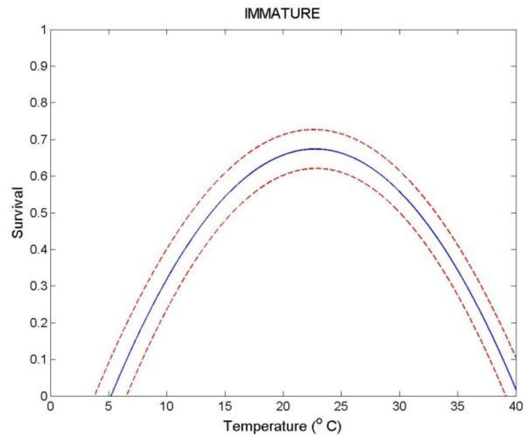
- The problem
  - Data on development, survival and fecundity temperature-dependent rates are affected by heterogeneity inherent the different experimental datasets which includes biological variability.

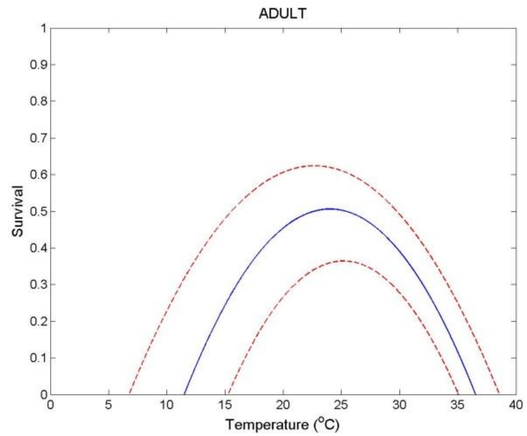
- The example
  - EFSA PLH Panel assessed the potential distribution in EU of *Bemisia tabaci* MEAM1 and Med under different scenarios considering biological variability in BDF and climate change
  - To take into account variations in BDF, the 95% confidence bands of the estimated development, mortality and fecundity rate functions have been estimated considering for each function all the relevant data available

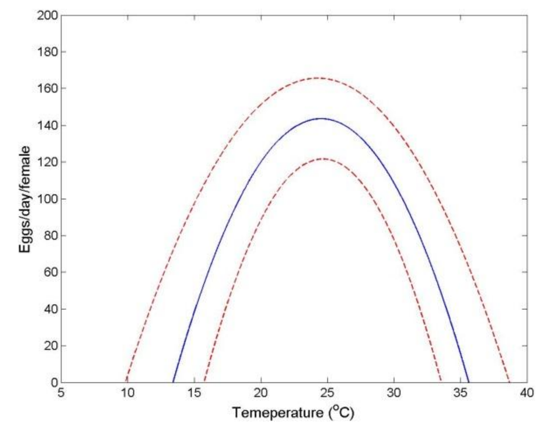
- The estimation of the confidence bands (for the parameters of the biodemographic functions)









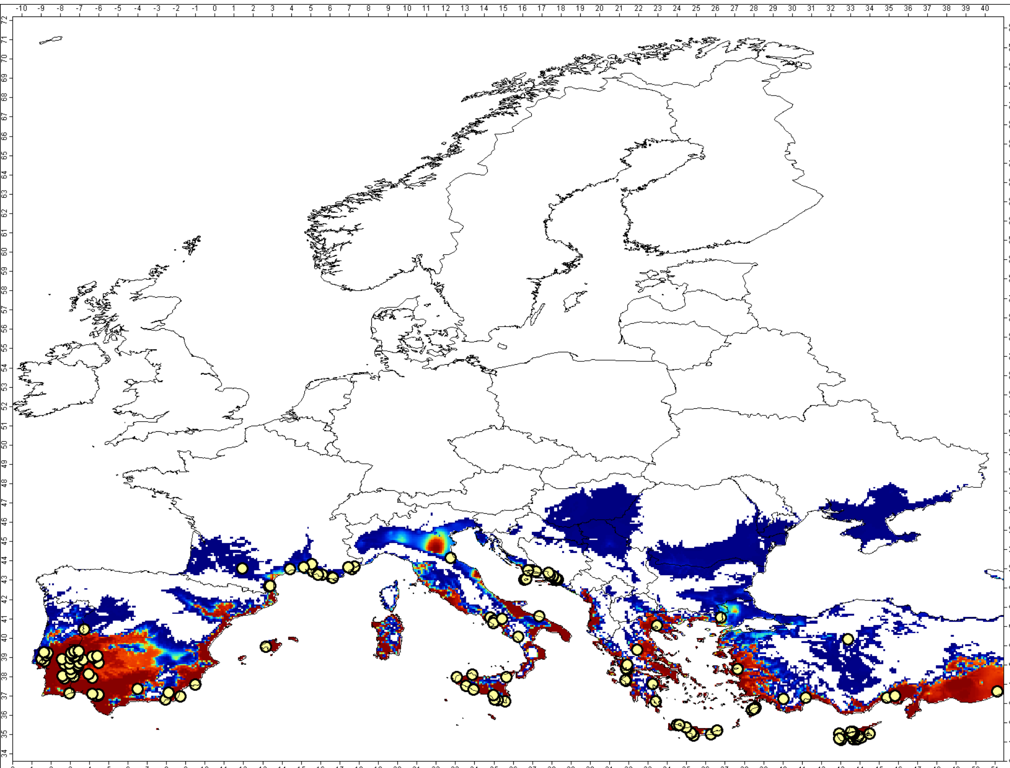


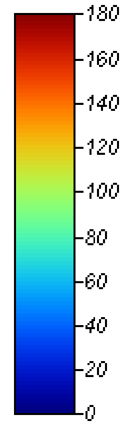
Development rate curves (continuous lines, in 1/day) as function of temperature (in °C) with 95% confidence bands (dotted lines) for immature (above) and adult (below)

Survival rate curves (continuous lines, in 1/day) as function of temperature (in °C) with 95% confidence bands (dotted lines) for immature (above) and adult (below)

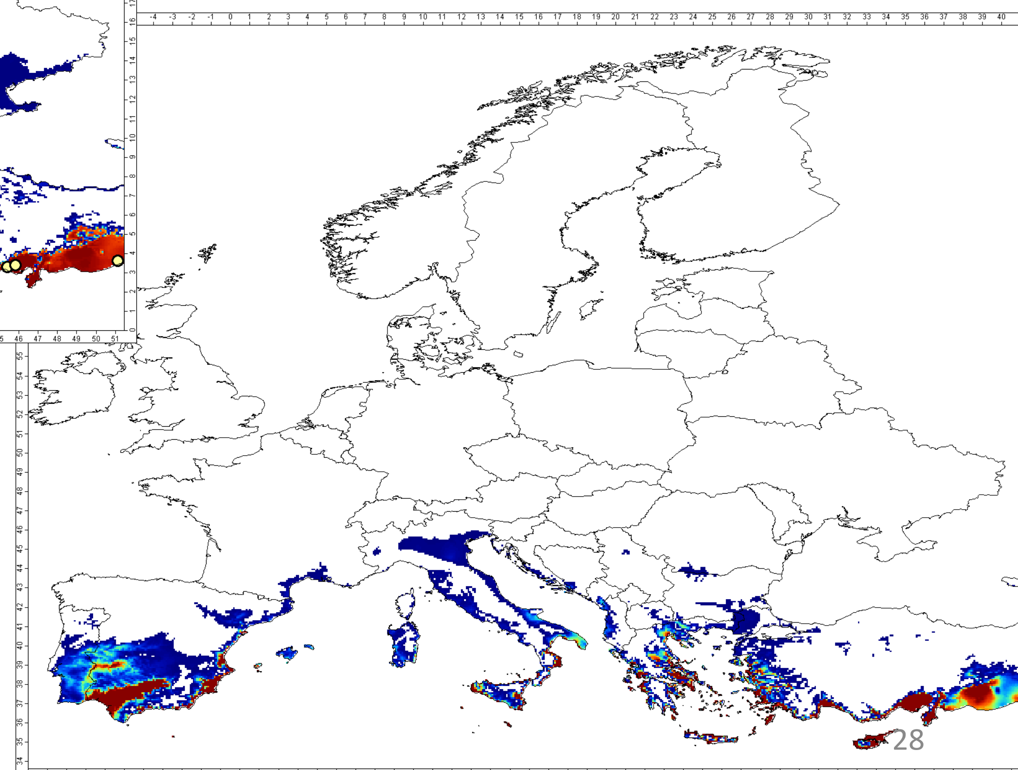
Fecundity rate curve (continuous lines, in 1/day) as function of temperature (in °C) with 95% confidence bands (dotted lines)

- Implications: Simulated spatial distribution of the simulated *B. tabaci* population pressure in Europe



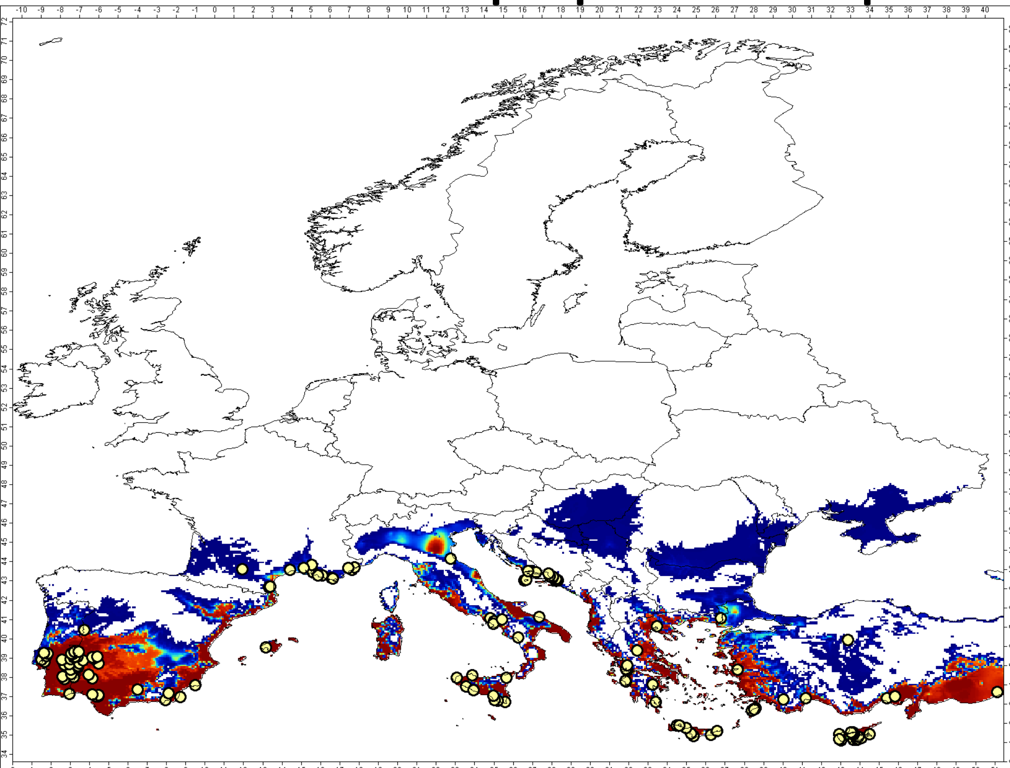


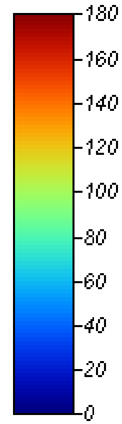
<u>Lower limits</u> of the confidence bands



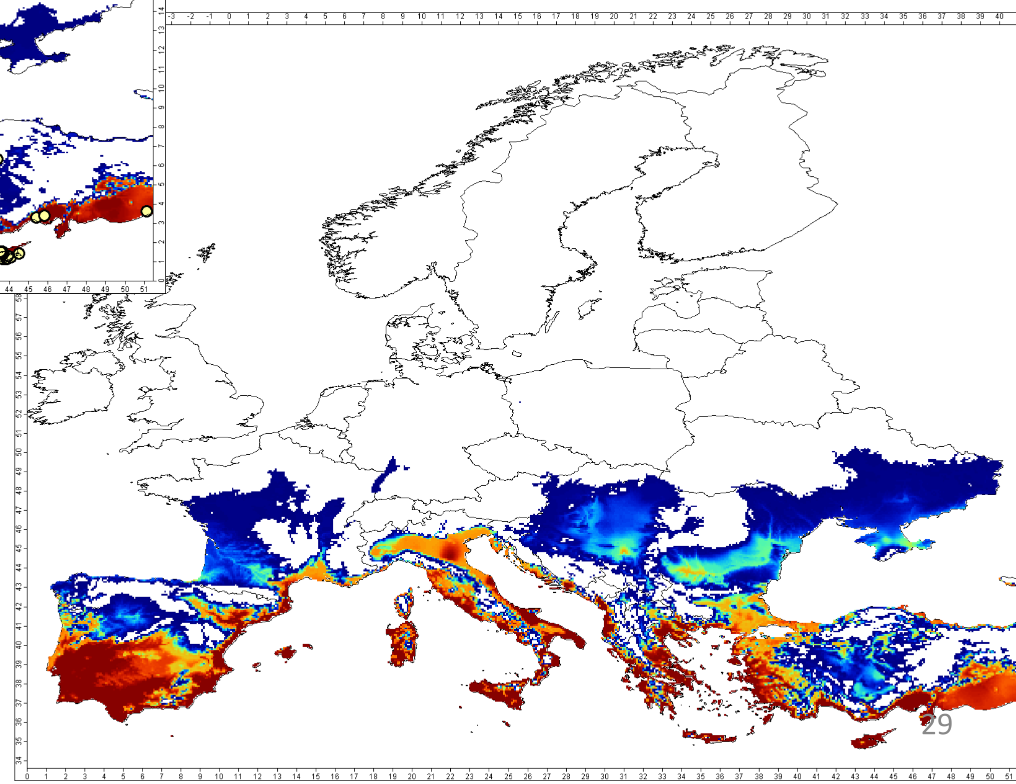
Spatial distribution of the simulated *B. tabaci* population pressure in Europe, starting from an initial condition of 0.1 individual per plant at March 1st, and considering **<u>lower limits</u>** of 95% confidence bands for development, survival and fecundity rate functions. Population pressure is the average number of adults per plant and time unit calculated for the period of the year in which the adult abundance is over one individual/plant.

- Implications: Simulated spatial distribution of the *B. tabaci* population pressure in Europe.





<u>Upper limits</u> of the confidence bands



Spatial distribution of the simulated *B. tabaci* population pressure in Europe, starting from an initial condition of 0.1 individual per plant at March 1st, and considering **<u>upper limits</u>** of 95% confidence bands for development, survival and fecundity rate functions. Population pressure is the average number of adults per plant and time unit calculated for the period of the year in which the adult abundance is over one individual/plant.

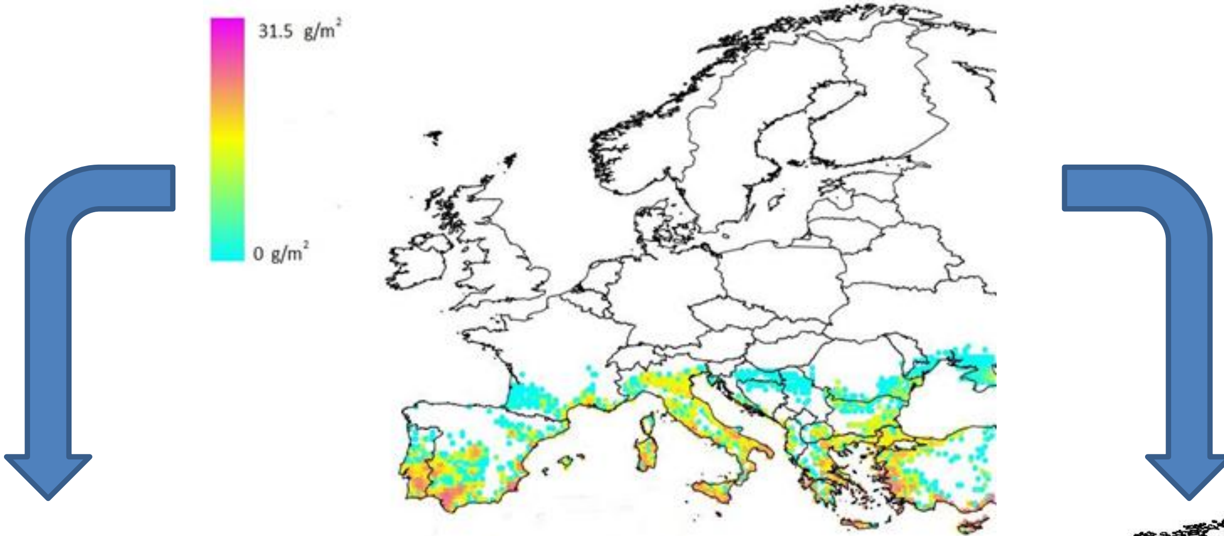
3.7. Uncertainty in the estimates

- The problem
  - Uncertainty in the estimates of BDF (e.g., in mortality rate) can affect component of scenario analysis in risk assessment
- The example
  - EFSA PLH was asked to perform a full E.R.A. of the invasive apple snails and considered the potential snail biomass (obtained by means of a population dynamics model) as the driving force of ecosystem change
  - The risk posed by apple snails to ecosystem traits, ecosystem services and biomass components is assessed under different scenarios considering, among others, future changes in the mortality factors regulating the snail biomass
  - Parameters used for the scenario analysis with their confidence intervals

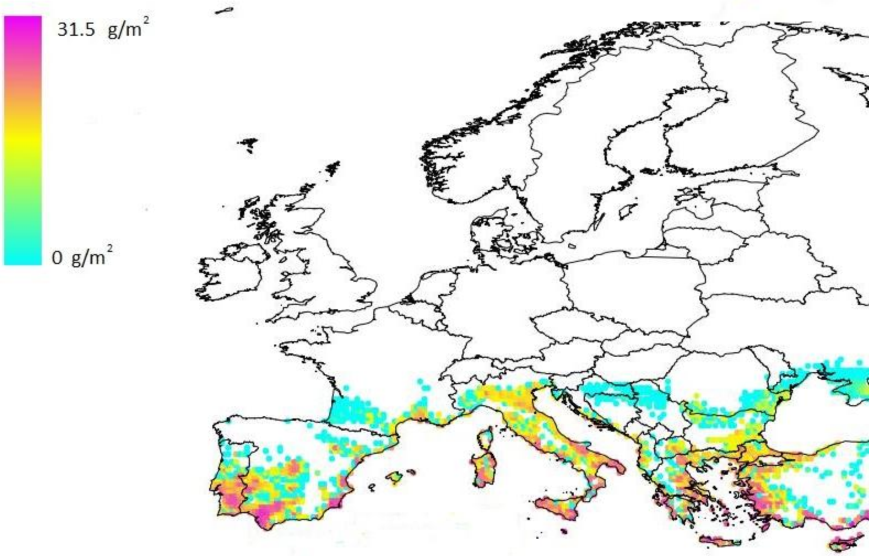
	Short term (ts) 5years	**Long term (tl) 30 years**
Mean Scaling factors		
Resistance *RS*	0.9 (C.I. [0,8242;0,9758]*)	1
Resilience *RL*	0.95 (C.I. [0,9021;0,9979]*)	0.5 (C.I. [0,3593;0,6407]*)
Management *MN*	0.99 (C.I. [0,9563;1]*)	0.8 (C.I. [0,6607;0,9393]*)
*RS*x*RL*x*MN*	0.84	0.4
Biomass		
Maximum potential biomass PBmax	31.5 grams/m2	31.5 grams/m2
Maximum realized biomass RBmax	26.5 grams/m2 (normalized 0.84)	12.6 grams/m2 (normalized 0.40)

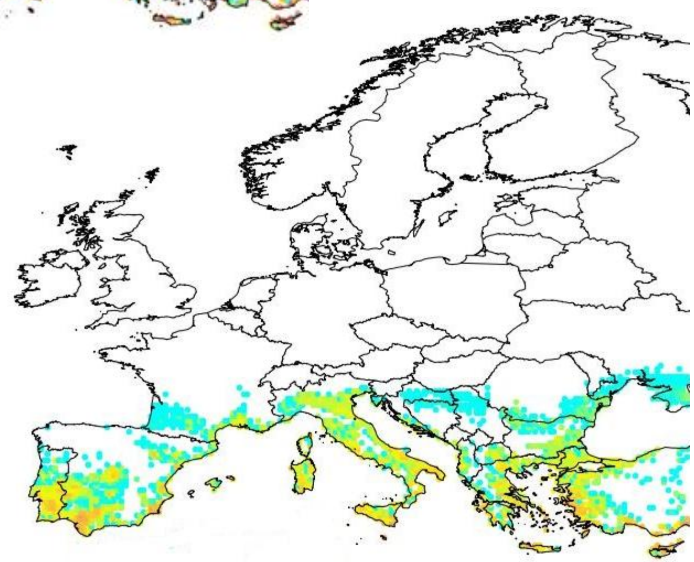
* 95% confidence interval for the mean of the scaling factor obtained as described in Appendix B

Scenario a.
Upper limit of 95% confidence intervals



Scenario b.
Lower limit of 95 % confidence intervals



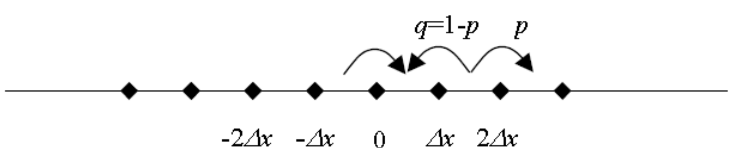


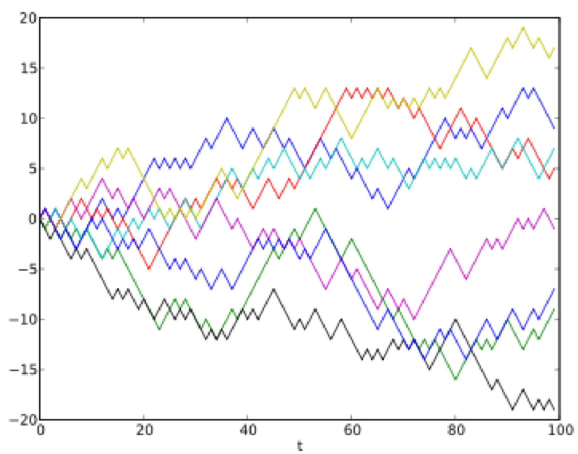
Distribution of realized biomass (g/m²) of *Pomacea canaliculata* juveniles + adults over Europe estimated with a time horizon of 5 years. **Two scenarios** are obtained by multiplying the potential biomass by the limits of the 95% confidence intervals of the three scaling factors: **a.** upper limits corresponding to the **more favourable scenario** for the snails; **b.** lower limits corresponding to the **less favourable scenario** for the snails.

3.8. Spatial processes

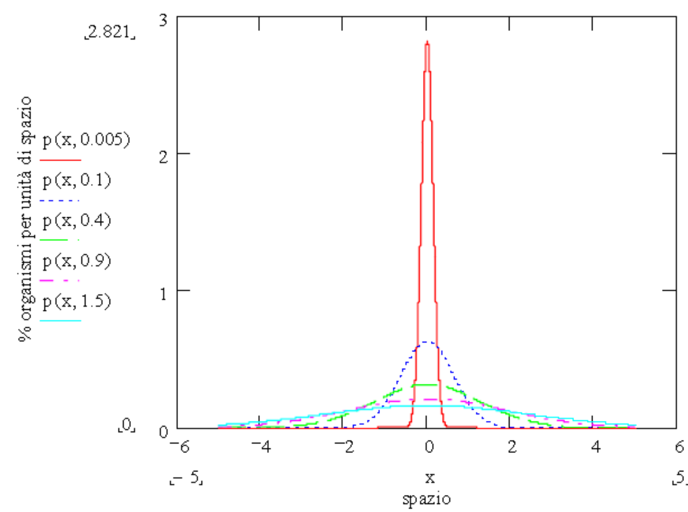
- The problem
  - Dispersal mechanisms at the *i*-state have influence on the type and pattern of spatial processes at the *p*-state level
- The example
  - The development of a spread model for the invasive chestnut gall wasp *Driocosmus kuriphilus*

The first step: the Brownian motion (i-state)





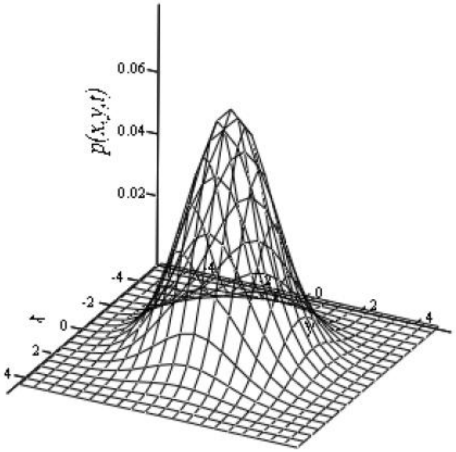
At population level: uni-dimensional



$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}$$

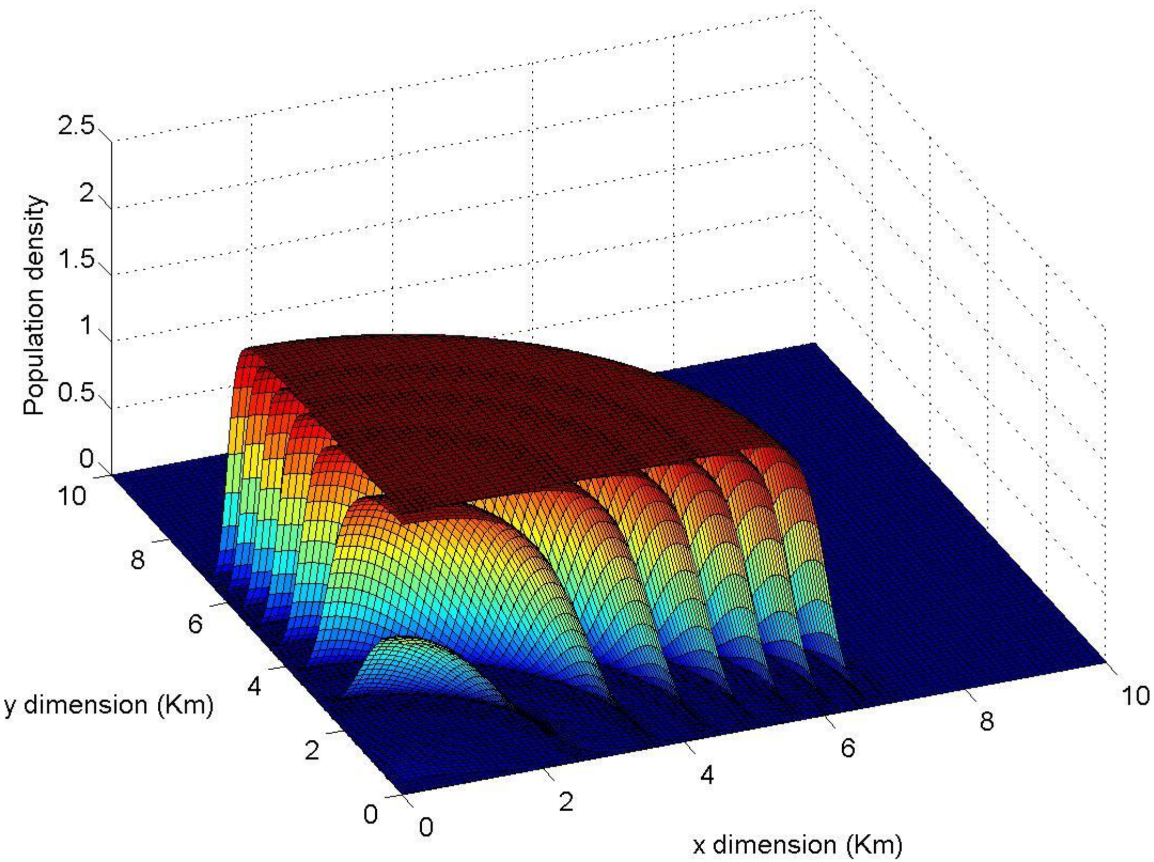
D → Diffusion coefficient (lenght^2/time)

- Second step: Addition of population growth and numerical simulation of random diffusion for the bi-dimensional case

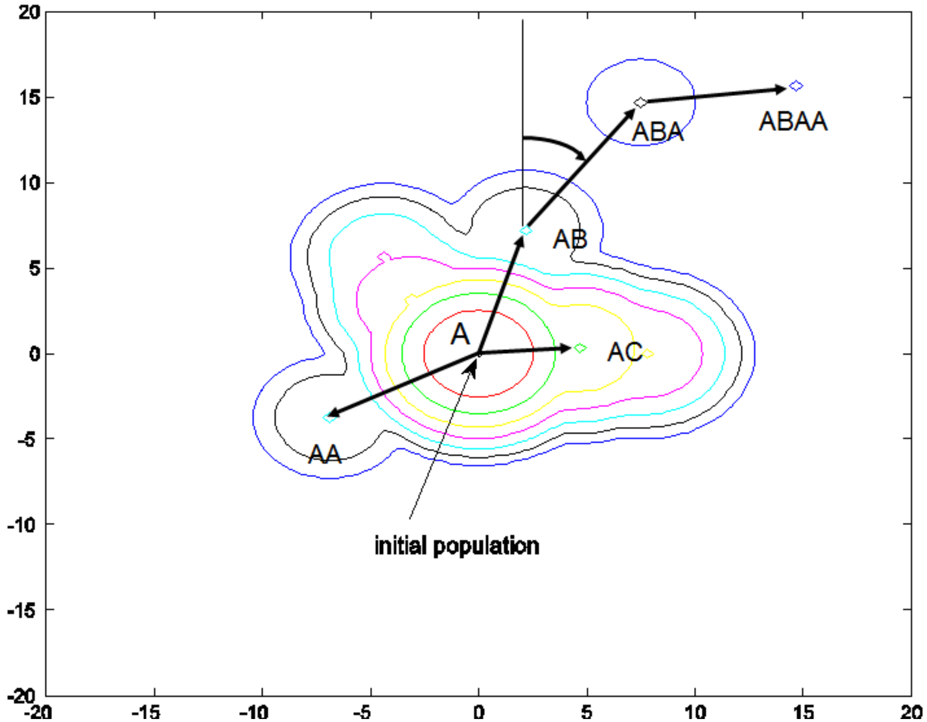


$$\frac{\partial c}{\partial t} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right)$$

$$p(x,y,t) = \frac{1}{4\pi Dt}\exp\left(-\frac{1}{2}\frac{x^2+y^2}{2Dt}\right)$$



- Third step: adding a long distance dispersal component
  - <u>Stepping-stone model</u> for LDD
    - Any established colony represents a possible source of new propagules
    - <u>Generation of *M* new colonies</u> at each time step
      - Where *M* is a Poisson random variable with fixed mean (frequency of LDD events, [$year^{-1}$])
    - <u>Position of the new colonies</u>
      - Generation of a random angle of dispersal from a uniform distribution [0, 2π]
      - Generation of a random distance of dispersal drawn from a Gamma distribution



4. Concluding remarks

- Biodemographic functions are effective tools for data selection and synthesis
  - Possibility to summarize huge amount of data with simple functions based on few parameters
  - Possibility to extract and generate knowledge at the *p*-state level from this method of data organization
  - Data representation is not static, data are organized in a functional way
    - This way to organize produce highly informative “objects”
    - These “object” can be easily manipulated (processed) to build up more complex analysis mainly via modelling

- Some important functional properties of the approach to data organization based on BDF
  - The biological realism and the way in which BDF can link *i*-state properties to *p*-state processes
  - The possibility to represent adaptive capacity of individuals and account for plasticity of population responses to environmental (geographic) variation
  - The possibility to account for different sources of variability and uncertainties and explore their implications for population dynamics
  - The possibility to be successfully used in many modelling approaches: from correlative models (niche models) to physiologically-based demographic models

- Indication for a fruitful use of biodemographic functions as a way to guide data selection and organization in pest risk analysis
  - Pest characterization
  - Support for entry, establishment and spread
  - Support for the assessment of control strategies
    - E.g., comparative evaluation of control options (as seen for the stressors) at different levels of resolution
  - Support for the analysis of the impact
    - E.g., Environmental Risk Assessment based on scenario analysis