Ecotoxicology & ERA

What exactly the ecotoxicological tests tell us?

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Ecotoxicological tests

(Leon & Van Gestel, 1994)

- review of 44 tests published in research papers on terrestrial ecotoxicology
  - 10 tests on microorganisms: 1 – 120 days
  - 6 tests on plants: 5 – 49 days
  - 25 tests on invertebrates: 2 – 63 days
  - 3 tests on vertebrates: 8 – 154 days

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Three reasons why we need short-term tests – they are:

1. **Fast** → almost immediate response → decisions can be taken quickly
2. **Simple** → can be routinely run by technical staff in any laboratory
3. **Cheap** → large number of chemicals can be tested on many species

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Ecotoxicological tests and organisms life time

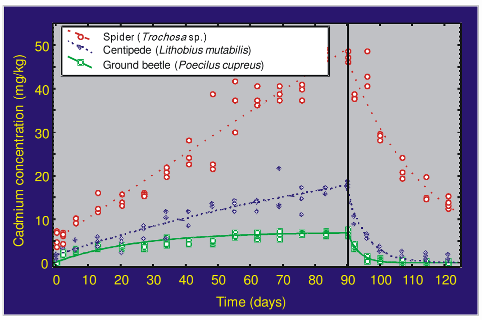
Organisms and test duration	Life time
• parasitic wasps: 2 - 18 days	3 - 4 weeks
• honeybee: 2 - 10 days	few weeks – few months
• earthworms: 2 - 8 weeks	few months – few years
• spiders: 2 - 14 days	ca. 1 year
• potworms: 4 - 9 weeks	ca. 10 weeks
• isopods: 8 weeks	1 - 2 years
• springtails: 4 - 9 weeks	few months
• carabids: 6 days	1 – 2 years
• rove beetles: 15 days	ca. 1 year

Four reasons why short-term tests are not necessarily adequate

1. They neglect the fact that certain chemicals accumulate in organisms
2. They neglect the possibility of an accumulation of toxic effects over time
3. They neglect the occurrence of effects other than increased mortality or decreased fertility (e.g., decreased growth rate or consumption, etc.)
4. They only take into account a small fragment of the organism's life history

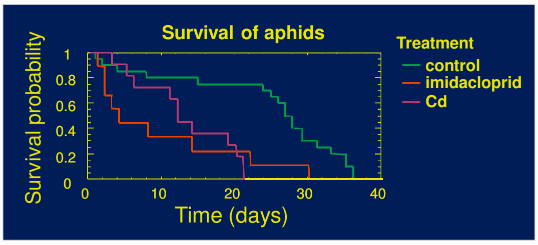
➔ **They do not allow inference about the effects on population dynamics**

Some chemicals accumulate in organisms and they do it differently in different species



(after Kramarz, 2000)

Toxic effects may cumulate over time



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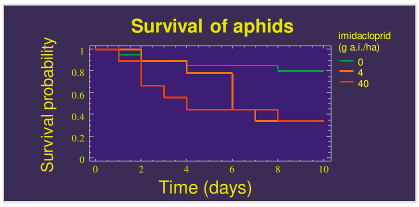
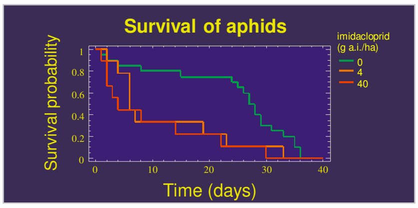
The results of the short-term and lifetime tests for pesticide toxicity in aphids are similar



10 days,
difference from control:

log-rank test p=0.016



Lifetime
difference from control:

log-rank test p=0.003

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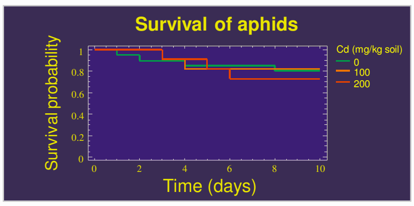
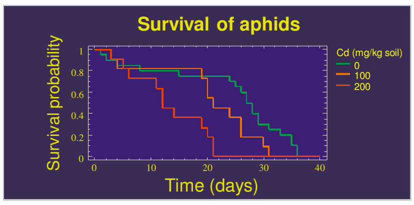
The results of the short and lifetime tests for cadmium toxicity in aphids are different



10 days
difference from control:

log-rank test p=0.89



Lifetime
difference from control:

log-rank test p=0.0002

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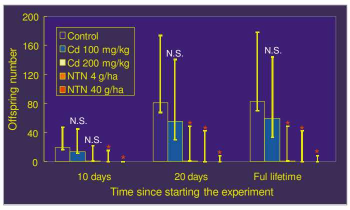
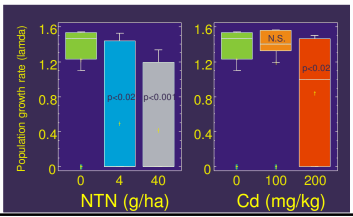
The results for aphids stabilize after about 20 days

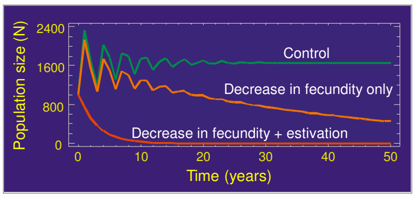


Influence of cadmium (Cd) and pesticide (dimethoate - NTN) on aphid reproduction: results after 10 and 20 days and the lifetime reproductive success



The effect of toxic substances on aphid fitness is similar to that measured for reproduction after 20 days of the experiment (approx. 50 - 60% of aphid lifespan)

Accounting for effects other than just an increase in mortality and a decrease in fertility can change the predictions dramatically



Predicted population dynamics of *Helix aspersa* snails in the environment where food is contaminated with 1000 mg Zn/kg dry weight. Two different scenarios: taking into account only the decline in fertility and taking into account the decline in fertility and the loss of one breeding season due to delayed development due to prolonged estivation

Conclusions

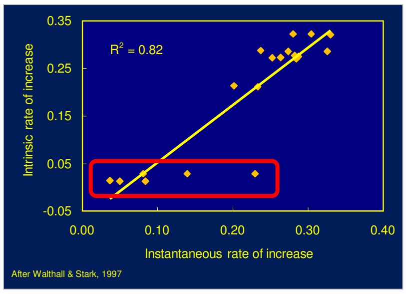
- Short-term (eco)toxicological tests do not account for effects of persistent, moderately toxic substances, but may overestimate the effects of highly toxic but degradable substances
- In the case of moderately toxic substances prone to accumulation in the body, long-term tests should be carried out

➔ Ecotoxicological tests should cover at least 1/2 - 2/3 of the organism's lifetime

Can the effects of toxic substances on the population be examined by means of short-term tests?

Instantaneous growth rate as a measure of population dynamics:

$$r_i = \frac{\ln \frac{N_t}{N_0}}{\Delta t}$$



Comparison of intrinsic and instantaneous growth rates in cohorts of pea aphids treated with pesticides

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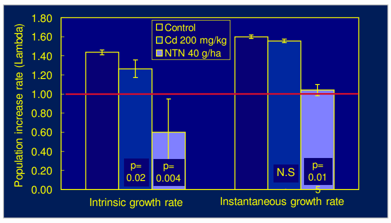
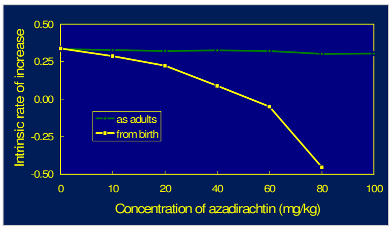


Comparison of the effects of cadmium and dimethoate on pea aphids (*Acyrthosiphon pisum*) expressed as intrinsic and instantaneous growth rates (Laskowski & Stone)



Comparison of the effect of azadirachtin on the intrinsic growth rate of pea aphids depending on the starting point of exposure (Stark & Wennergren, 1995)

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Conclusions

- Changes in the instantaneous population growth rate (r_i) under the influence of toxic substances are only an approximation of the effect on the intrinsic growth rate (r)
- The data indicate that at low r_i values, estimates of the effects of toxic substances on r may be underestimated
- BUT: even measuring the impact on r does not guarantee certainty as to the actual changes in the population dynamics ➔ **the age structure of the studied population is important**

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Accounting for the age structure requires the use of life tables and Leslie projection matrices: a "cookbook"

Matrix projections in relation to a stable "control" population → possibility to estimate the time to extinction of the population:

1. construct a Leslie matrix for the natural population;
2. adjust P values to get a stable population;
3. construct a new matrix with *P* and *F* values taking into account the effect of the toxic substance;
4. make a projection to estimate the time to extinction.

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Let us recall the life tables...

Age interval	Age class x	Probability of survival until the beginning of class x l_x	Probability of survival until the middle of class x L_x	Survival probability between age classes x & x+1 P_x	Number of offspring born by a female in class x F_x
0-1	0	1.00	0.90	0.72	0
1-2	1	0.80	0.65	0.54	2
2-3	2	0.50	0.35	0.29	4
3-4	3	0.20	0.10	0.00	4
4-5	4	0.00	0.00	-	-

A life table for females of a hypothetical organism living for up to 4 years, whose females in consecutive age classes give birth to 0, 2, 4 i 4 progeny females. The l_x *and* F_x values are observed in the population, L_x values are calculated from l_x as: $L_x = (l_x + l_{x+1})/2$, P_x values are calculated from L_x as: $P_x = L_{x+1}/L_x$

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... Leslie matrices ...

$$\begin{bmatrix} 0 & 2 & 4 & 4 \\ 0.72 & 0 & 0 & 0 \\ 0 & 0.54 & 0 & 0 \\ 0 & 0 & 0.29 & 0 \end{bmatrix}$$

$$\begin{bmatrix} F_0 & F_1 & F_2 & \dots & F_{n-1} & F_n \\ P_0 & 0 & 0 & \dots & 0 & 0 \\ 0 & P_1 & 0 & \dots & 0 & 0 \\ 0 & 0 & P_{n-2} & \dots & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & 0 & \dots & P_{n-1} & 0 \end{bmatrix}$$

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... and the projection of population dynamics

$$\begin{bmatrix} 0 & 2 & 4 & 4 \\ 0.72 & 0 & 0 & 0 \\ 0 & 0.54 & 0 & 0 \\ 0 & 0 & 0.29 & 0 \end{bmatrix} \times \begin{bmatrix} 200 \\ 150 \\ 100 \\ 50 \end{bmatrix} = \begin{bmatrix} 900 \\ 144 \\ 81 \\ 29 \end{bmatrix}$$

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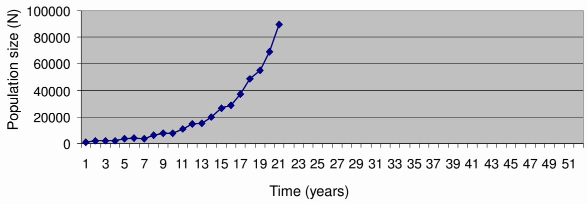
Helix aspersa – approximate *F* & *P* values for natural populations

F(i)	0	0	75	75	75	75
P(i)	0.1	0.2	0.25	0.25	0.15	0

➔ $\lambda = 1.23$



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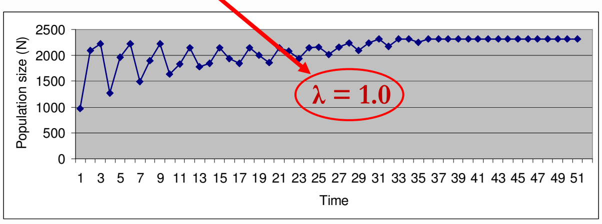
Helix aspersa – „populacja kontrolna": deterministyczny model dynamiki

F(i)	0	0	75	75	75	75
P(i)	**0.052**	0.2	0.25	0.25	0.15	0



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How do you convert laboratory test data to effects in the "real" population?

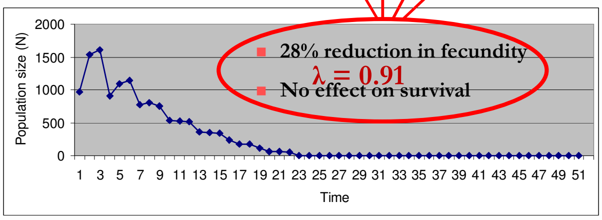
$$\lambda^{(T)} = \lambda^{(1)} \delta^{(T)}$$

$$\delta_i^{(F)} = \frac{F_i^{(E)}}{F_i^{(C)}} \qquad \delta_i^{(P)} = \frac{P_i^{(E)}}{P_i^{(C)}}$$

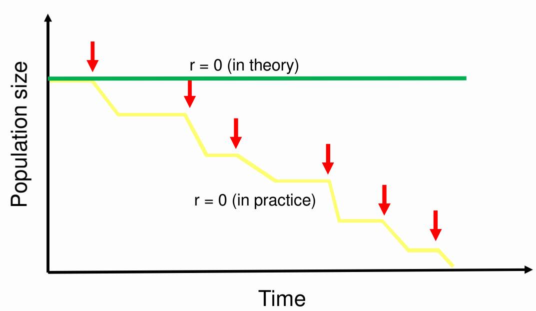
$$F_i^{(T)} = F_i^{(1)} \delta_i^{(F)} \qquad P_i^{(T)} = P_i^{(1)} \delta_i^{(P)}$$

Helix aspersa – 3000 mg Zn kg^{-1}: deterministic population dynamics model

F(i)	0	0	54	54	54	54
P(i)	0.052	0.2	0.25	0.25	0.15	0



Problem: unrealistic assumption that $r = 0$



How is it actually?

- Individuals of a species are usually organized into **metapopulations**, consisting of the source and sink populations
- Source populations – **overproduction of offspring → *r* > 0**
- Population size is regulated, among others, by **density-dependent factors** → the ability to compensate for an increase in mortality and a decrease in fertility

Models taking into account the density dependence

Ricker model – the lack of food or other resources results in "overcompensation" of density dependence – the equivalent of scramble competition:

$$n_j(t+1) = a_{ij} n_i(t) e^{-cn_i(t)}$$

Beverton-Holt model – the resource depletion results in compensation – the equivalent of contest competition):

$$n_j(t+1) = \frac{a_{ij} n_i(t)}{1 + cn_i(t)}$$

Let's introduce the density dependence to the matrix model

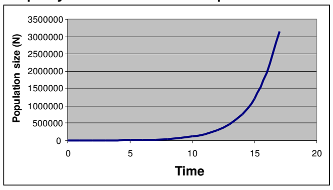
Matrix projection for the exponential model

$$\begin{bmatrix} 0 & 2 & 4 & 4 \\ 0.72 & 0 & 0 & 0 \\ 0 & 0.54 & 0 & 0 \\ 0 & 0 & 0.29 & 0 \end{bmatrix} \times \begin{bmatrix} 200 \\ 150 \\ 100 \\ 50 \end{bmatrix} = \begin{bmatrix} 900 \\ 144 \\ 81 \\ 29 \end{bmatrix}$$

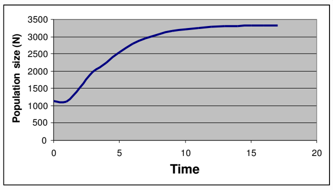
Matrix projection for a density-regulated population according to the Beverton-Holt model (c = 0.001)

$$\begin{bmatrix} 0 & 2 & 4 & 4 \\ 0.72 & 0 & 0 & 0 \\ 0 & 0.54 & 0 & 0 \\ 0 & 0 & 0.29 & 0 \end{bmatrix} \times \begin{bmatrix} 200 \\ 150 \\ 100 \\ 50 \end{bmatrix} = \begin{bmatrix} 900 \\ \dfrac{0.72 \times 200}{1 + 0.001 \times 200} \\ 81 \\ 29 \end{bmatrix} = \begin{bmatrix} 900 \\ 48 \\ 81 \\ 29 \end{bmatrix}$$

Matrix projection for the exponential model



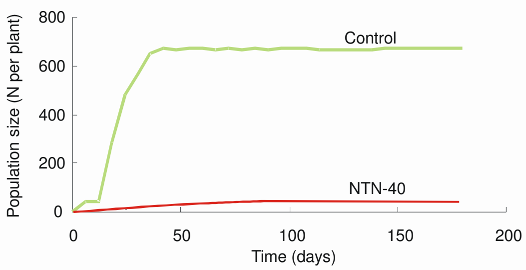
Matrix projection for the Beverton-Holt model (c = 0.001)



Example: pesticide-treated aphid cohorts

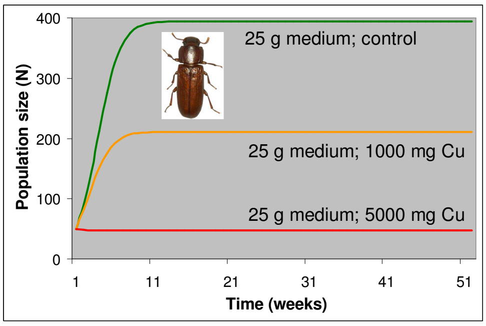
Age (days)	Age class *i*	l_i	q_i	L_i	e_i	f_i	p_i
		Control					
1-6	1	1.00	0.15	0.93	23.38	**0.00**	**0.89**
7-12	2	0.85	0.07	0.82	20.85	**38.25**	**0.94**
13-18	3	0.79	0.05	0.77	16.26	**37.79**	**0.95**
19-24	4	0.75	0.06	0.73	11.00	**6.94**	**0.69**
25-30	5	0.71	0.59	0.50	5.47	**0.08**	**0.29**
31-36	6	0.29	1.00	0.15	3.00	**0.00**	**0.00**
		40 mg imidacloprid kg^{-1}					
1-6	1	1.00	0.58	0.71	9.25	**0.00**	**0.50**
7-12	2	0.42	0.30	0.35	12.00	**3.13**	**0.71**
13-18	3	0.29	0.29	0.25	9.86	**10.38**	**0.67**
19-24	4	0.21	0.40	0.17	6.60	**1.50**	**0.38**
25-30	5	0.13	1.00	0.06	3.00	**0.00**	**0.00**
31-36	6	0.00		0.00		**0.00**	**0.00**

Projection of the aphid population dynamics during the growing season: Beverton-Holt model



Do we really see such effects of toxic substances?

Example: *Tribolium* beetles in a copper-contaminated medium



Conclusions

- Life tables and Leslie matrix projections are a powerful tool in the hands of an ecologist and ecotoxicologist as they:
  - allow to take into account various toxic effects in different life stages;
  - allow to use density-dependent models;
  - indicate that perhaps the most common effect of toxic substances on populations is the decrease in their equilibrium size (carrying capacity, K); **this, however, can increase the probability of extinction**