Ecotoxicology & ERA

Stochastic processes in populations and effects of toxicants

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Problems for the discussion

- What does it mean "**ecological risk**"?
- What do standard ecotoxicological assays tell about ecological risk?
- The meaning of **stochastic demographic processes**
  - natural population processes are *per se* dangerous
- Life in nature - nature is changeable and dynamic!
- *Can random phenomena be included in the ecological risk assessment?*

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Ecological risk: What does it mean?

- Ecological risk can only be defined in terms of ecology, not toxicology!
- Ecology is the study of populations, communities, and ecosystems.

→ Ecological risk can therefore be defined as:
- for populations: probability of extinction (or time to extinction)
- for communities: decline in species richness, changes in diversity, etc.
- for ecosystems: changes in functioning (e.g. decrease in productivity, decrease in decomposition rate).

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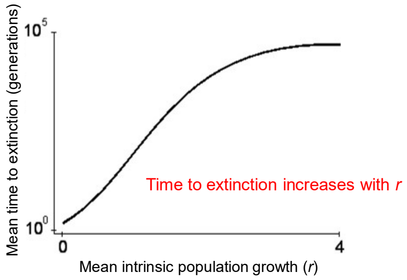
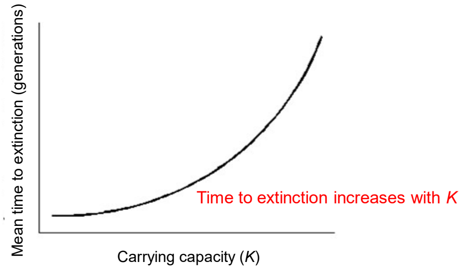
The probability of a population extinction in a random environment depends on its internal growth rate



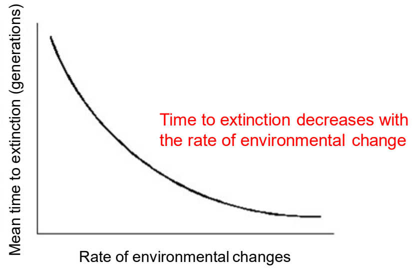
Initial population size equal to the carrying capacity of the habitat K
(after Bürger & Lynch 1997)

The probability of a population extinction in a random environment depends on the carrying capacity of the habitat



Initial population size equal to the carrying capacity of the habitat K
(after Bürger & Lynch 1997)

The probability of population extinction in a random environment depends on the rate of changes in the environment



Initial population size equal to the carrying capacity of the habitat K
(after Bürger & Lynch 1997)

Stochastic processes

- **Demographic**
  - random fluctuations in the number of survivors and newborns (p_x and f_x remain unchanged)
  - important in populations smaller than about 100 individuals
- **Environmental**
  - random fluctuations in fertility and survival due to variability of environmental conditions (variable p_x and f_x values)
  - impact on population dynamics independent of population size
- **Genetic**
  - random fluctuations in fertility and survival due to genetic heterogeneity of the population (variable p_x and f_x values)
  - impact on population dynamics independent of population size

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Where does the demographic stochasticity come from?

- The population size is finite → very rarely are the long-term fertility averages and survival probabilities actually realized:
  - If f_i = 2.15 and N = 50, then the actual number of newborns could be 107 or 108 but NEVER 107.5
  - If p_i = 0.13 and N = 50, then the actual number of survivors may be 6 or 7, but NEVER 6.5

→ The smaller the population, the more important random demographic phenomena

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How to study stochastic processes?

- **Monte Carlo** simulations
  - invented in the 1930s, later used, e.g., in the Manhattan Project
  - among the creators: Stanisław Ulam
  - a class of calculation algorithm methods based on the use of random or pseudo-random numbers

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Studying stochastic processes in populations

- What kind of stochasticity is to be simulated?
  - **demographic**: number of newborns from the Poisson distribution; number of survivors of the binomial distribution
  - **environmental**: f_x from log-normal distribution; p_x from the beta distribution.
  - genetic stochasticity is indistinguishable from environmental

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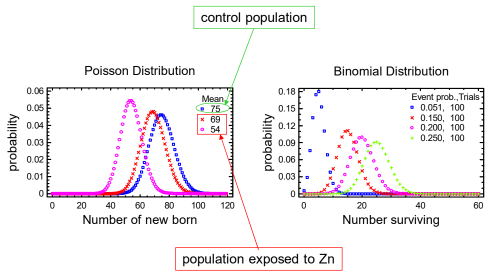
The effect of demographic stochasticity in the snail population



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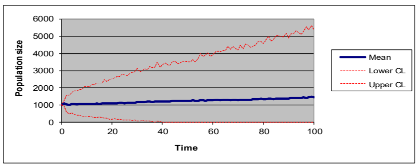
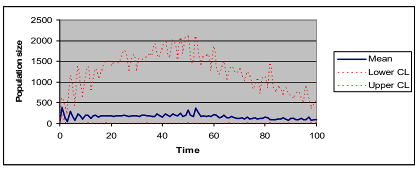
→ Even in an unpolluted environment, populations can get extinct due to demographic stochasticity

$N_0 = 1000$
$p_{ext} = 0.13$
$(t = 100)$



$N_0 = 30$
$p_{ext} = 0.74$
$(t = 100)$



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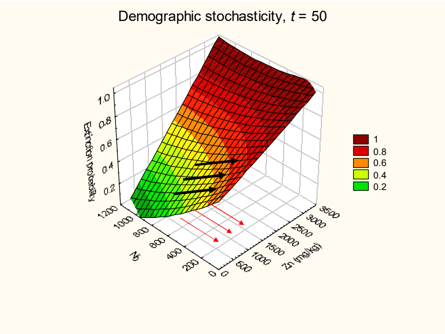
The interaction between toxicity and demographic stochasticity



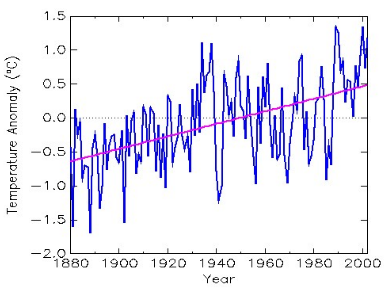
Conclusions

- The importance of demographic stochasticity depends on the population size;
- Toxicants affect the population size:

→ ***the effects of toxic substances under field conditions are not independent, but depend on the interaction between the direct toxic effects and stochastic phenomena.***

- Interaction is probably most important at moderate contamination levels and in low to medium size populations (high contamination will outweigh random effects, and in large populations demographic randomness is of little importance).

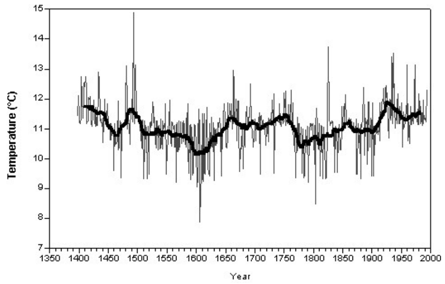
Living in a natural environment: The environment is changeable and unpredictable



Latitude 50º – 70ºN, longitude -60º – 60º
(Global Historical Climatology Network)

The short-term temperature variation is even greater

Reconstructed summer temperatures in Finland, 1398-1993



http://www.greeningearthsociety.org

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The influence of temperature on the fertility of grasshoppers

Species	Temeperature (°C)	Cocoons per female	Eggs per cocoon	Total reproductive output
Chorthippus brunneus	25	1.6	8.3	13.28
	30	8.2	9.7	79.54
	35	22.6	10.1	228.26
Stenobothrus lienatus	30	0.5	-	0
	35	2.2	3.2	7.04

S. J. Willot i M. Hassall. 1998. Life-history responses of British grasshoppers (Othoptera: Acrididae) to temperature change. Functional Ecology, 12: 231-241.

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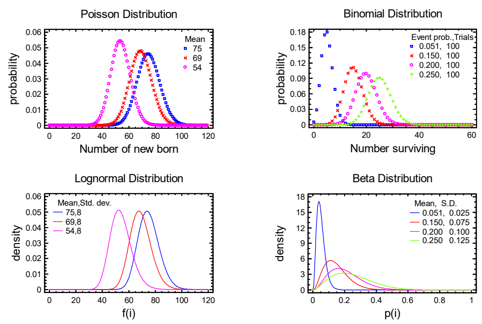
Let's add demographic and environmental stochasticity



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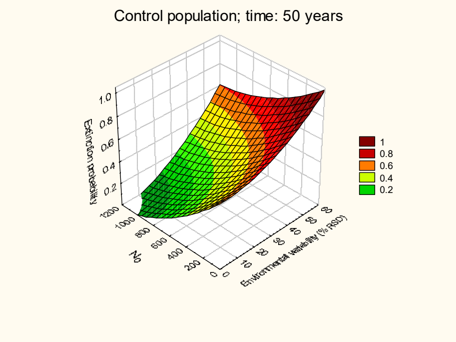
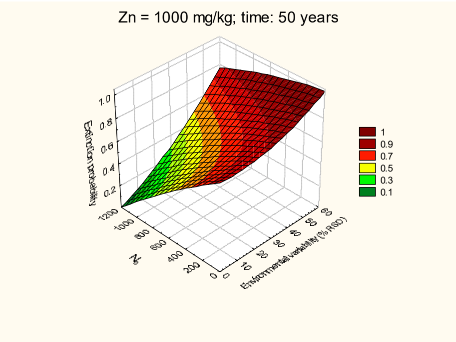
Closer to reality: demographic + environmental stochasticity



Ecological risk assessment in a changing world



Conclusions

- Stochastic processes can significantly change the ecological risk caused by contamination;
- Although in non-polluted environments, demographic stochasticity is important only in small populations, toxicants decrease the population size and, consequently, increase the importance of demographic stochasticity;
- Environmental stochasticity can also be important in large populations (e.g., at N_0 = 1000, p_{ext} increased from ca. 0.2 at RSD = 0 to 0.7 at RSD = 50%)

Conclusions for risk assessment

- The following data are necessary for a meaningful assessment of the extinction risk:
  - the life history of the organism;
  - population size;
  - variability of environmental conditions.
- However, facts contradict the high risk of extinction at moderate contamination levels: risk assessment models should take into account the density dependence.

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Application of MS-Excel spreadsheet and PopTools add-in for Monte Carlo analysis

http://www.cse.csiro.au/poptools/

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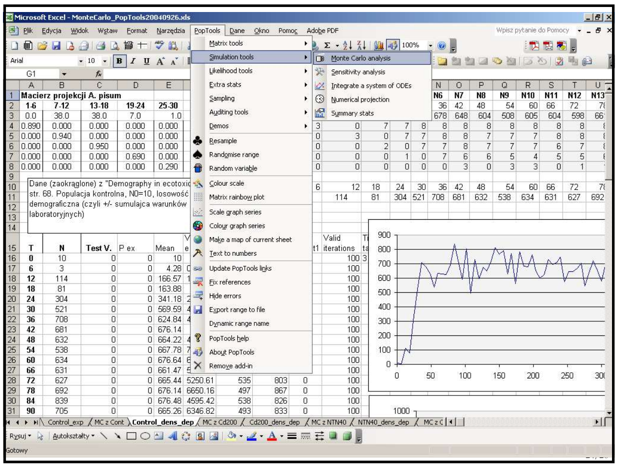
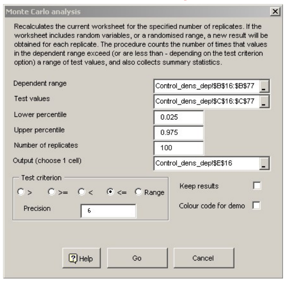


Data summary and calculations in PopTools

	A	B	C	D	E	F
1	**Macierz projekcji A. pisum**					
2	**1-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**
3	0.0	38.0	38.0	7.0	1.0	0.0
4	0.890	0.000	0.000	0.000	0.000	0.0
5	0.000	0.940	0.000	0.000	0.000	0.0
6	0.000	0.000	0.950	0.000	0.000	0.0
7	0.000	0.000	0.000	0.690	0.000	0.0
8	0.000	0.000	0.000	0.000	0.290	0.0
9						
10	Data from "Demography in ecotoxicology"					
11	handbook (page 68). Control population:					
12	N_0=10, demographic stochasticity (i.e.					
13	simulation of laboratory conditions).					
14						



$$n_{2,t+1} = \frac{p_1 n_{1,t}}{1 + cN_t}$$

N0	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
0	6	12	18	24	30	36	42	48	54	60
10	0	156	117	454	582	542	651	605	670	722
0	4	0	8	7	8	8	8	8	8	8
0	=dBinomialDev(H4,B5)			7	6	8	7	7	7	8
0	0	0	2	0	7	5	8	6	7	7
0	0	0	0	1	0	6	3	5	4	6
0	0	0	0	0	0	0	2	0	2	1
0	6	12	18	24	30	36	42	48	54	60
10	4	159	127	469	603	569	679	631	698	752

N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21
66	72	78	84	90	96	102	108	114	120	126
650	707	715	654	773	784	658	710	574	643	579
8	8	8	8	8	8	8	8	8	8	8
8	8	8	8	8	8	8	6	8	8	8
7	7	8	8	8	8	8	8	5	8	8
4	5	6	7	7	5	6	5	5	3	5
2	2	1	1	1	2	2	3	1	2	2
66	72	78	84	90	96	102	108	114	120	126
679	737	746	686	805	815	690	740	601	672	610

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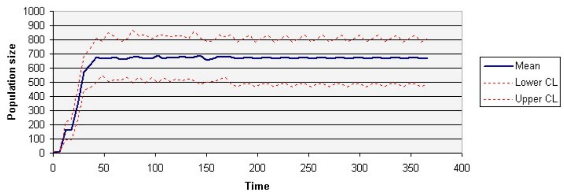
Simulation result



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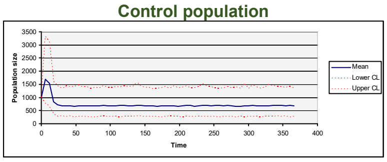
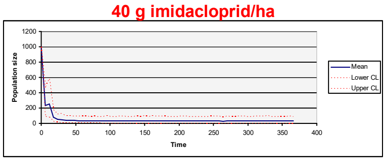
Influence of pesticide and demographic and environmental stochasticity on aphid population

Control population



40 g imidacloprid/ha



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A farewell message:

Living in an unpredictable world is dangerous!