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Ecotoxicology
Populations & Communities

Ludek Blaha + ecotox colleagues

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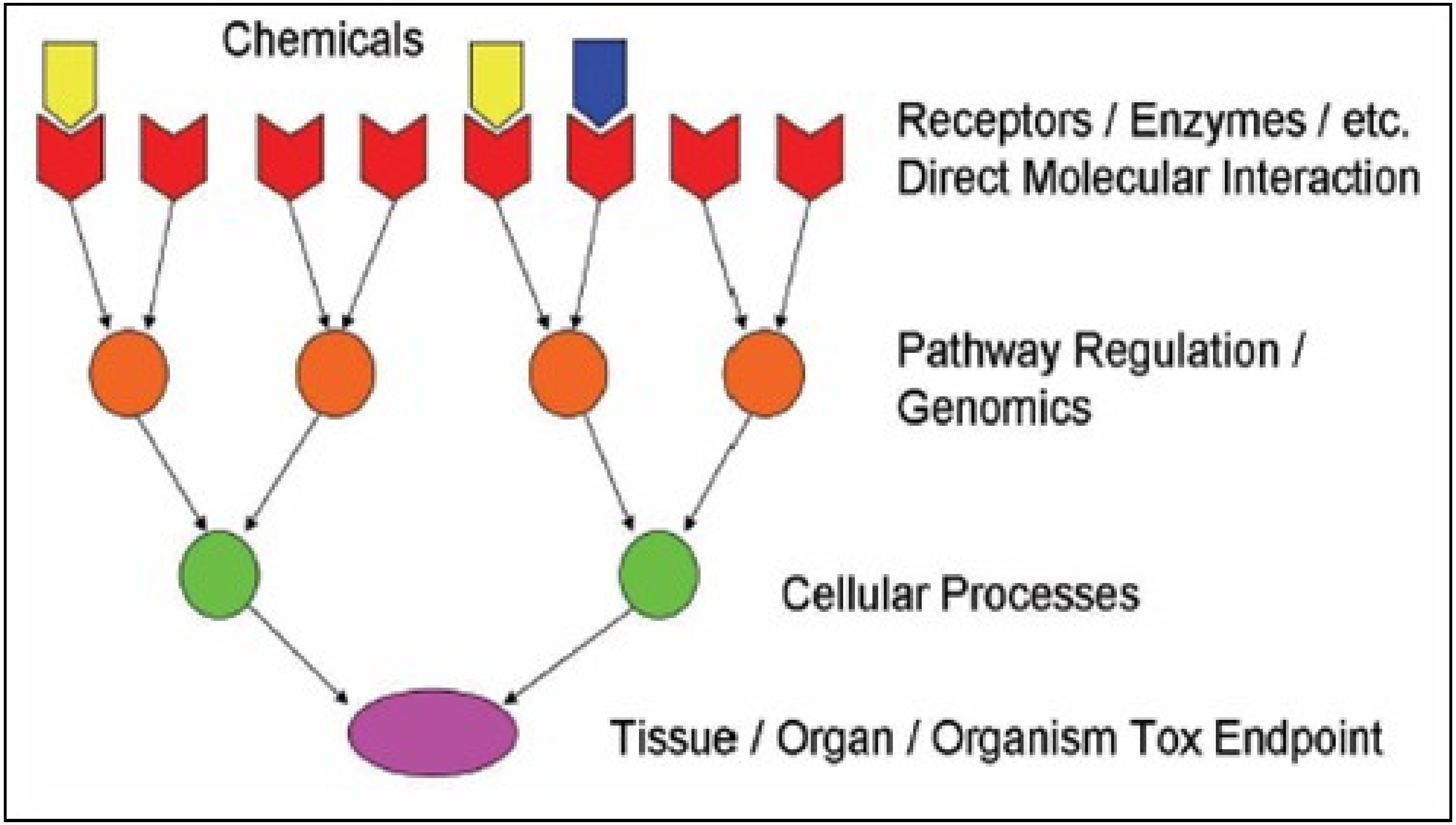
UNIVERSITAS MASARYKIANA BRUNENSIS

1) From molecules to individuals

MECHANISMS OF TOXICITY



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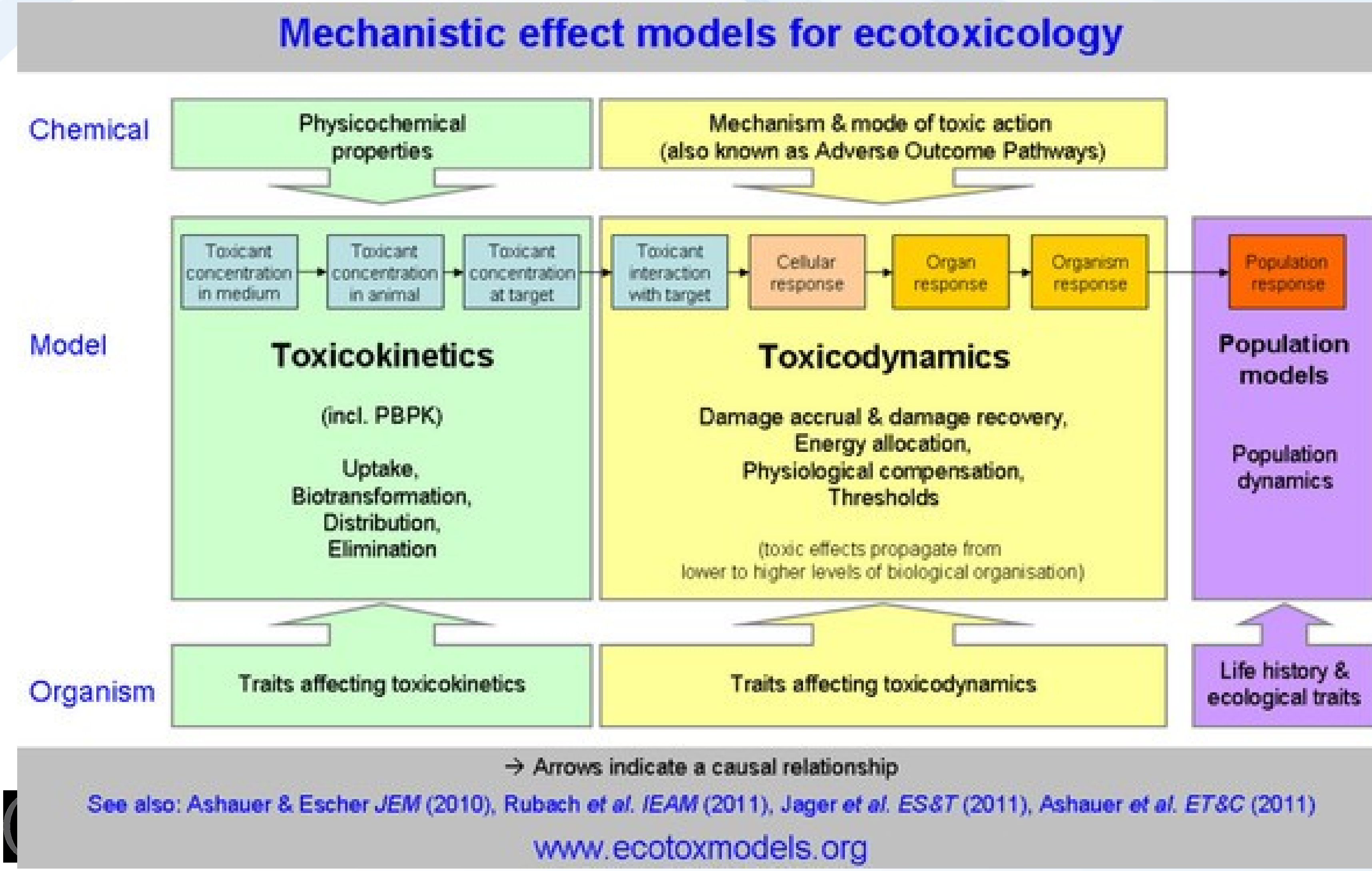
2) From molecules to individuals - AOPs

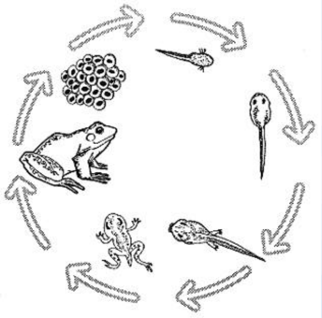
ADVERSE OUTCOME PATHWAYS



The ultimate objective of **ECO**TOXICOLOGY

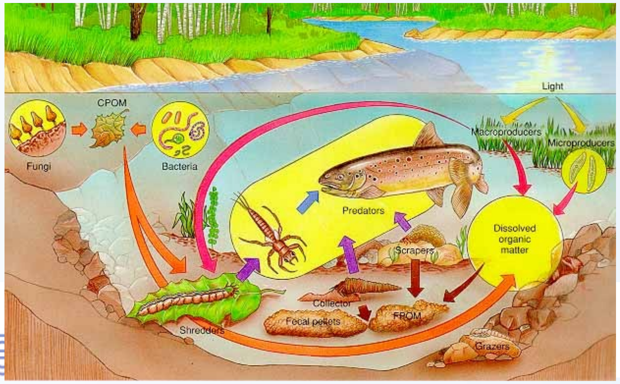
→ to understand and protect populations, communities, ecosystems

Populations



Communities
(interacting populations)

Ecosystems
(communities
interacting with
abiotic environment)



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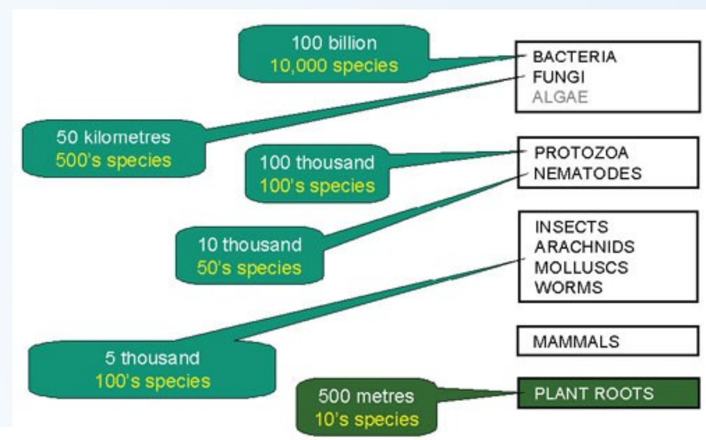
- Ecosystems are
  - – not only more complex than **we think**
  - – but more complex than **we can think** *

**** FRANK E. EGLER, THE NATURE OF VEGETATION: ITS MANAGEMENT ANDMISMANAGEMENT (1977).***



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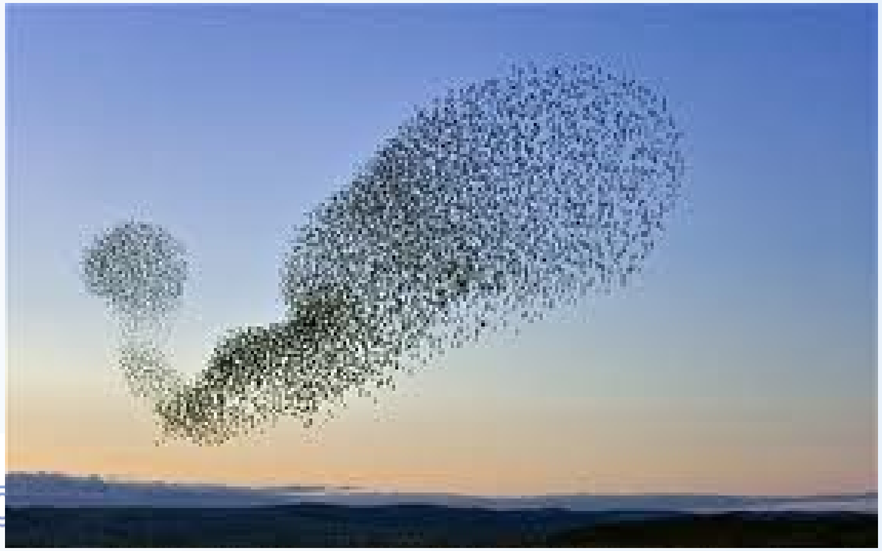
Effects at different levels

- **Population**

  … all the individuals that belong to the same taxonomic group or species, they can sexually reproduce, and they live within the same time and within the same geographical area

Toxicants have …

- effects on structure (→ we can measure structural parameters)
  - elderly vs. young, males vs. females
- effects on functioning (→ we can measure functional parameters) (~ maintenance & growth)
  - Natality, mortality, reproduction fitness



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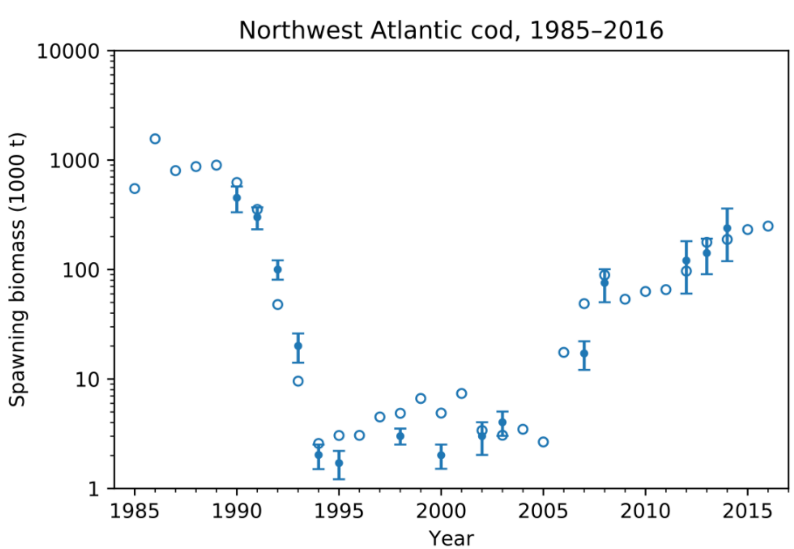
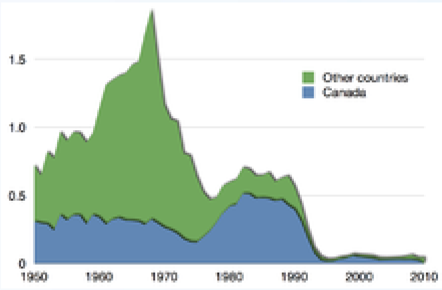
STRUCTURAL PARAMETERS of populations („demographic parameters“)

Primary parameters

- size (performance) – number of individuals (animals), surface coverage (plants), amount of biomass (algae)
- natality – increase of population size: numbers of organisms per unit of time
- mortality – decrease of size: numbers of organisms per unit of time

Temporal variability in population of fish *(due to overfishing)*





Capture of the Atlantic northwest cod stock in million tonnes, with Canadian capture in blue[8]

Air contamination effects on populations
(evolutionary adaptation, natural selection of genetic & phenotypic variants)

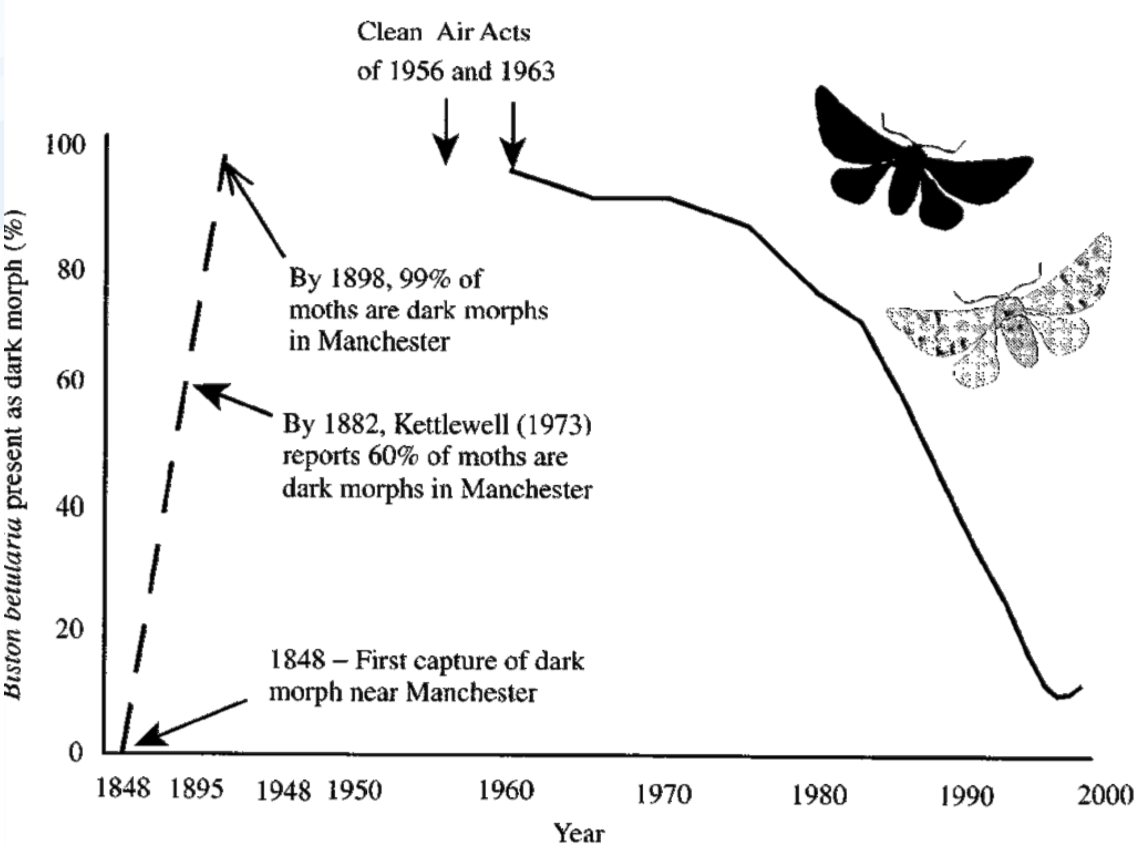
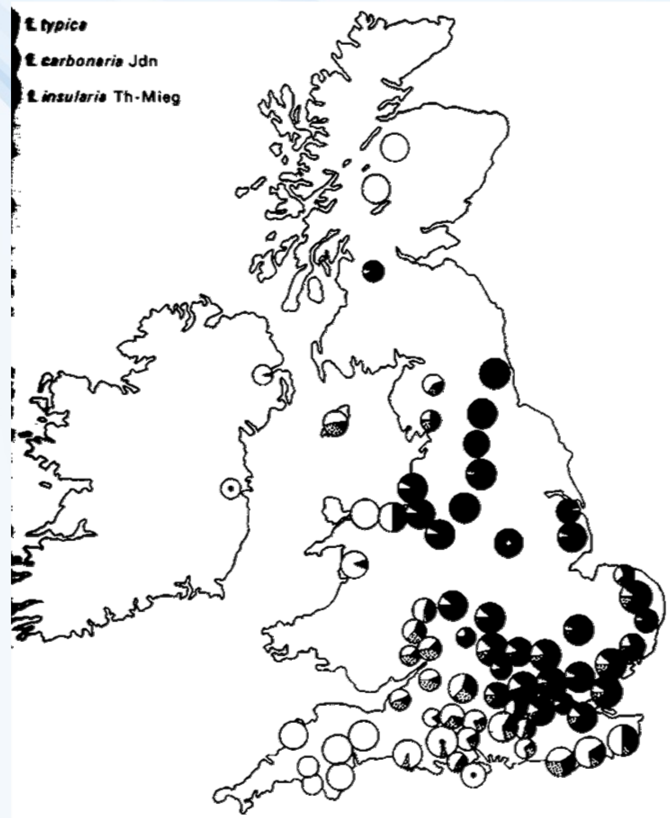


Fig. 2.2. Rise and fall in the proportion of *Biston betularia* of the melanistic morph caught near Liverpool, UK. Information for the decline in the dark morph come from Clarke and Grant (Clarke *et al.* 1994; Grant and Clarke 1999) who monitored a moth population outside of Liverpool from 1959 to the present



. 4.4 The relative frequencies of the normal and two melanic forms of the peppered moth, *Biston betularia*, in Britain. The results are based on re than 30 000 records collected from 1952 to 1970 at 83 sites. (From Kettlewell, 1973.)

Air contamination effects on populations
(evolutionary adaptation, natural selection of genetic & phenotypic variants)

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Published online: 21 October 2005; | doi:10.1038/news051017-16

Pollution makes for more girls

The stress of dirty air skews sex ratios in Sao Paulo.

Erika Check

Toxic fumes favour the fairer sex, a group of researchers in Brazil has found.

Babies born in highly polluted areas are more likely to be girls.

Jorge Hallak and his team at the University of Sao Paulo turned up the surprising result by studying babies born in their city. They divided the metropolis of 17 million people into areas of low, medium and high air pollution, using test results from air-quality monitoring stations. They then studied birth registries of children born from 2001 to 2003.

The team found that 48.3% of babies were female in the least polluted areas, but 49.3% were female in the dirtiest parts of town. After measuring the ratio of boys to girls born in all the areas, they calculated that 1,180 more babies would have been boys in the polluted areas if they had the same sex ratios as the cleaner areas. The team reported their findings on 17 October at the American

Effects of benzene and lead (Pb) on sex ratio in Drosophila

Generic effect:

HIGHER STRESS
→ more FEMALES

(F are more „resistant" also to assure survival of the population during the crisis)

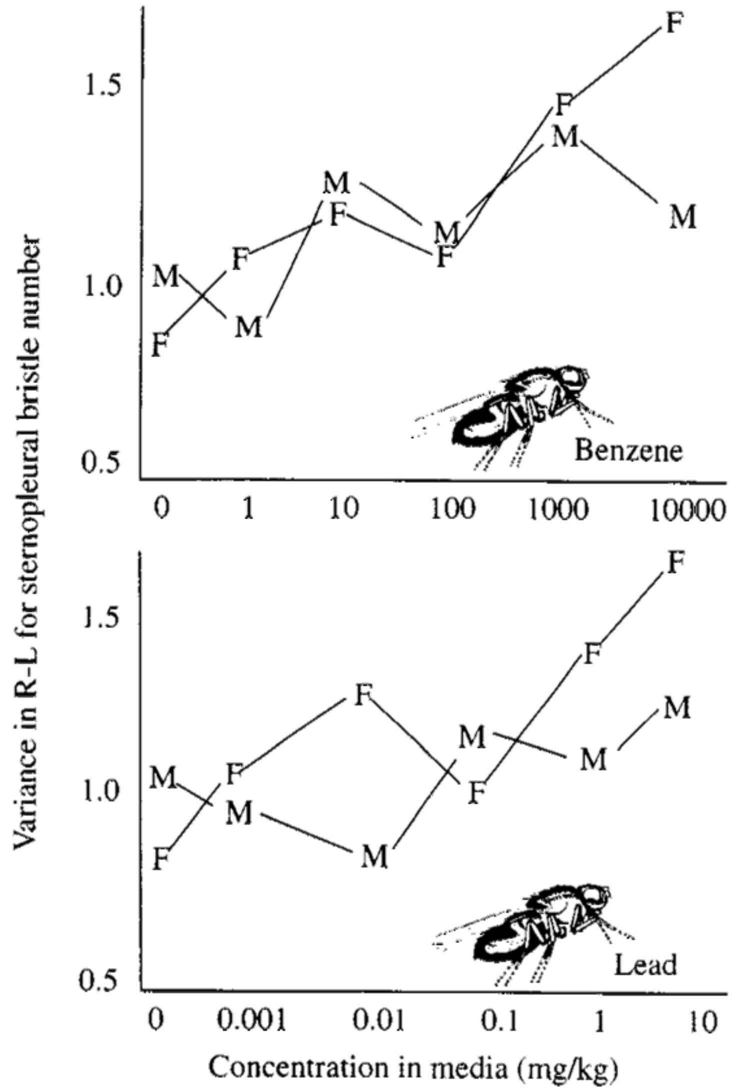
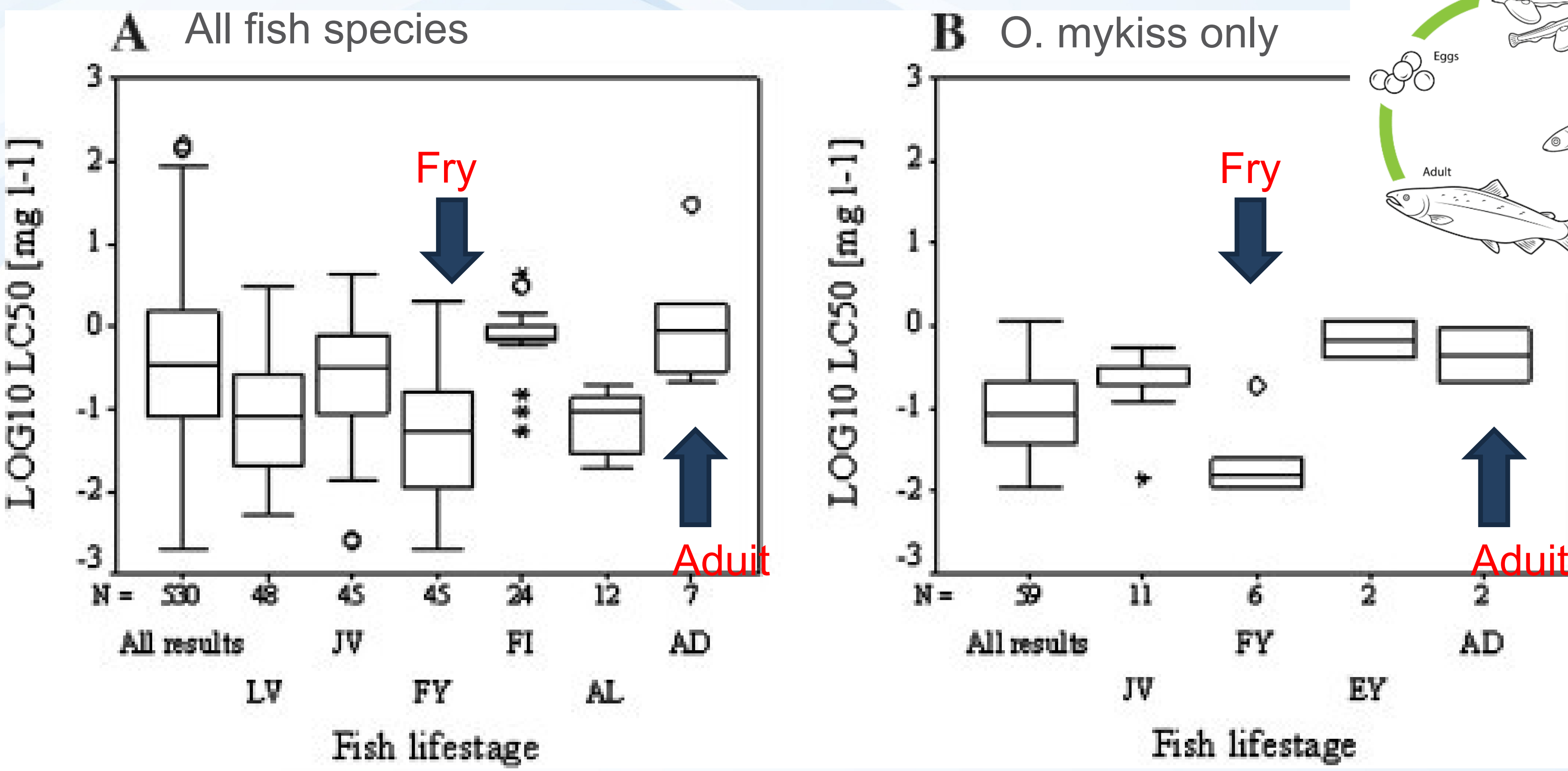


Fig. 6.7. The influence of lead and benzene concentrations in media on the developmental stability of *Drosophila melanogaster* (Data from Table 3 in Graham, Roe and West. 1993b). Sternopleural bristle number was counted on the right and left sides of each individual. M = male and F = female

Population = individuals at all life stages

Higher sensitivity of juveniles → less adults → <u>aging population</u>



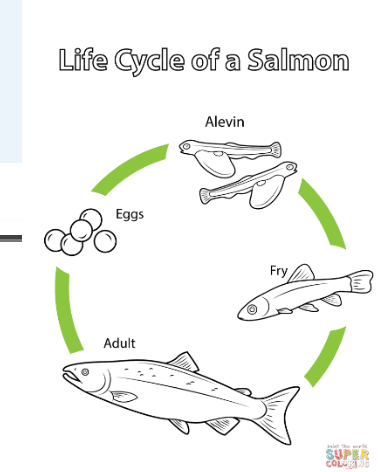


Fig. 2. Log LC50 variability for all available test results and for the five most frequently used fish life stages (larvae (LV), juvenile (JV), fry (FY), fingerling (FI), alevin (AL), eyed egg (EY) and adult (AD) life stage) for **CuSO4** - sulphuric acid, copper(2+) salt (1:1) (CAS 7758-98-7).

Test results for <u>all reported fish test species</u> (A) and for <u>*Oncorhynchus mykiss*</u> (B) were compared.

<u>http://www.sciencedirect.com/science/article/pii/S0273230009000956</u>

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Population = individuals at all life stages

*Higher sensitivity of **elderly individuals***

Caddisfly larvae

Higher mortality at elderly at the same concentration

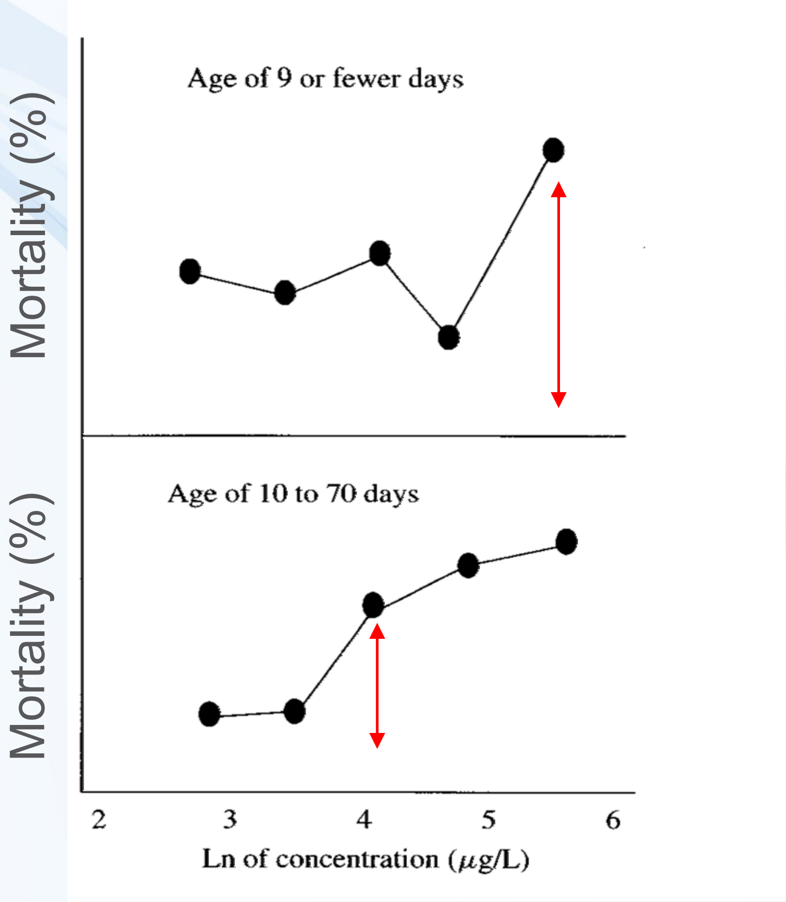

Fig. 6.1. Density-dependent, natural mortality can obscure the concentration–effect relationship for caddisfly larvae exposed to 4,5,6-trichloroguaiacol. There was no discernible relationship for larvae ≤9 days old, an age class with high levels of natural, density-dependent death. Note the high mortality in all treatments. (Probit values of 4 and 5 correspond to 16 and 50% mortality, respectively.) There was a clear relationship between mortality and toxicant concentration of older larvae (>9 to 70 days old). (Modified from Figure 4A&B of Petersen and Petersen 1988)

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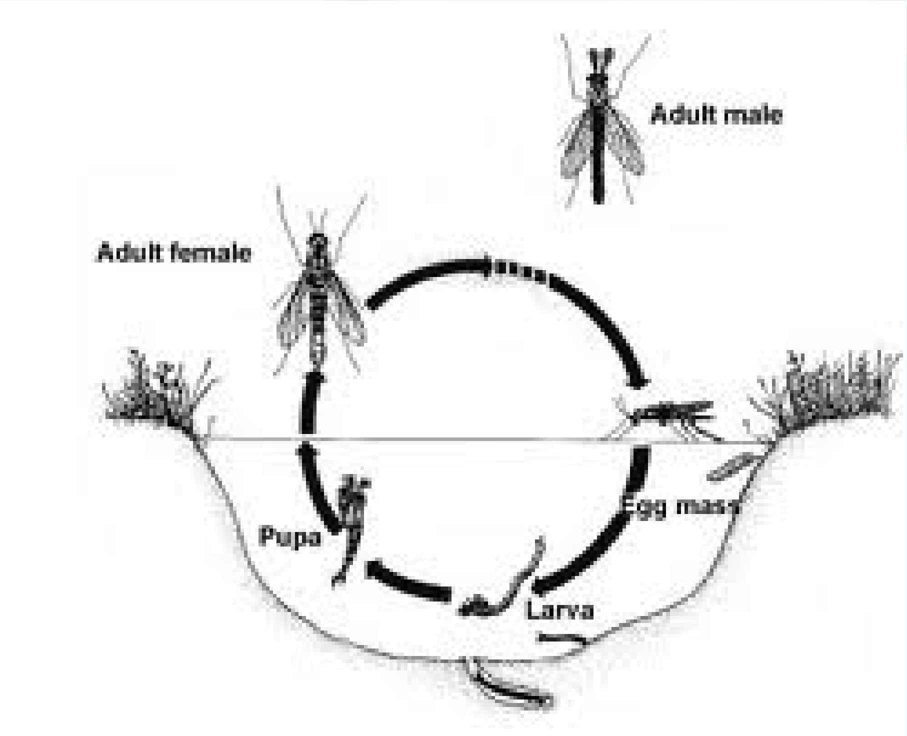
How to study effects on populations?

1) Reproduction toxicity assays

- *D. magna* – 21-day reproduction
- *Earthworms* – several weeks: reproduction tests
- *Folsomia candida (springtails)* – reproduction tests

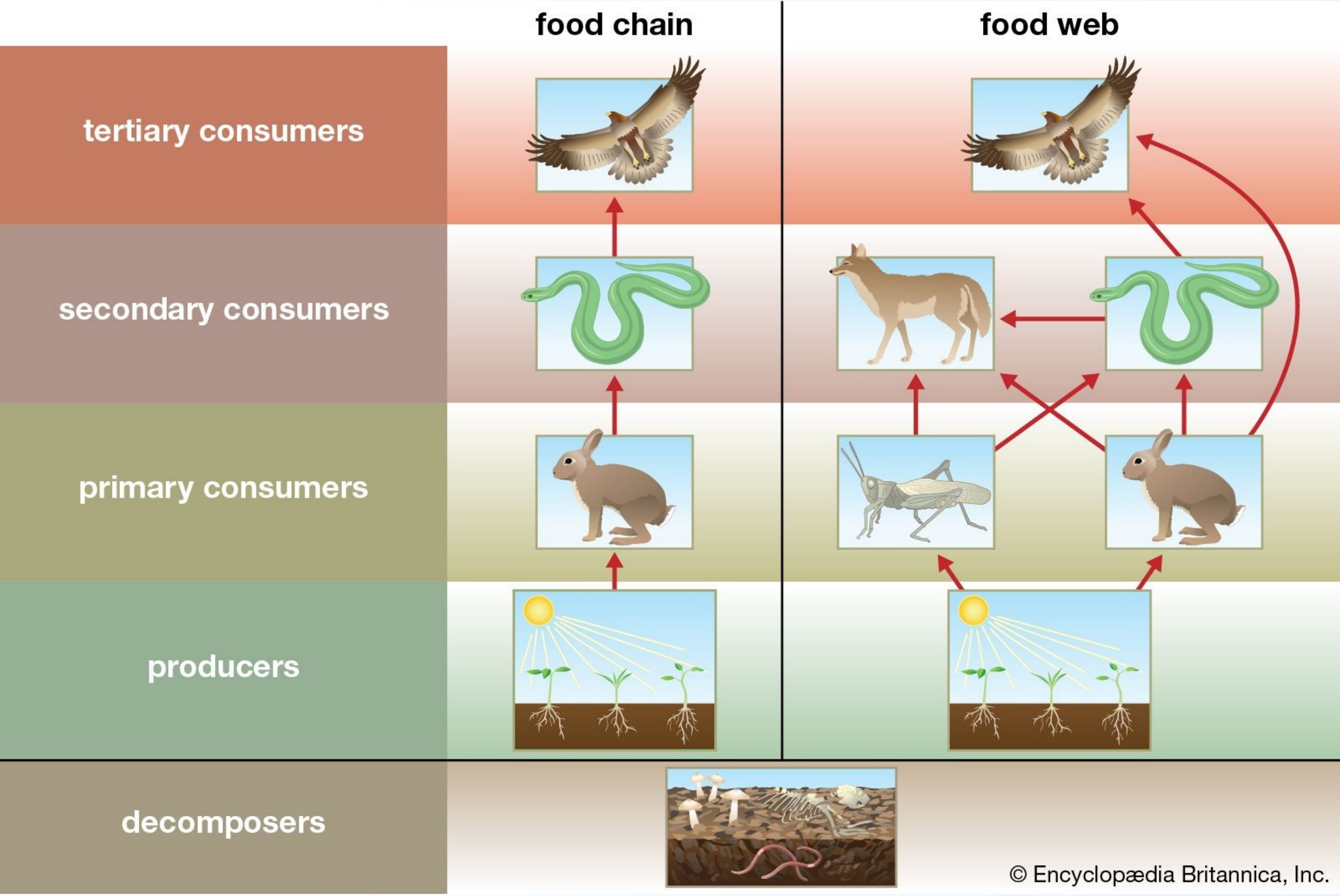
2) Whole life cycle toxicity test

- *E.g. Chironomus (nonbiting mi*
(OECD guideline 233)



3) **Modelling**

(např. Distribution of energy –the „Enth“ example)


food chain
food web
tertiary consumers
secondary consumers
primary consumers
producers
decomposers
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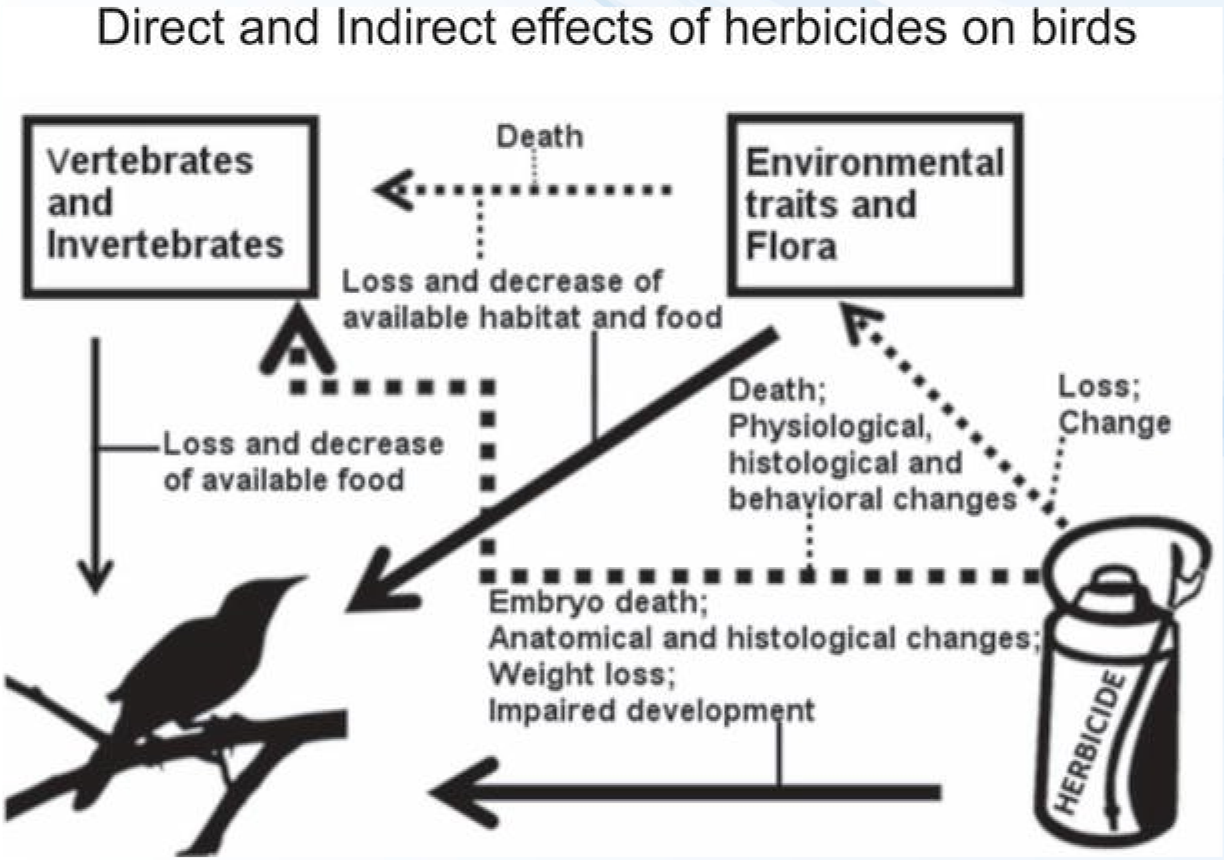
Ecotoxicity of glyphosate-based herbicide (GBH) to aquatic birds. Direct (continuous arrows) and indirect (dashed arrows) effects of GBH on birds.



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https://www.intechopen.com/books/biochemical-toxicology-heavy-metals-and-nanomaterials/ecotoxicology-of-glyphosate-based-herbicides-on-aquatic-environment

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Communities *… interacting populations*

Toxicants (stressors) may have

- … effects on structure of communities
  - Loss of species, loss of biodiversity
- … effects on functioning

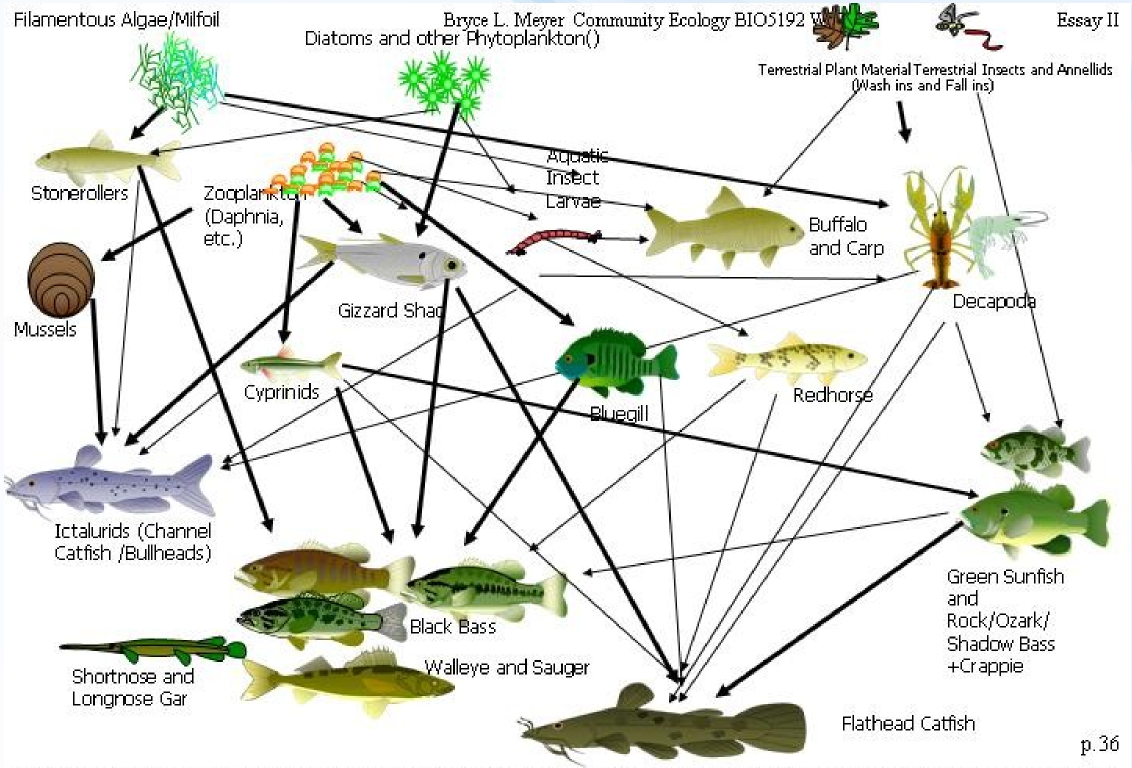

Figure #31: Simplified Food Web (Source Down) similar to warm water lower end of river before entry into Mississippi River System or impoundment. The Flathead acts as a super predator when present as large speciemens, and many predators such as walleyes and Gars compete for minnows and shad. Channel Catfish also appear and prey upon mussels and other invertebrates.

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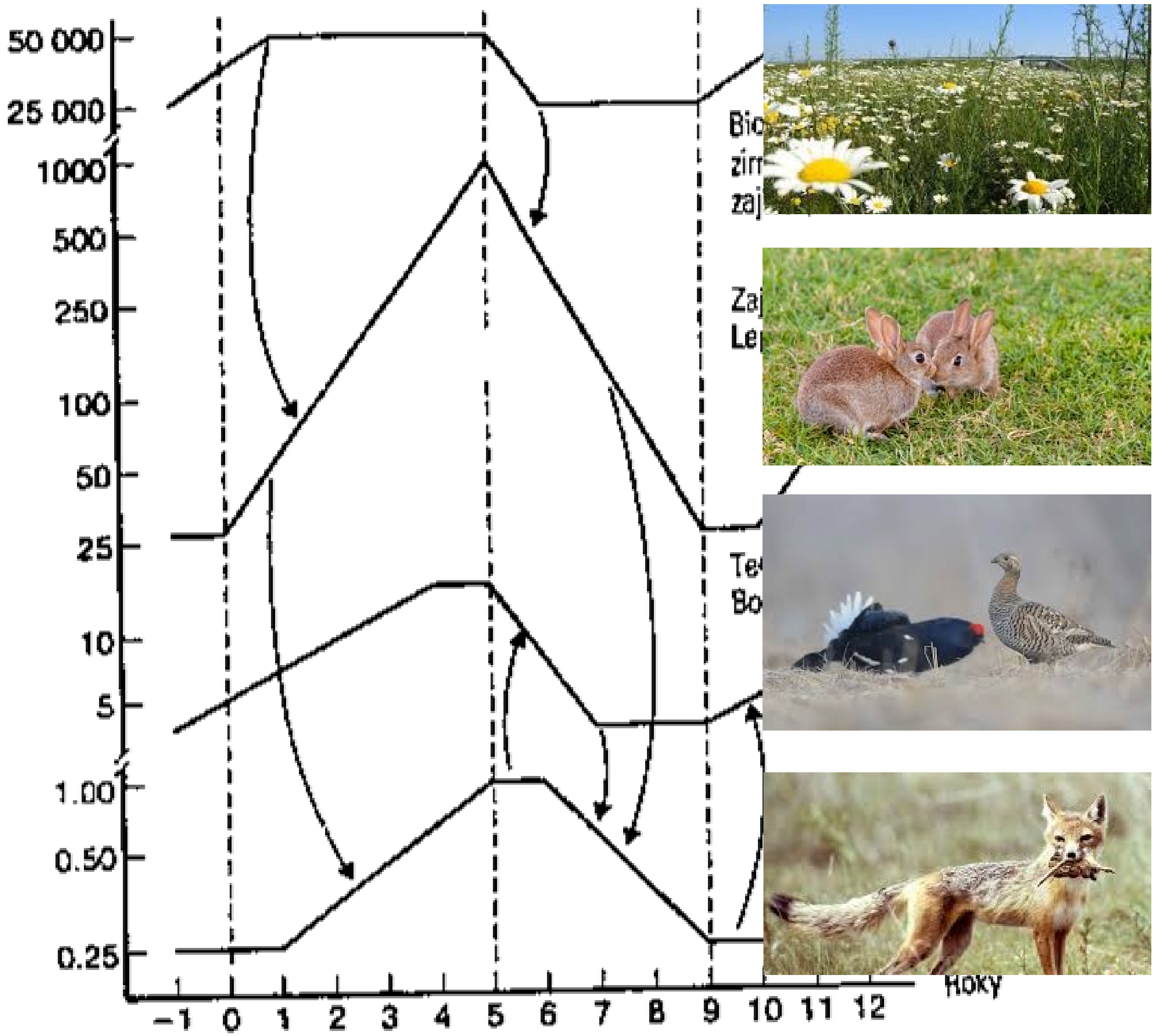
Natural variability in community (food web)

Changes in populations (biomass / numbers of animals) during 12 years



Community STRUCTURE characterization

-- example --

Floristic record

Occurrence of species (+ < 1 < 2 < 3 < 4 < 5)

in relationship to „stressor“ (conditions) MOIST vs DRY

➔ *B vs D are very different communities*

Table 3.4 The relative abundance of plant species in 12 samples in Polish forests[a]

		Fir forests				Pine-bilberry forests							
						Moist				Dry			
Group	Species	1	2	3	4	5	6	7	8	9	10	11	12
A	*Abies alba*	4	2	2	2	+	+	+	+	+	+		+
	Pinus sylvestris	+	+	+	+	4	3	2	4	4	1	2	3
	Picea excelsa	+	+	2	+		2	+	+	+	+		+
	Vaccinium myrtillus	+	2	+	+	5	4	2	+	1	+	+	2
	Vaccinium vitis-idaea	+		+	+	+	+		+	1	3	3	2
B	*Lycopodium selago*	+		+	+								
	Circaea alpina	+	+		+								
	Pyrola secunda		1	+	+								
	Pyrola minor		+	+	+	+							
C	*Lycopodium annotinum*	+		+	+	+		+	+	+			
	Ptilium crista-castrensis	2		4	+	2	+	3	3				
	Dicranum undulatum	4	+	2	2	+	+	+	+				+
	Entodon schreberi			+		5	1	5	2		+		
D	*Pyrola chlorantha*					+			+	+	+		
	Melampyrum vulgatum					1	+	1	2		+		
	Calluna vulgaris						+	+		2	+	+	
	Cladonia sylvatica					2	+			3	+	3	+
	Cladonia rangiferina					1			1	2	+	4	+
E	*Quercus sessilis*		+						+	+	+	+	+
	Betula verrucosa									+	+	+	+
	Thymus ovatus							+		+	2	+	+
	Lycopodium clavatum									+	+	+	1
Total number of species		35	37	38	37	20	17	24	25	39	41	32	34

From Whittaker (1975): original data from Frydman (1968).

[a] +, Rare; 1–5, increasing degrees of abundance. The species of groups B–E are diagnostic.

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Ecotoxicology example

Changes in community treated with three doses and control (L-low, M-medium, H-high, VH-vehicle/solvent)

Same exposures but different responses in two different set-ups Microcosm << Mesocosm (highlighted)

Organism	2 m² microcosm L[b]	M	H	VH	480 m² mesocosm L	M	H	VH
Zooplankton								
Rotifera	no effect	increase 50–95%	increase 50–95%	increase >95%	no effect	no effect	no effect	no effect
Copepoda	no effect	no effect	no effect	↓ decrease	decrease 50–95%	decrease 50–95%	decrease 50–95%	decrease >95%
Macroinvertebrates								
Oligochaeta	no effect	no effect	no effect	no effect	no effect	no effect	no effect	no effect
Ephemeroptera - Baetidae	decrease 50–95%	decrease 50–95%	decrease >95%	decrease >95%	↓ decrease	↓ decrease	↓ decrease	↓ decrease
Ephemeroptera - Caenidae	decrease <50%	decrease >95%	decrease >95%	↓ decrease	decrease >95%	decrease >95%	decrease >95%	decrease >95%
Odonata	no effect	no effect	no effect	decrease <50%	no effect	no effect	no effect	no effect
Diptera - Chaoboridae	decrease >95%	decrease >95%	decrease >95%	decrease >95%	decrease >95%	decrease >95%	decrease >95%	decrease >95%
Diptera - Chironominae	no effect	no effect	increase >95%	increase <50%	no effect	no effect	no effect	no effect
Diptera - Tanypodinae	no effect	no effect	decrease <50%	decrease 50–95%	decrease <50%	decrease 50–95%	decrease 50–95%	decrease >95%
Fish - survival[c]	no effect	no effect	no effect	no effect	no effect	no effect	no effect	no effect
Fish - growth[d]	no effect	decrease <50%	decrease 50–95%	decrease <50%	no effect	no effect	no effect	no effect
Fish - reproduction					no effect	no effect	no effect	no effect

▯ = no effect (quantitative or qualitative)
quantitative decrease = <50%, = 50–95%, = >95%
quantitative increase = <50%, = 50–95%, = >95;
qualitative data ⬇ = decrease, ⬆ = increase.

Treated with 10 drift (D) and 5 run-off (R) applications; each application as % of USA maximum label cotton rate:

	microcosm	mesocosm
Low	D 0.7% + R 4.2%	D 0.8% + R 5.1%
Mid	D 1.8% + R 4.2%	D 2.1% + R 5.1%
High	D 3.5% + R 4.2%	D 4.2% + R 5.1%
Very High	D 3.5% + R 21%	D 4.2% + R 25%

Survival of juveniles (microcosms) and adults (mesocosms) added prior to pyrethroid treatments.

Biomass of juveniles (microcosms) and adults/young-of-year juveniles (mesocosms)

How to simplify complexity of community characterization? Use index / indices

Diversity indices

- Shannon-Wiener ($H = -\sum Ni/N \ln (Ni/N)$)
  - Higher H → Higher diversity
- Shannon's index of eveness ($E = H / \ln S$)
  - Higher E → higher „eveness of community“

… and many others (Margalef's e.g. $D = (S-1) / \ln N$)

Ni – Number of individuals of one species
N – Total number of individuals in community
S – Number of species

Which of the following three communities has the highest Biodiversity? Which has the highest Eveness?

Example of H calculation for locality A:

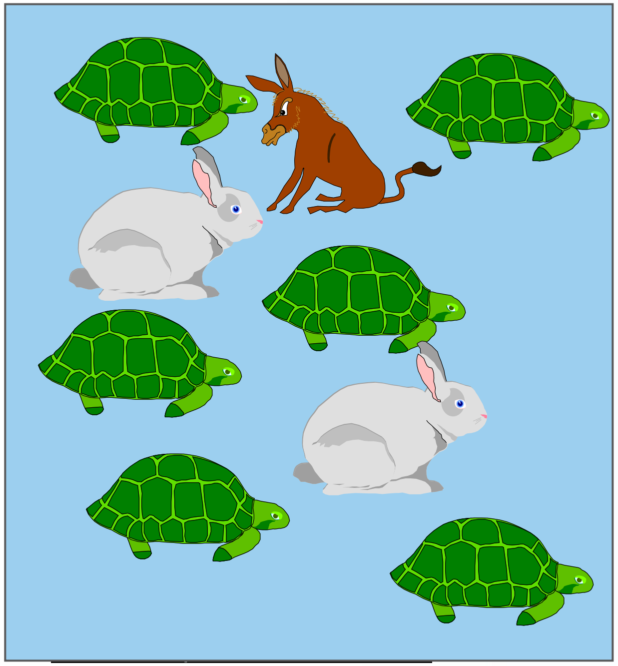
H' = **-** (6/9 . ln (6/9) turtles
+ 1/9 . ln (1/9) donkeys
+ 2/9 . ln (2/9) rabbits   = ……

E = …. ?

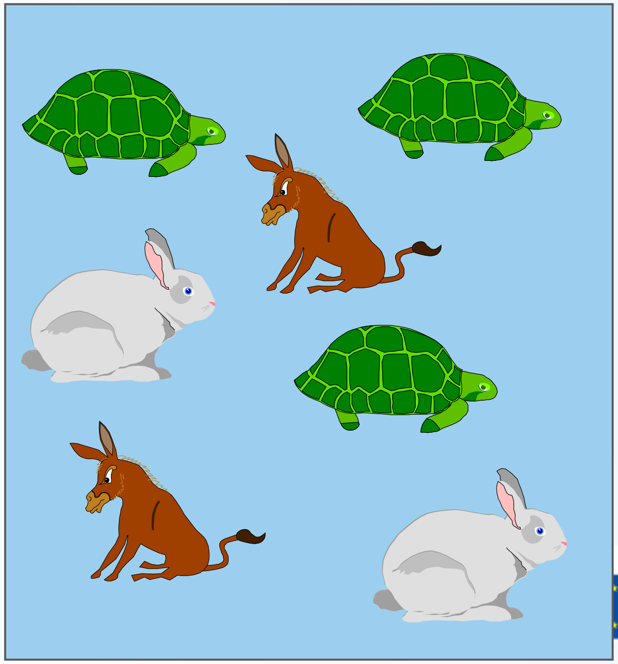
Homework task(!)
(see ROPOT in IS MUNI)

Identify community with the highest diversity & highest eveness

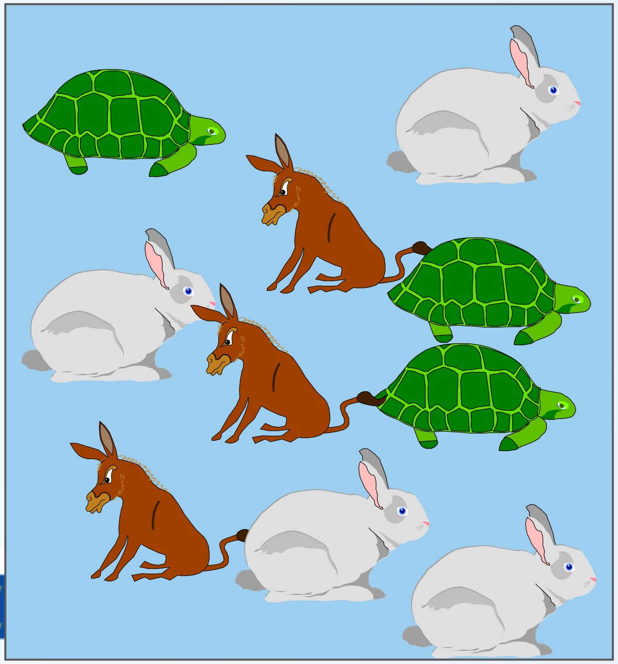
A



B



C



How to compare communities?

c – number of shared (common) species

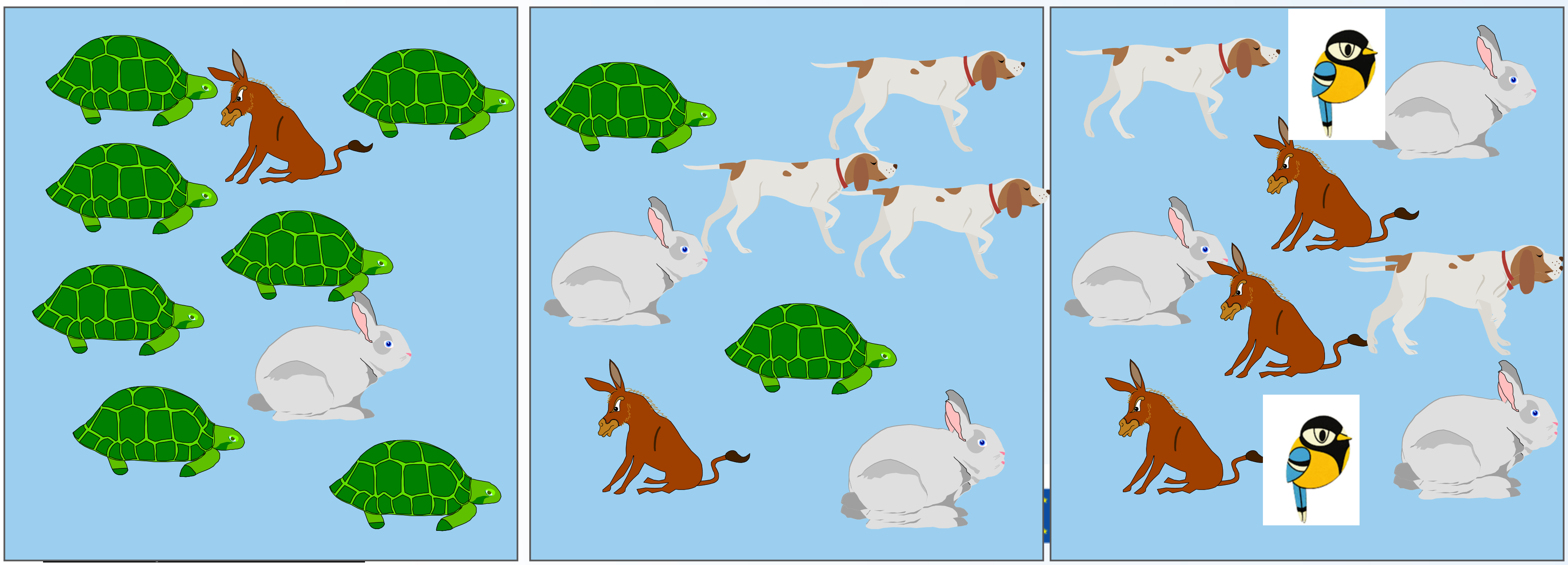
A – number of species at locality A

B – number of specieas at locality B

- **INDICES … for example …**
  - Jaccard's similarity index = [c / (A + B - c)] x 100%
    - Higher J-index – higher similarity

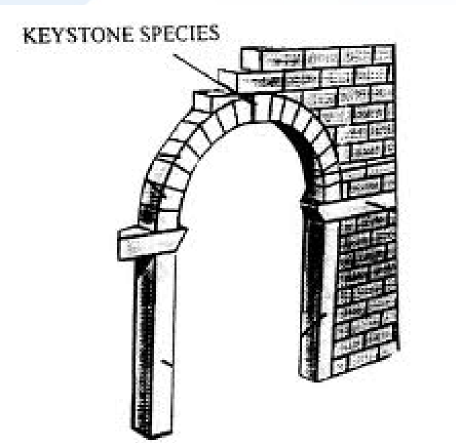
Homework (see ROPOT in IS MUNI): Which communities are the most similar? AxB or AxC or BxC?
(Ecotoxicology: A = control; B and C – different pesticides … which pesticide has „strongest“ effect?)

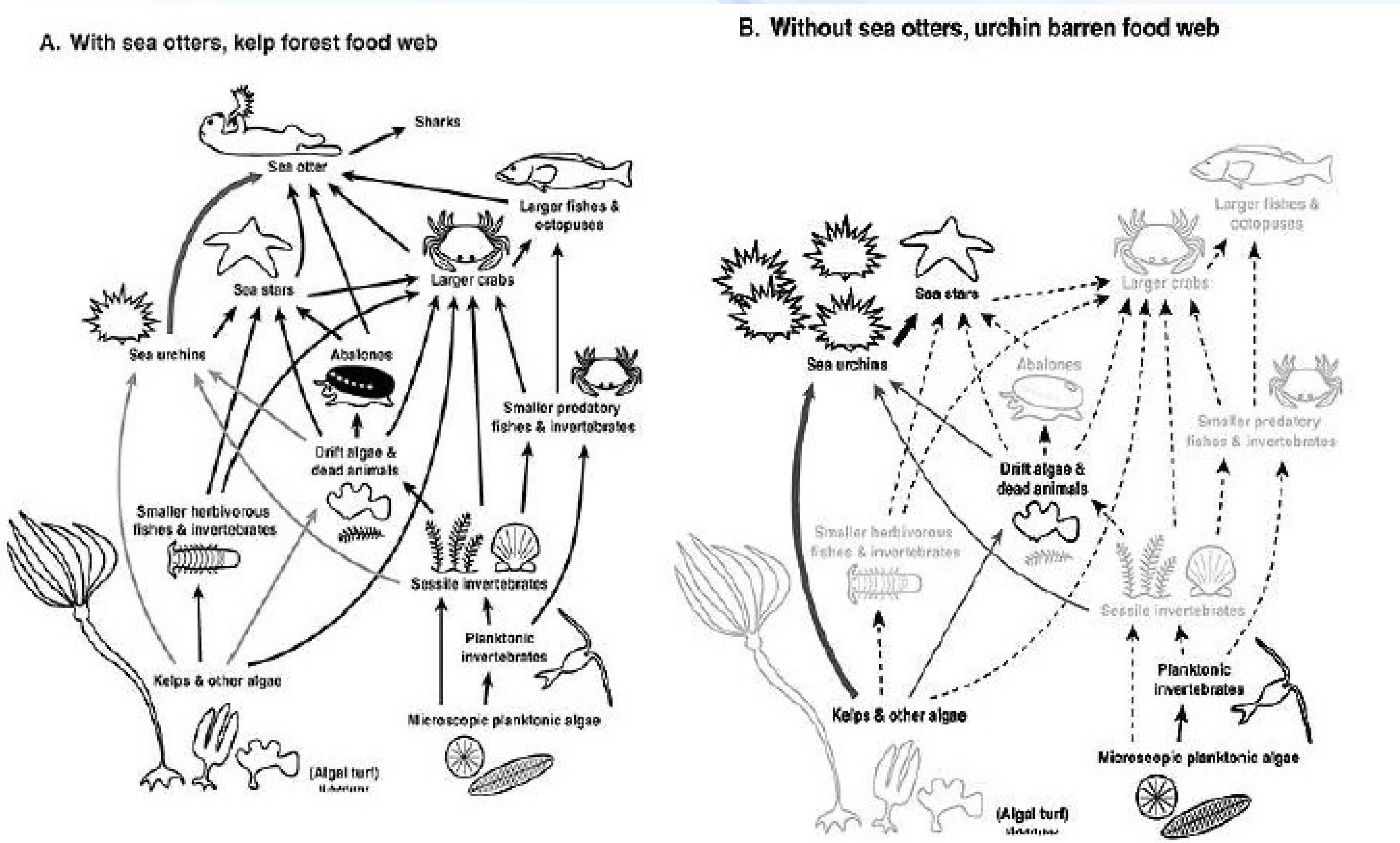
A B C



Key / Keystone species

- Effects on keystone species → dramatic changes on all community
- Usually predators (low numbers = high sensitivity to disruption)





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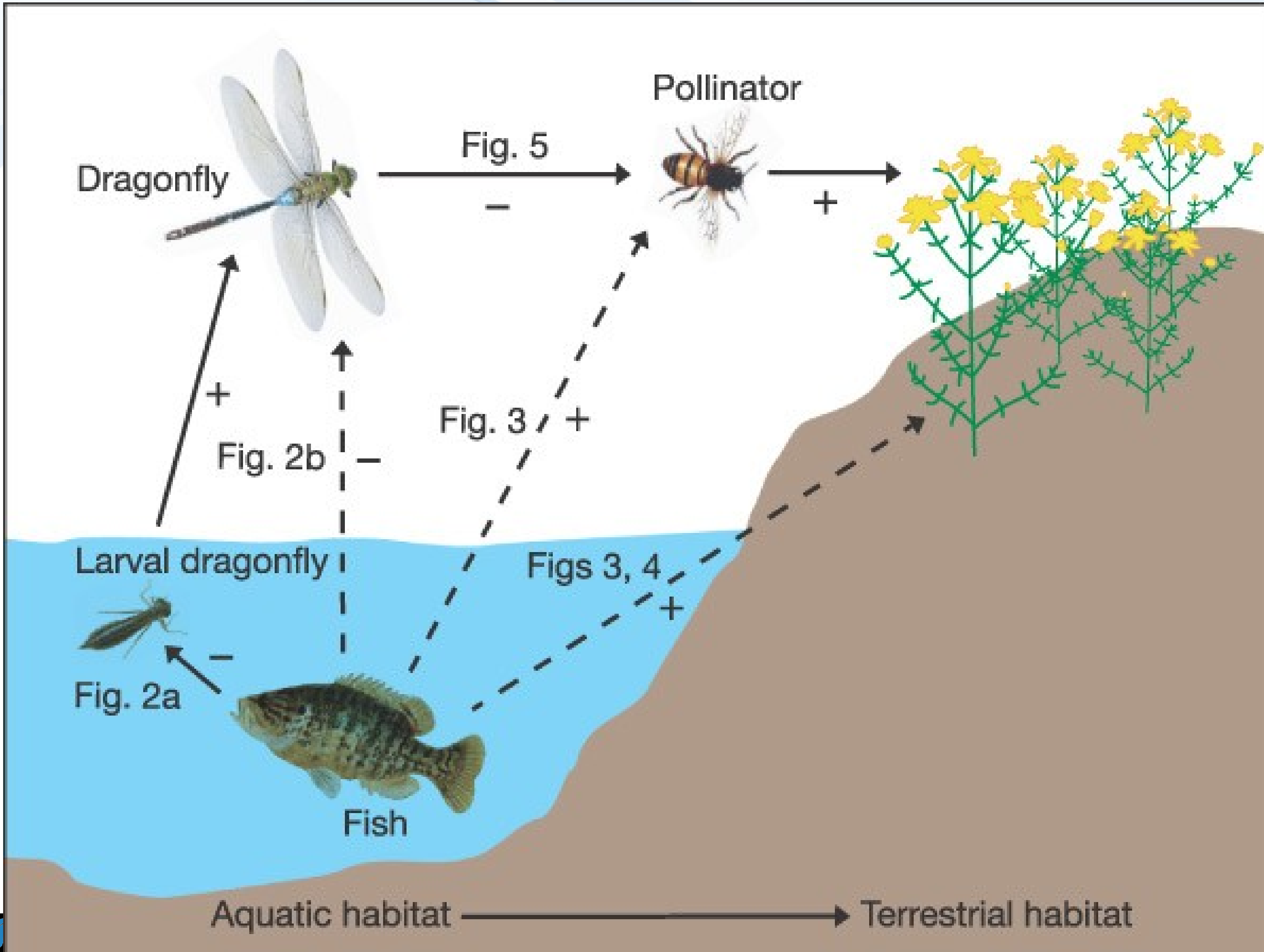
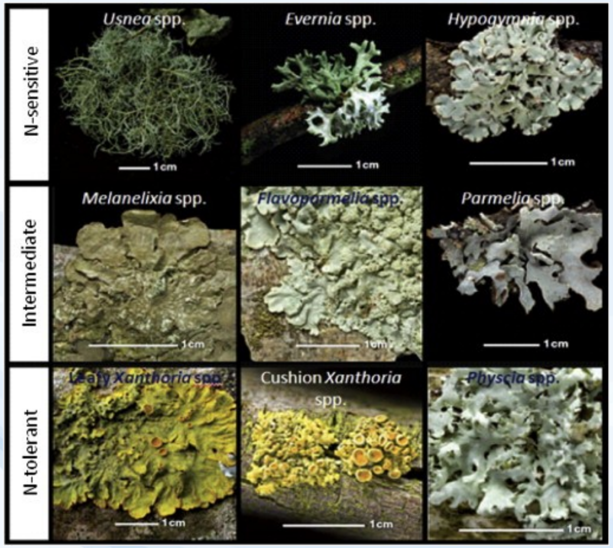
Knight et al., NATURE (2005) 437: 880

Fish as keystone species affecting also yields on nearby fields

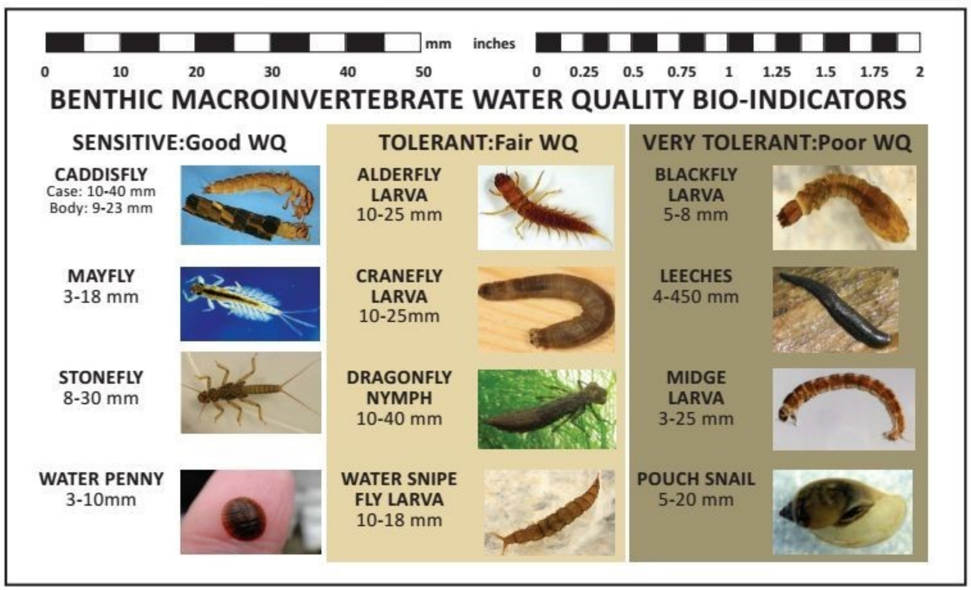


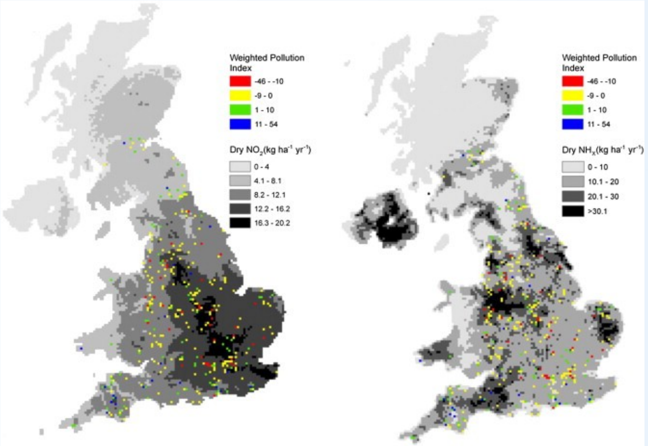
INDICATOR SPECIES (bioindicators)

- Species for which (not)presence indicate certain parameter of the environment
  - Sensitive or tolerant species
  - Ocurrence in community → INDICES



LICHENS – air quality
Dry deposition of nitrogenous pollutants across the UK overlaid with dots showing the value of the lichen-based Weighted Pollution Index





https://doi.org/10.1016/j.envpol.2013.07.045

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