



Research centre  
for toxic compounds  
in the environment

# Ecotoxicology Populations & Communities

**Ludek Blaha + ecotox colleagues**

cecoen



EUROPEAN UNION  
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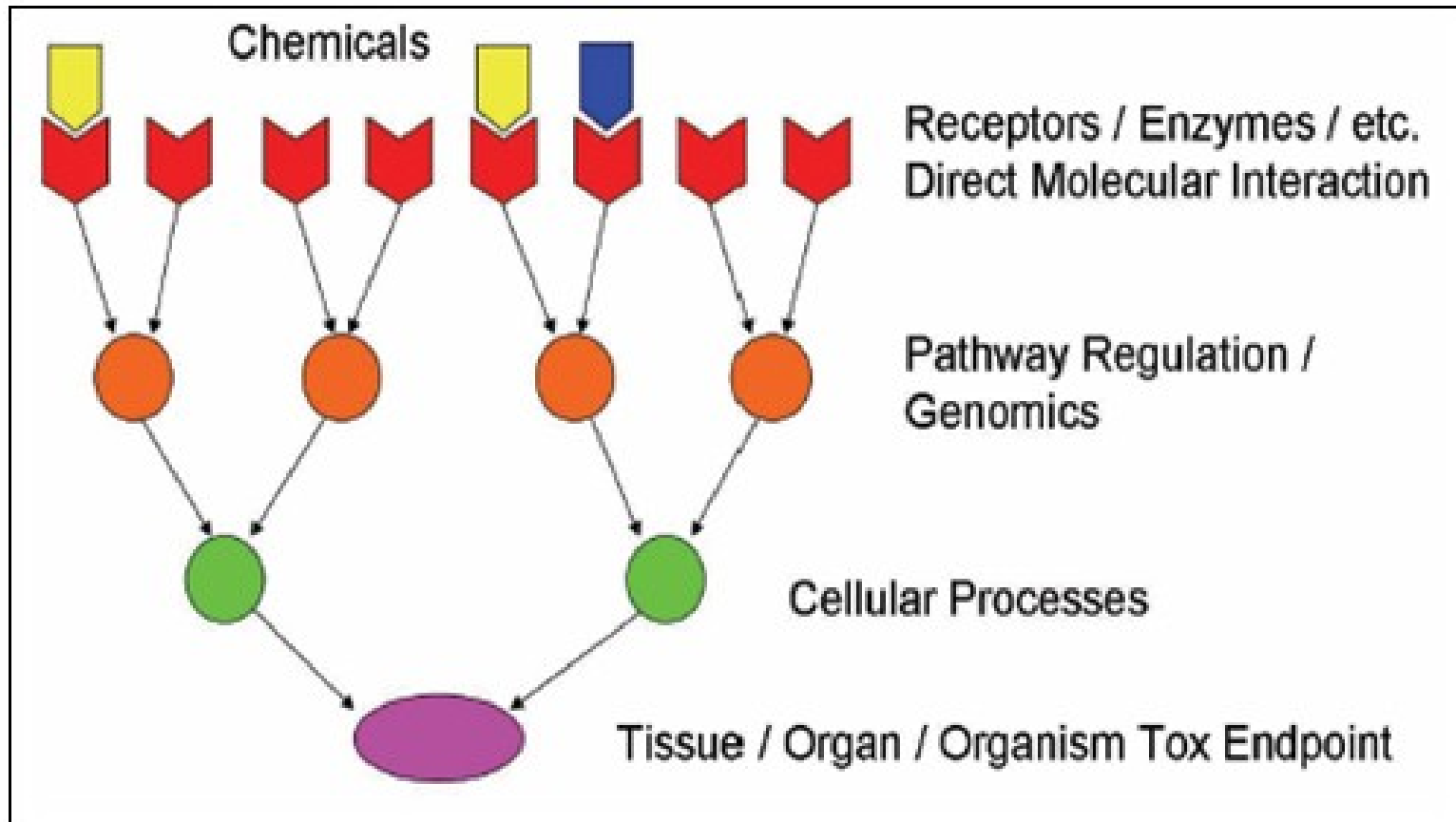


OP Research and  
Development for Innovation



# 1) From molecules to individuals

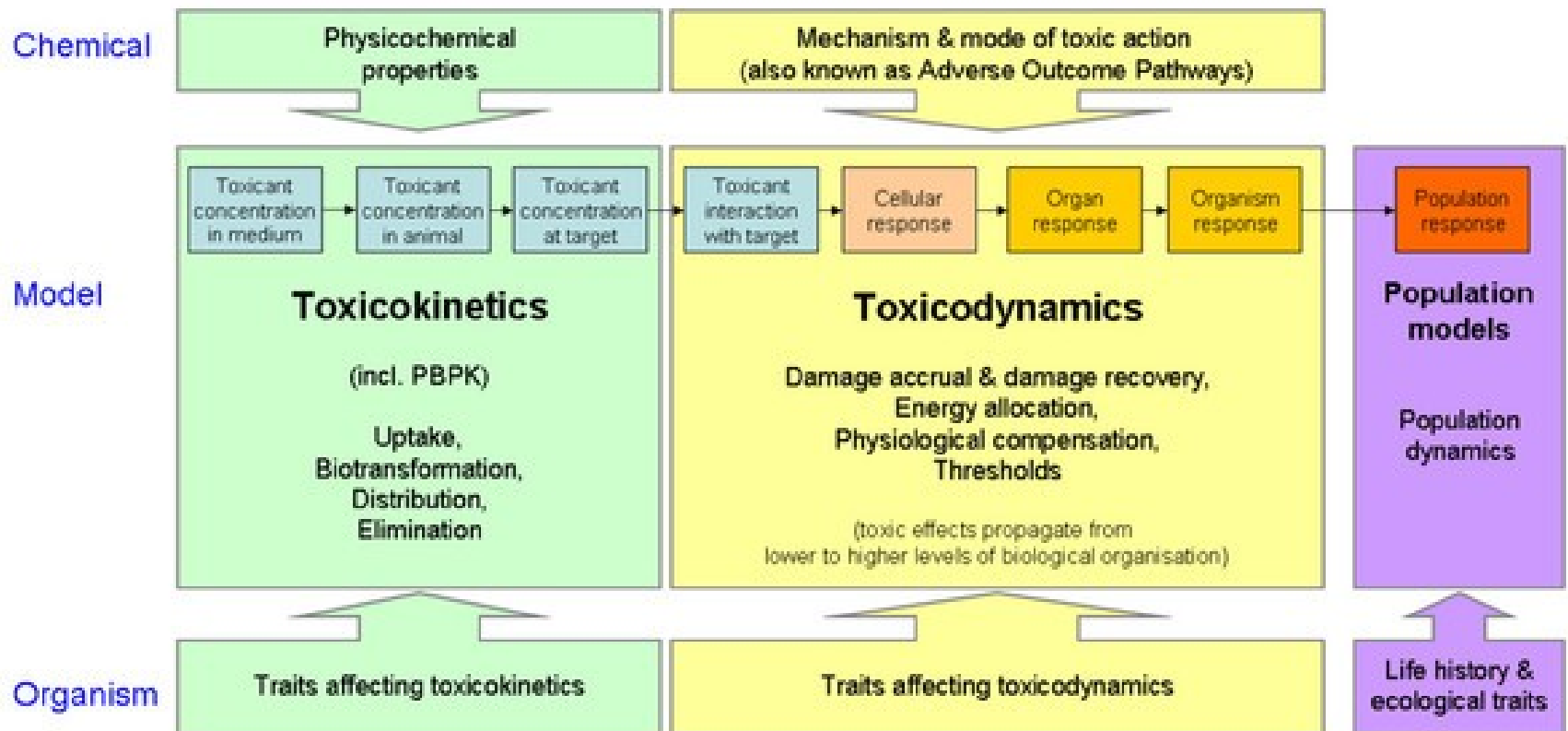
## MECHANISMS OF TOXICITY



# 2) From molecules to individuals - AOPs

## ADVERSE OUTCOME PATHWAYS

### Mechanistic effect models for ecotoxicology



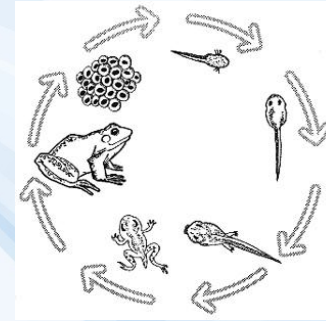
→ Arrows indicate a causal relationship

See also: Ashauer & Escher *JEM* (2010), Rubach *et al. IEAM* (2011), Jager *et al. ES&T* (2011), Ashauer *et al. ET&C* (2011)

# The ultimate objective of ECOTOXICOLOGY

→ to understand and protect populations, communities, ecosystems

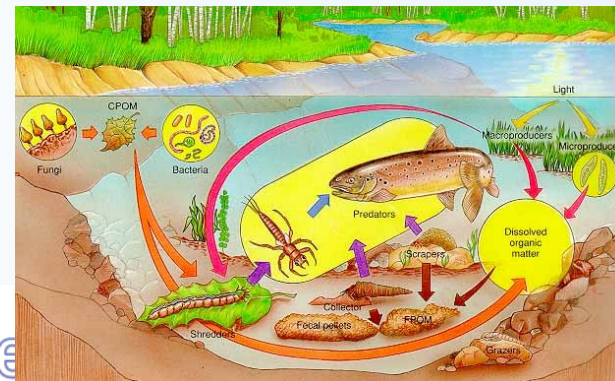
Populations



Communities  
(interacting populations)

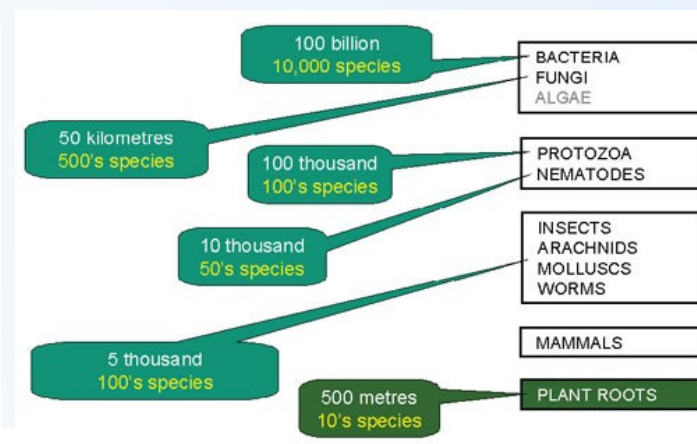


Ecosystems  
(communities interacting with abiotic environment)



- 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 AND MISMANAGEMENT (1977).*



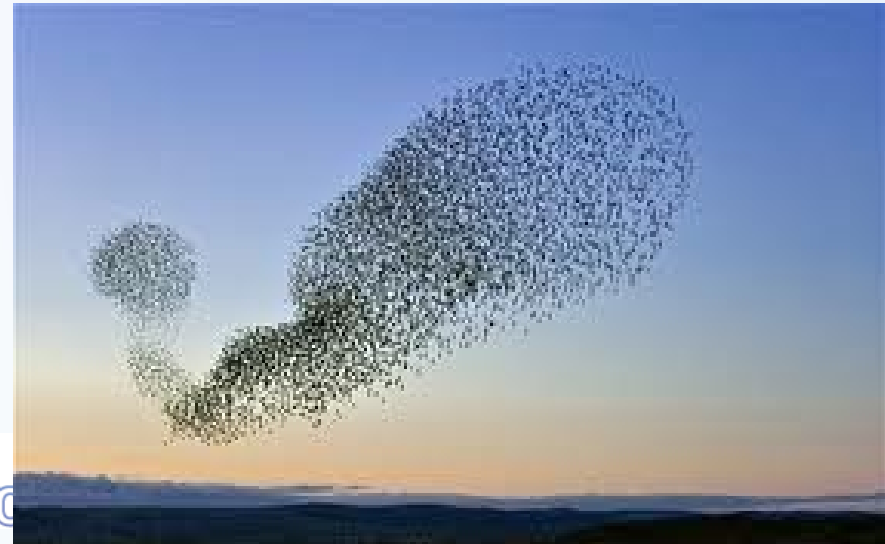
# Effects at different levels

- **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

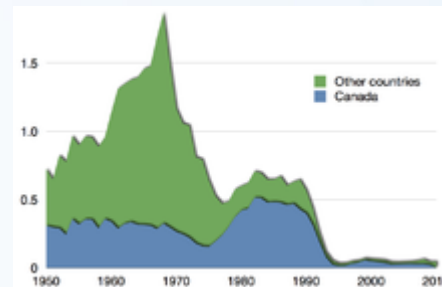
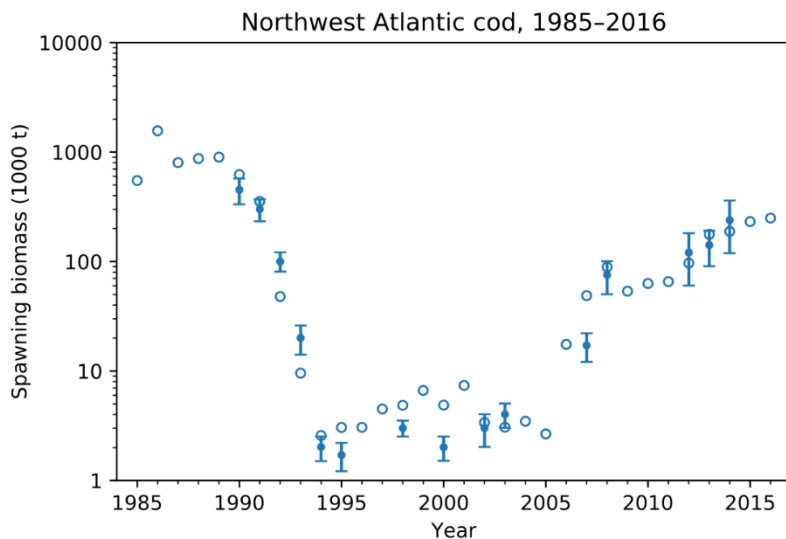


# STRUCTURAL PARAMETERS of populations („demographic parameters“)

## Primary parameters

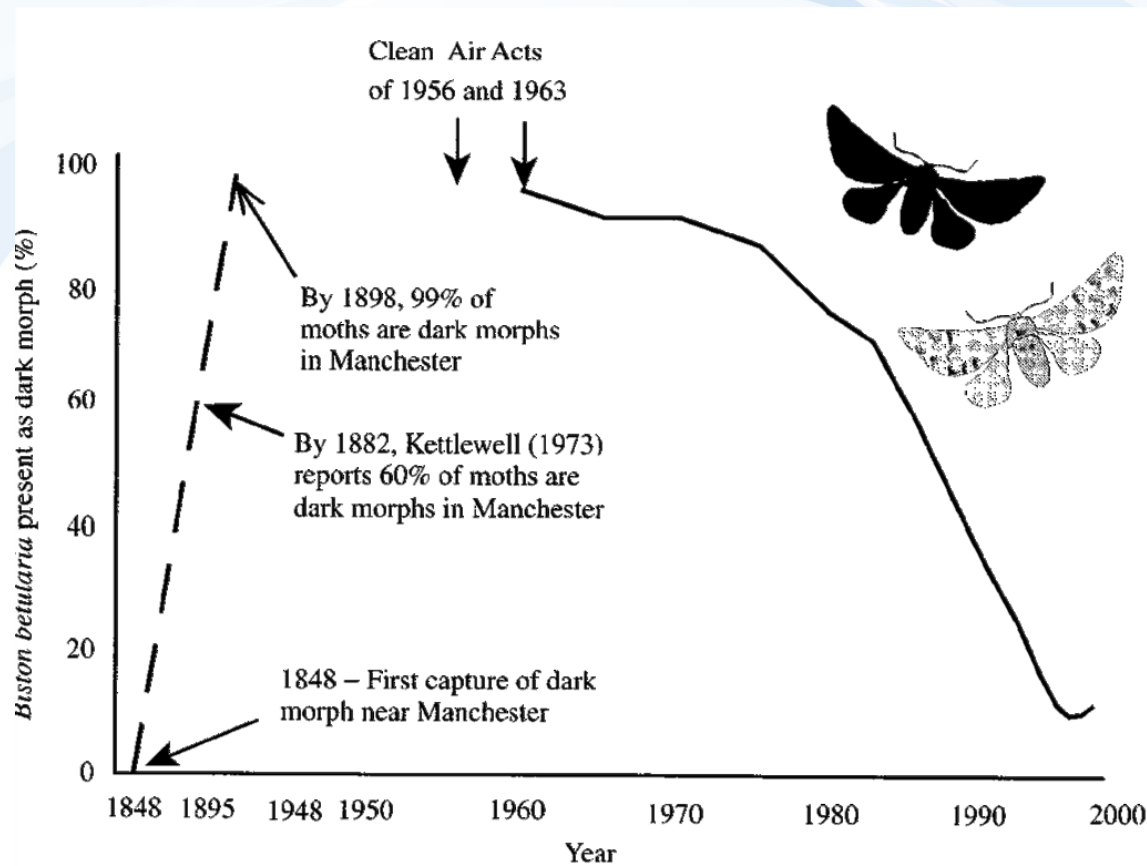
- **size** (performance) – number of individuals (animals), surface coverage (plants), amount of biomass (algae)
- **natality** – increase of population size: numbers of organisms per unit of time
- **mortality** – decrease of size: numbers of organisms per unit of time

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

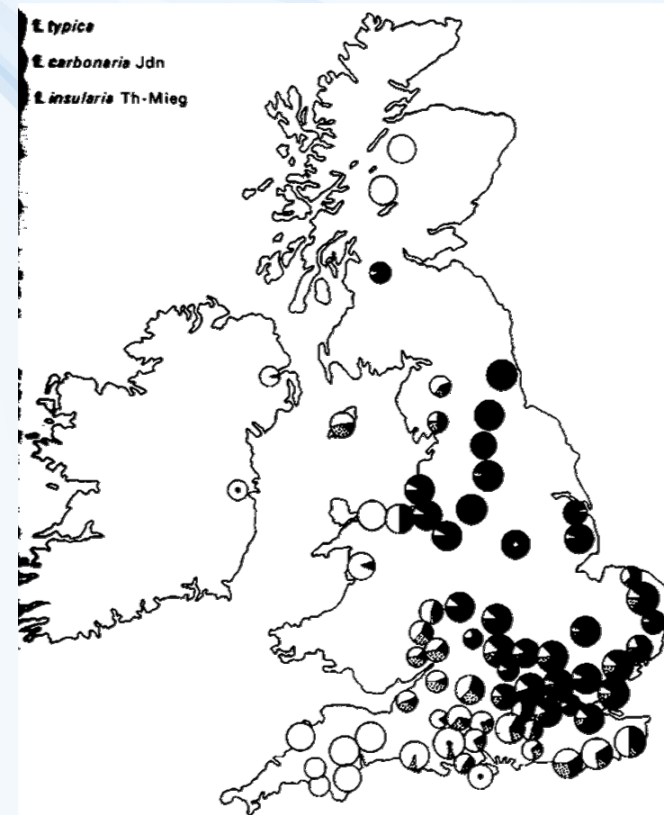


Capture of the Atlantic northwest cod stock in million tonnes, with Canadian capture in blue<sup>[8]</sup>

# 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



**Fig. 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 more 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.

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



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

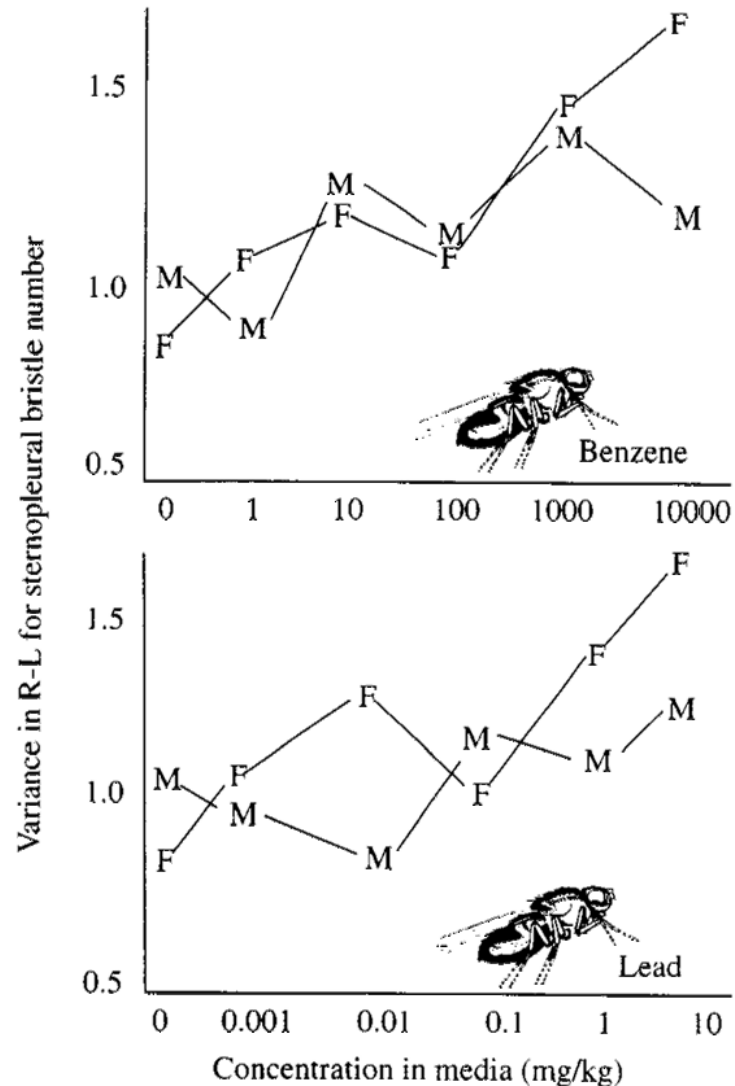
© Alamy

## 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 → aging population

Life Cycle of a Salmon

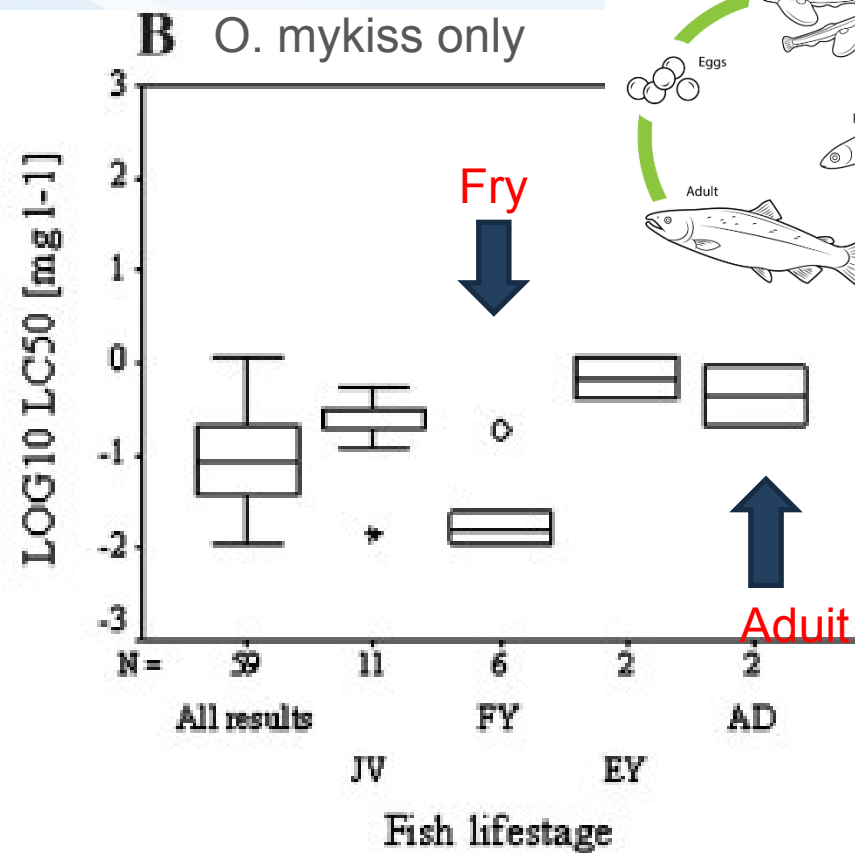
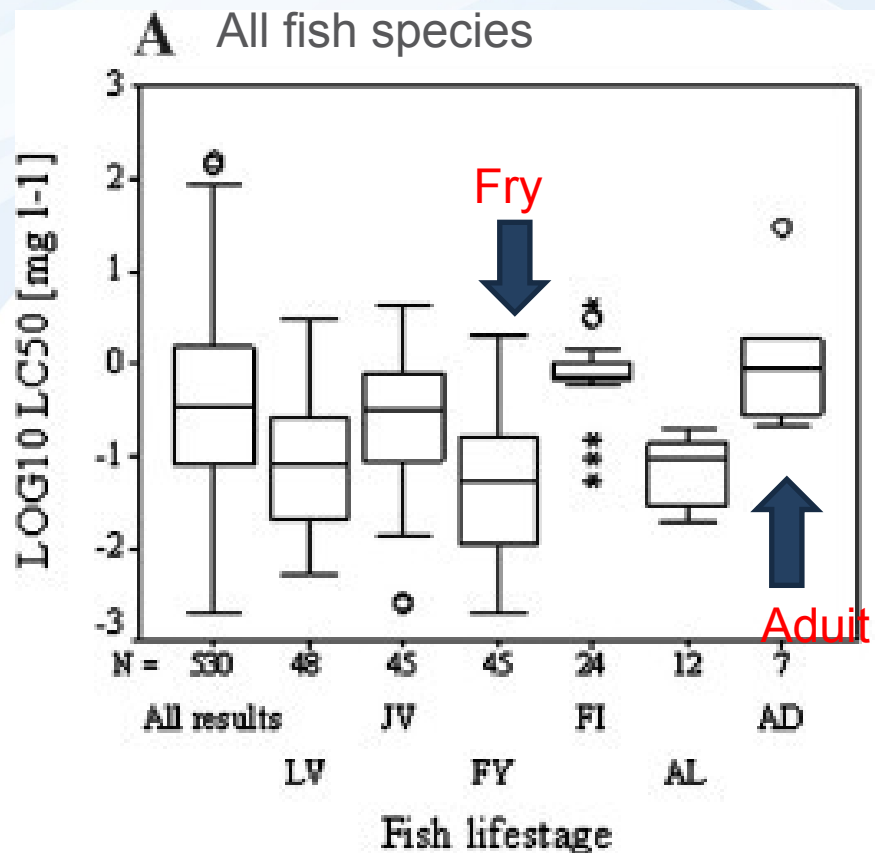
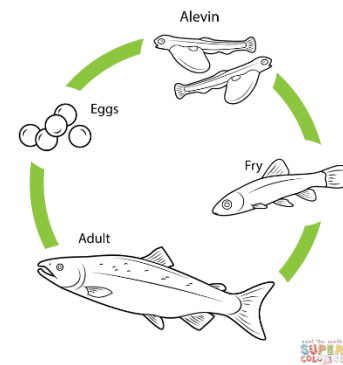


Fig. 2. Log LC50 variability for all available test results and for the five most frequently used fish life stages (larvae (LV), juvenile (JV), fry (FY), fingerling (FI), alevin (AL), eyed egg (EY) and adult (AD) life stage) for **CuSO4** - sulphuric acid, copper(2+) salt (1:1) (CAS 7758-98-7).

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

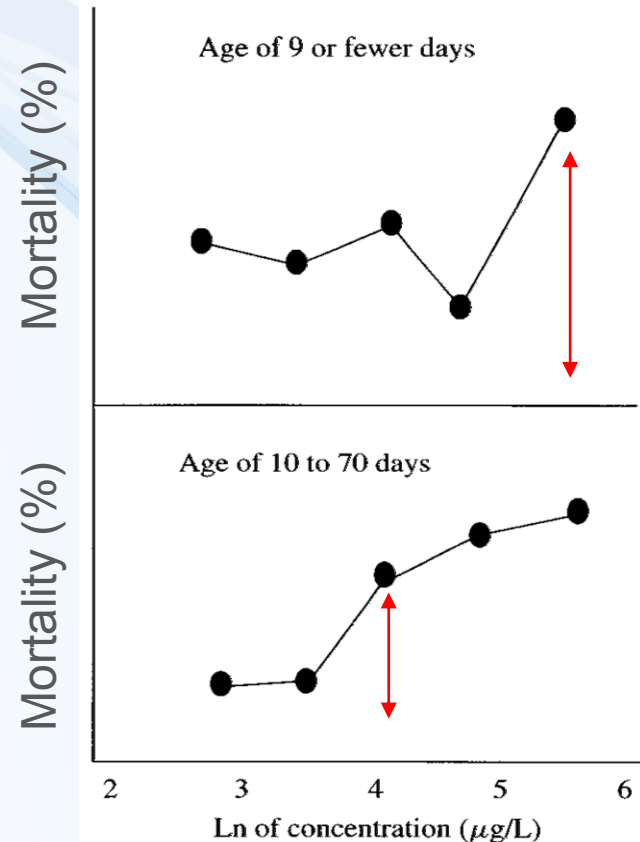
<http://www.sciencedirect.com/science/article/pii/S0273230009000956>

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  $\leq 9$  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)

# 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

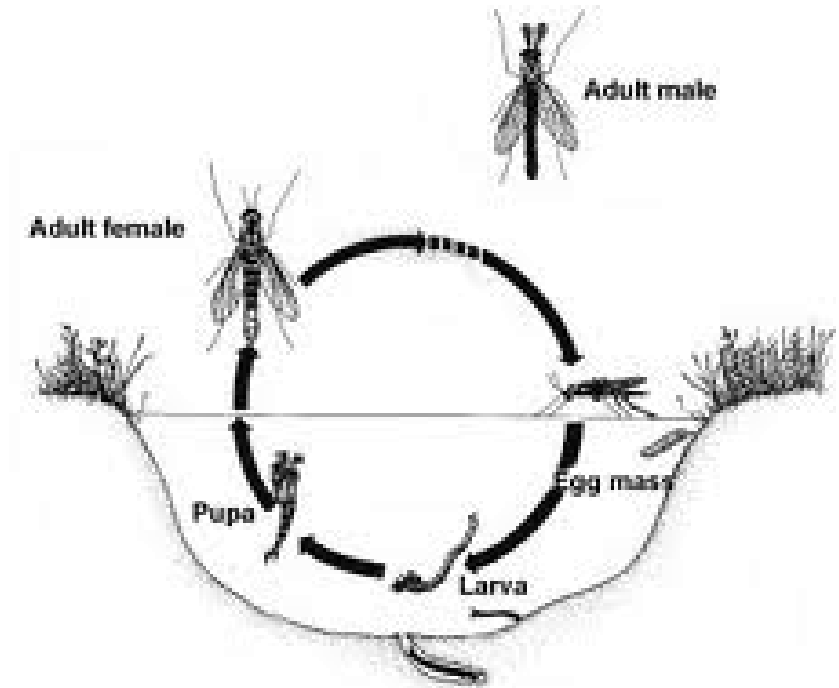


## 2) Whole life cycle toxicity test

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

## 3) Modelling

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



# Communities ... interacting populations

Toxicants (stressors) may have

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

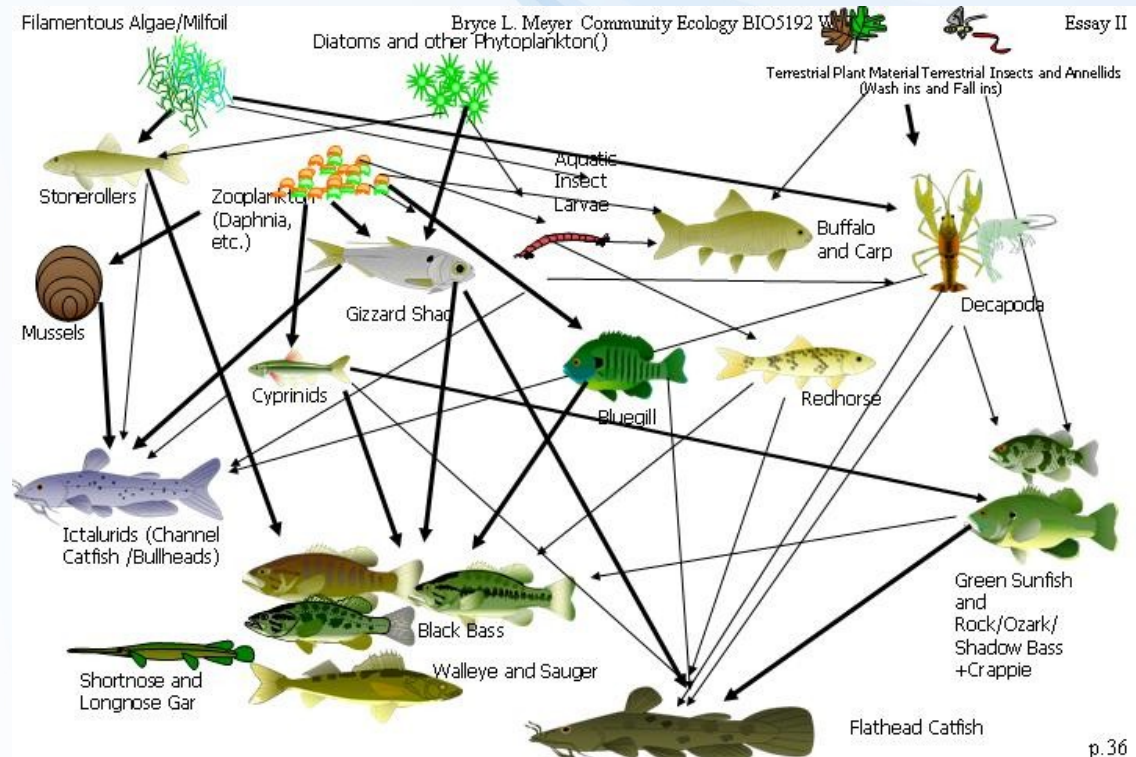
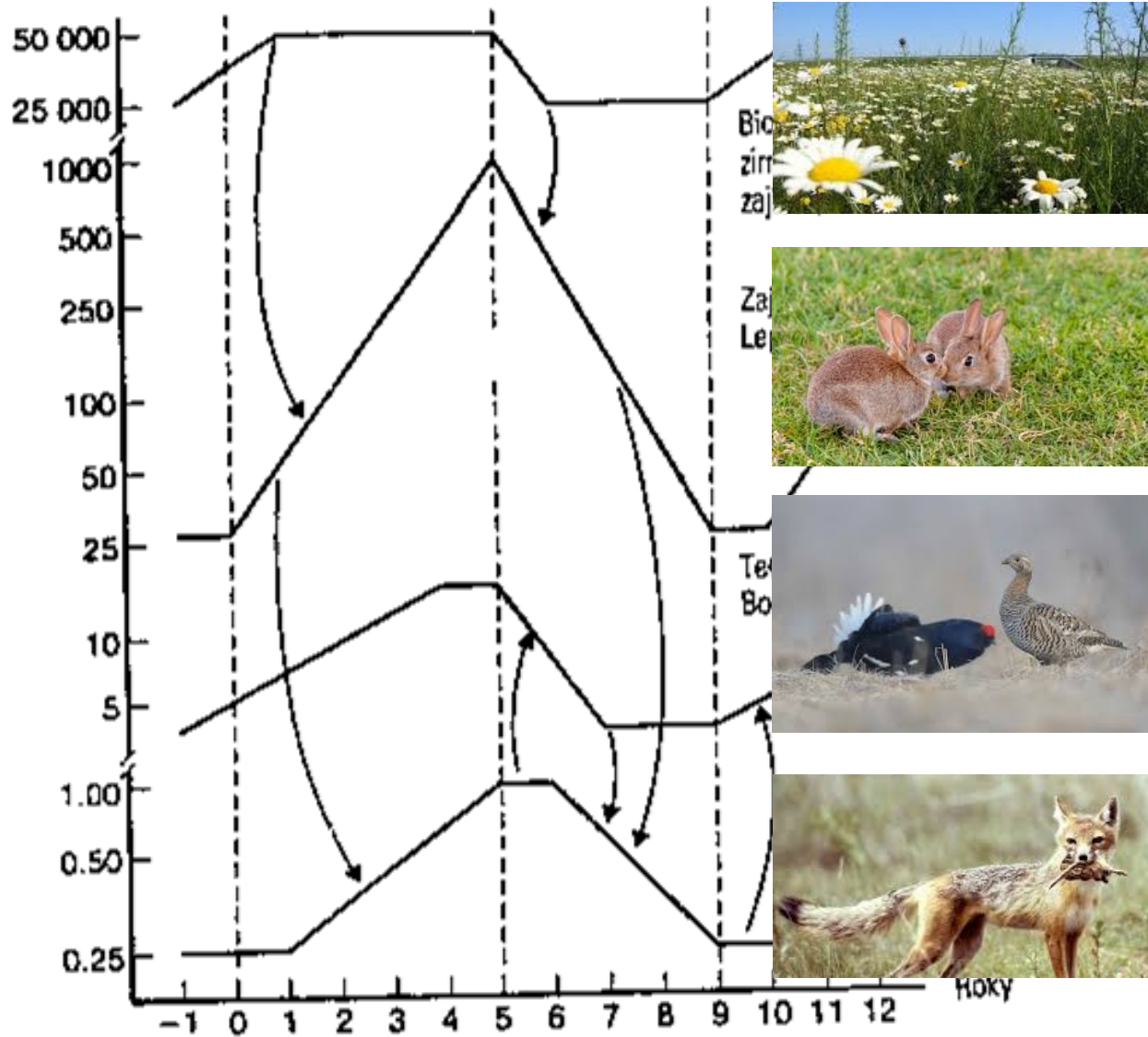


Figure #31: Simplified Food Web (Source Down) similar to warm water lower end of river before entry into Mississippi River System or impoundment. The Flathead acts as a super predator when present as large specimens, and many predators such as walleyes and Gars compete for minnows and shad. Channel Catfish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

# Natural variability in community (food web)

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



for toxic compounds  
in the environment

cercoen



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# 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<sup>a</sup>

Group	Species	Sample no....	Fir forests				Pine-bilberry forests									
			1	2	3	4	Moist		Dry							
A	<i>Abies alba</i>		4	2	2	2	+	+	+	+	+	+				
	<i>Pinus sylvestris</i>		+	+	+	+	4	3	2	4	4	1	2	3		
	<i>Picea excelsa</i>		+	+	2	+		2	+	+	+	+		+		
	<i>Vaccinium myrtillus</i>		+	2	+	+	5	4	2		+	1	+	+	2	
	<i>Vaccinium vitis-idaea</i>		+		+	+	+	+			+	1	3	3	2	
B	<i>Lycopodium selago</i>		+		+	+										
	<i>Circaea alpina</i>		+	+		+										
	<i>Pyrola secunda</i>			1	+	+										
	<i>Pyrola minor</i>			+	+	+		+								
C	<i>Lycopodium annotinum</i>		+		+	+	+		+	+		+				
	<i>Ptilium crista-castrensis</i>		2		4	+	2	+	3	3						
	<i>Dicranum undulatum</i>		4	+	2	2	+	+	+	+				+		
	<i>Entodon schreberi</i>				+		5	1	5	2			+			
D	<i>Pyrola chlorantha</i>									+	+	+	+			
	<i>Melampyrum vulgatum</i>								1	+	1	2		+		
	<i>Calluna vulgaris</i>									+	+		2	+	+	
	<i>Cladonia sylvatica</i>								2	+			3	+	3	+
	<i>Cladonia rangiferina</i>								1			1	2	+	4	+
E	<i>Quercus sessilis</i>			+							+		+	+	+	+
	<i>Betula verrucosa</i>												+	+	+	+
	<i>Thymus ovatus</i>									+			+	2	+	+
	<i>Lycopodium clavatum</i>												+	+	+	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).

<sup>a</sup> +, Rare; 1–5, increasing degrees of abundance. The species of groups B–E are diagnostic.



# Ecotoxicology example

Changes in community treated with four doses (L-low, M-medium, H-high, V H-very high)  
 <Results relative to controls>

Same exposures in two different set-ups  
 Microcosm vs Mesocosm  
 <Different responses of communities highlighted>

Organism	2 m <sup>2</sup> microcosm				480 m <sup>2</sup> mesocosm			
	L <sup>b</sup>	M	H	VH	L	M	H	VH
Zooplankton Rotifera Copepoda								
Macroinvertebrates								
Oligochaeta								
Ephemeroptera - Baetidae - Caenidae								
Odonata								
Diptera - Chaoboridae - Chironominae - Tanypodinae								
Fish - survival <sup>c</sup> - growth <sup>d</sup> - reproduction								

= 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 evenness** ( $E = H / \ln S$ )
  - Higher E → higher „evenness of community“

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

*N<sub>i</sub> – Number of individuals of one species*  
*N – Total number of individuals in community*  
*S – Number of species*

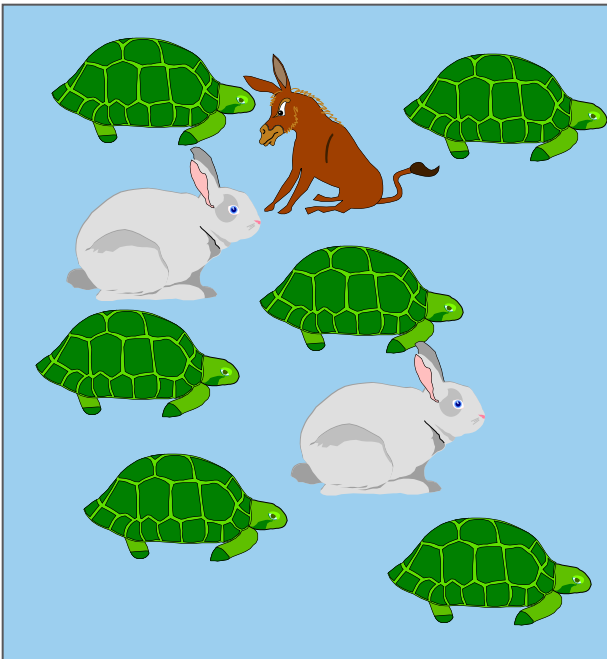
# Which of the following three communities has the highest EVENESS?

Example of  $H'$  calculation for locality A:

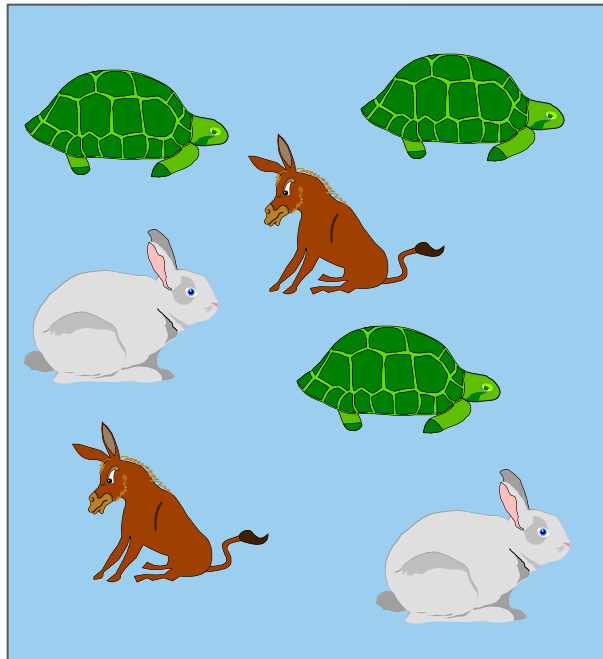
$$\begin{aligned} H' &= - (6/9) \cdot \ln(6/9) \text{ turtles} \\ &+ 1/9 \cdot \ln(1/9) \text{ donkeys} \\ &+ 2/9 \cdot \ln(2/9) \text{ rabbits} = \dots \end{aligned}$$

$E = \dots ?$

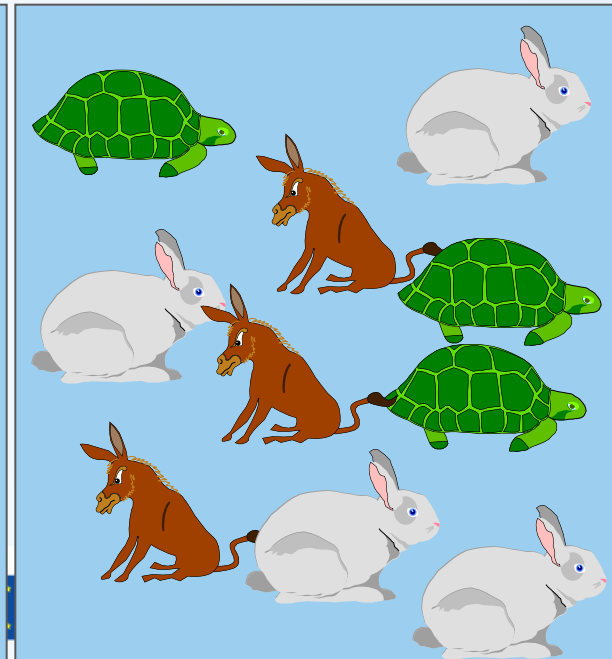
A



B



C



# How to compare communities?

$c$  – number of shared (common) species

$A$  – number of species at locality  $A$

$B$  – number of species at locality  $B$

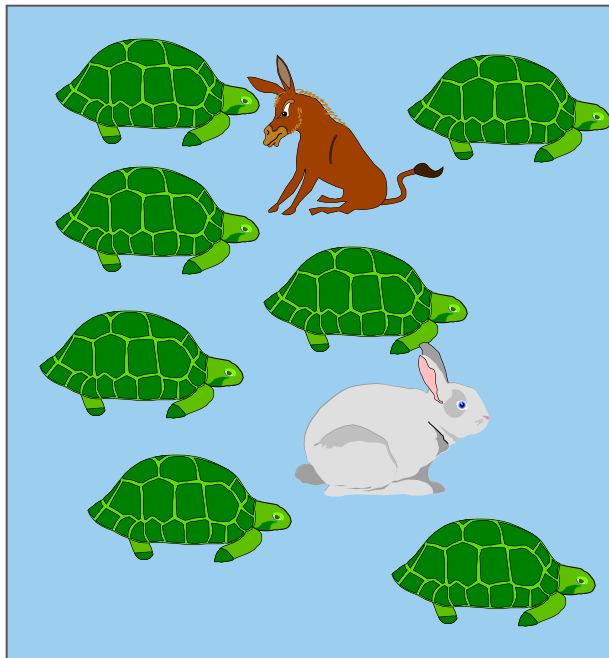
- **INDICES ... for example ...**

- **Jaccard's similarity index =  $[c / (A + B - c)] \times 100\%$** 
  - Higher J-index – higher similarity

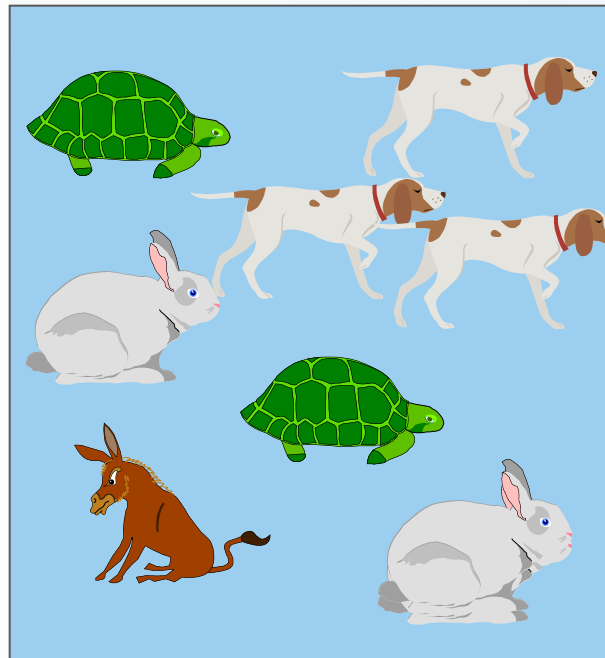
Which two are the most similar? AxB or AxC or BxC?

(Ecotoxicology:  $A$  = control;  $B$  and  $C$  – different pesticides ... which pesticide has „strongest“ effect?)

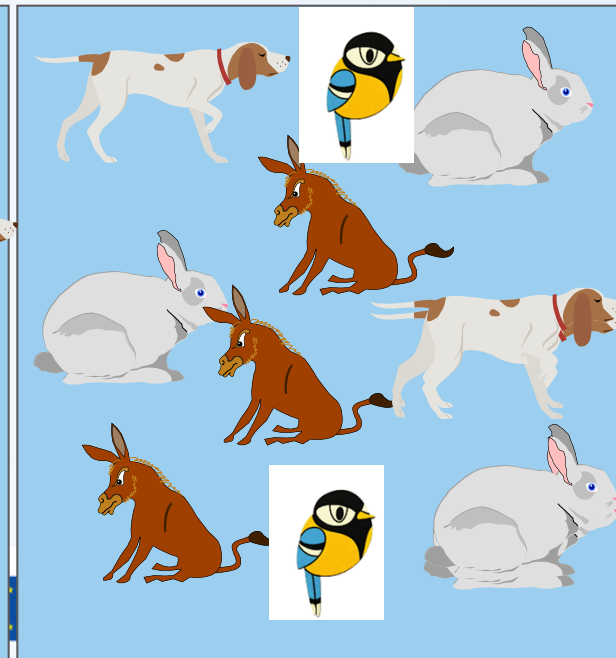
**A**



**B**



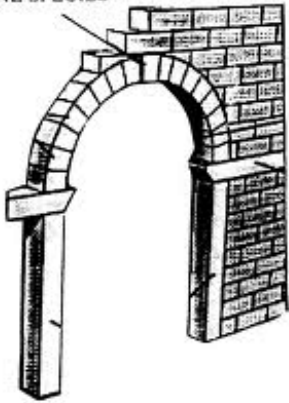
**C**



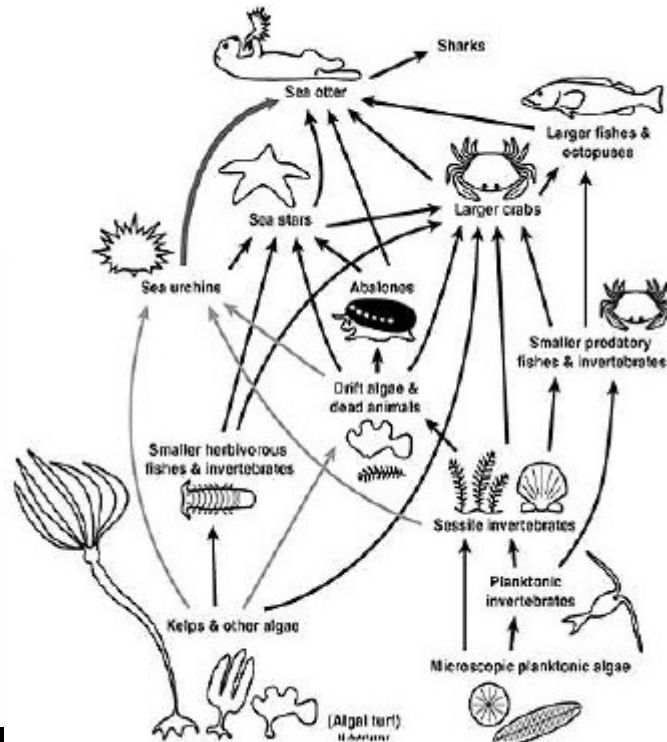
# Key / Keystone species

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

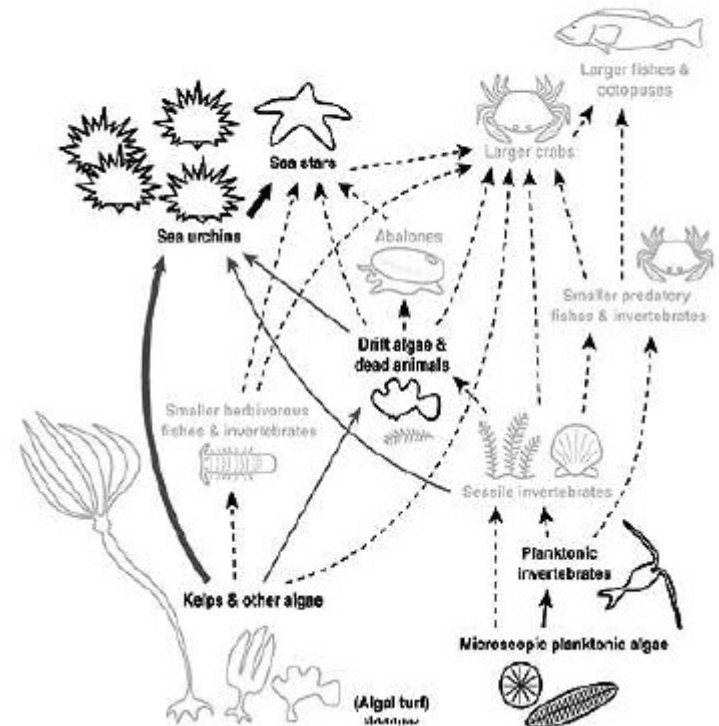
KEYSTONE SPECIES



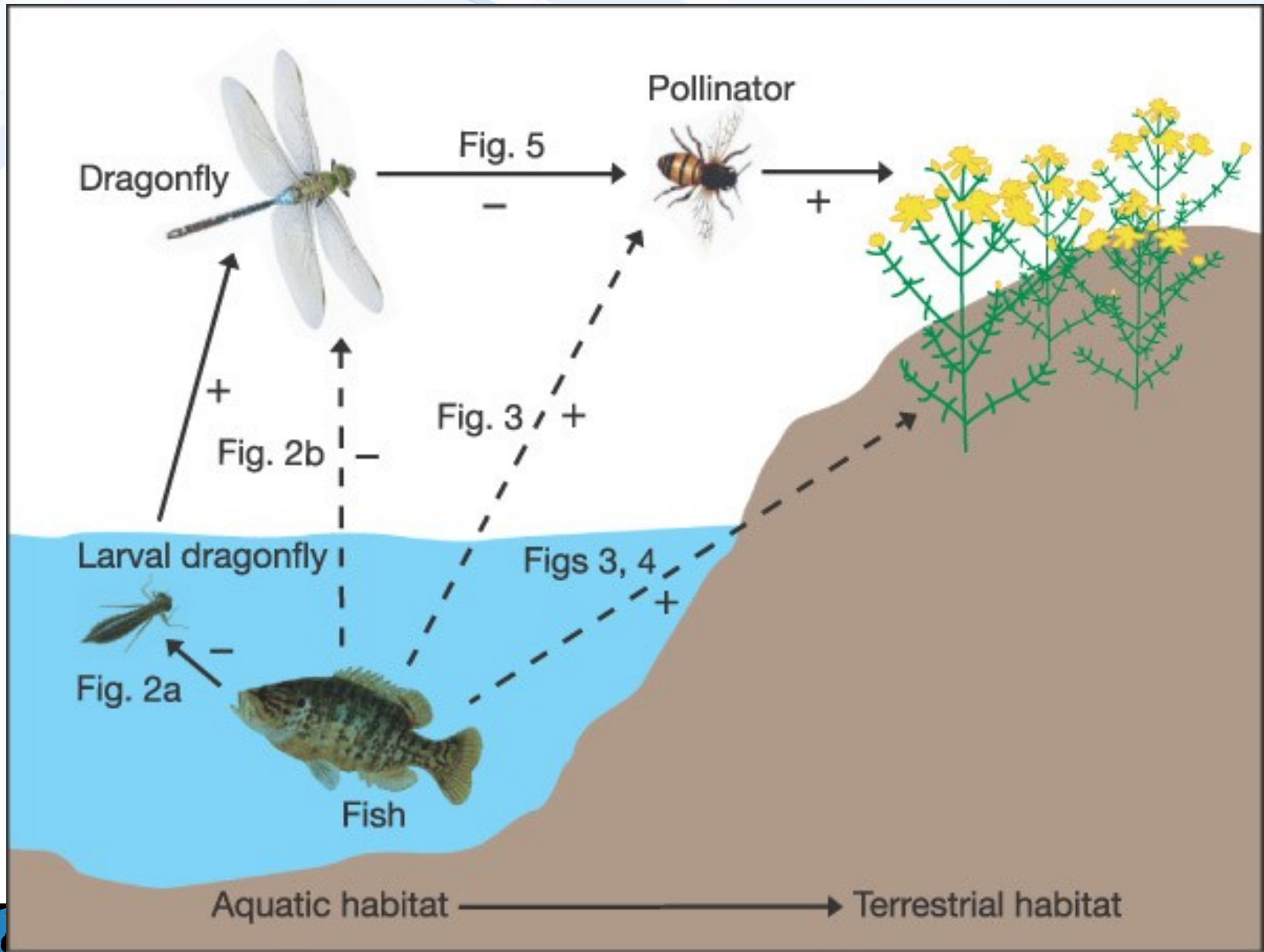
A. With sea otters, kelp forest food web



B. Without sea otters, urchin barren food web

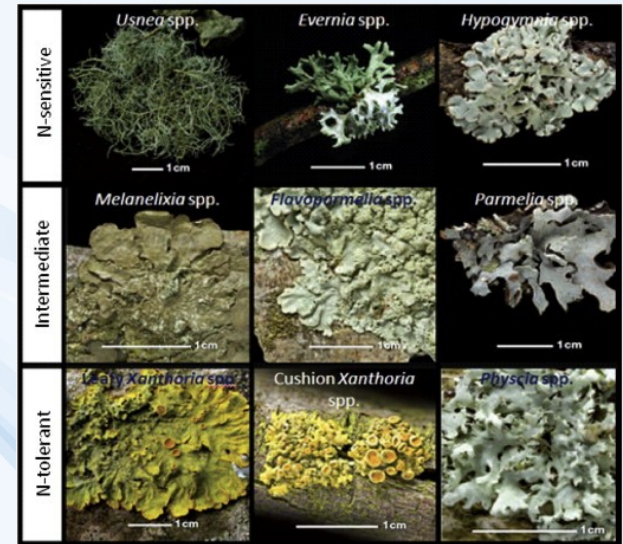


# Fish as keystone species affecting also yields on nearby fields



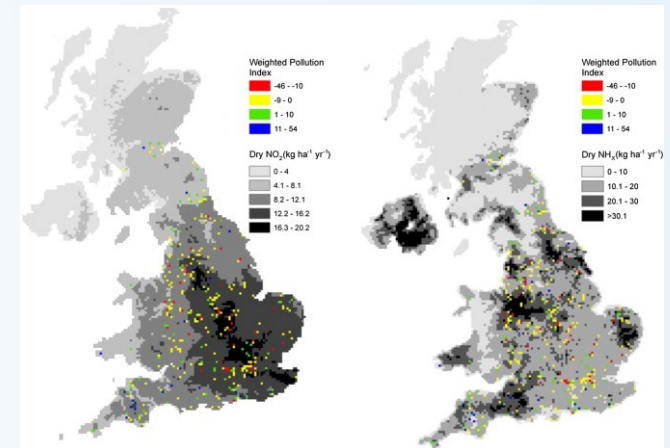
# INDICATOR SPECIES (bioindicators)

- 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>

0 10 20 30 40 50 mm inches 0 0.25 0.5 0.75 1 1.25 1.5 1.75 2

### BENTHIC MACROINVERTEBRATE WATER QUALITY BIO-INDICATORS

SENSITIVE: Good WQ		TOLERANT: Fair WQ		VERY TOLERANT: Poor WQ	
<b>CADDISFLY</b> Case: 10-40 mm Body: 9-23 mm		<b>ALDERFLY LARVA</b> 10-25 mm		<b>BLACKFLY LARVA</b> 5-8 mm	
<b>MAYFLY</b> 3-18 mm		<b>CRANEFLY LARVA</b> 10-25 mm		<b>LEECHES</b> 4-450 mm	
<b>STONEFLY</b> 8-30 mm		<b>DRAGONFLY NYMPH</b> 10-40 mm		<b>MIDGE LARVA</b> 3-25 mm	
<b>WATER PENNY</b> 3-10 mm		<b>WATER SNIPE FLY LARVA</b> 10-18 mm		<b>POUCH SNAIL</b> 5-20 mm	