Biological effects vs ecological effects: A Systems Ecologist's Perspective

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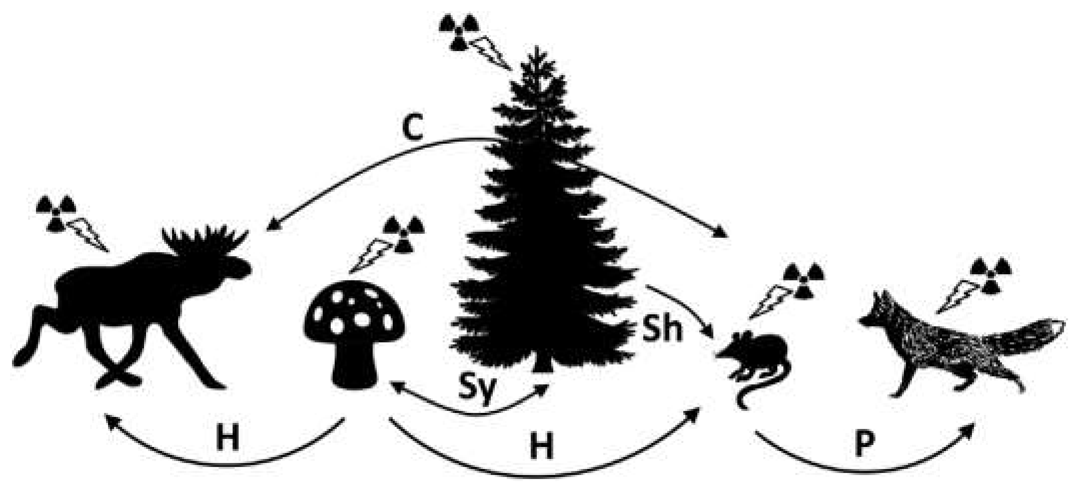
Why focus on ecosystems?

- Because in reality individuals or single species do not exist in isolation
- Interactions between species, populations, biotic-abiotic => non-linearity
  - – Feedbacks
  - – Emergent properties
  - – Resilience



Bradshaw et al (2014) Fig 2.
C = competition, P = predation,
H = herbivory , Sy = symbiosis ,
Sh = shelter

Purely organism- or species-based approaches do not address ecosystems

- Interactions between species and indirect effects not considered
- non-linear responses, emergent properties, resilience, etc

- effect at ecosystem level cannot be predicted/extrapolated from effects on individual species
- may over- or under-estimate effects / risk

Indirect effects

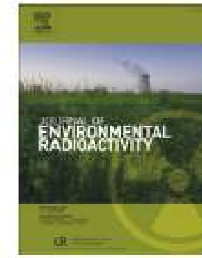
- Caused by changes in the types or strengths of interactions between species (different sensitivity of species to the stressor)
- Competitive
  - When ecologically similar species have different sensitivities to stress => competitive release
- Trophic
  - Changes in resource quantity/quality => changes in consumption
  - Trophic cascades (indirect effects mediated through consumer-resource interactions) - both top down and bottom up
- Behavioural
  - Altered predation rates, increased susceptibility to predation
- Parasites/disease
  - Stressed organisms may have weakened immune systems

Journal of Environmental Radioactivity 101 (2010) 915–922

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad



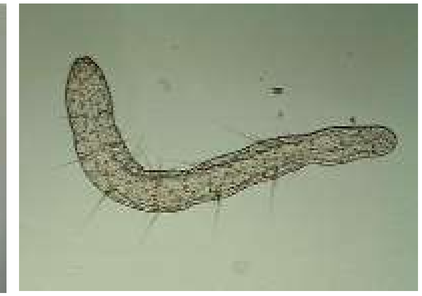
Effects of acute γ-irradiation on community structure of the aquatic microbial microcosm

Shoichi Fuma [a,*], Nobuyoshi Ishii [a], Hiroshi Takeda [a], Kazutaka Doi [b], Isao Kawaguchi [b], Shuichi Shikano [c], Nobuyuki Tanaka [d], Yuhei Inamori [e]

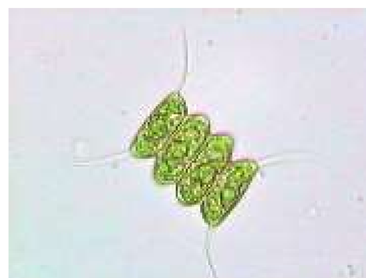
Fuma et al (2010) JER 101: 915-922

- Microcosms consisting of populations of :
  - Consumers: a ciliate protozoan (*Cyclidium glaucoma*), rotifers (*Lecane* sp. and *Philodina* sp.) and an oligochaete (*Aeolosoma hemprichi)*

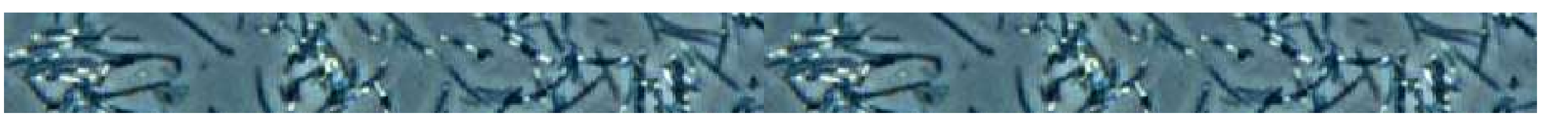


  - Primary producers: green algae (*Chlorella* sp. and *Scenedesmus* sp.) and a blue-green alga (*Tolypothrix* sp.)

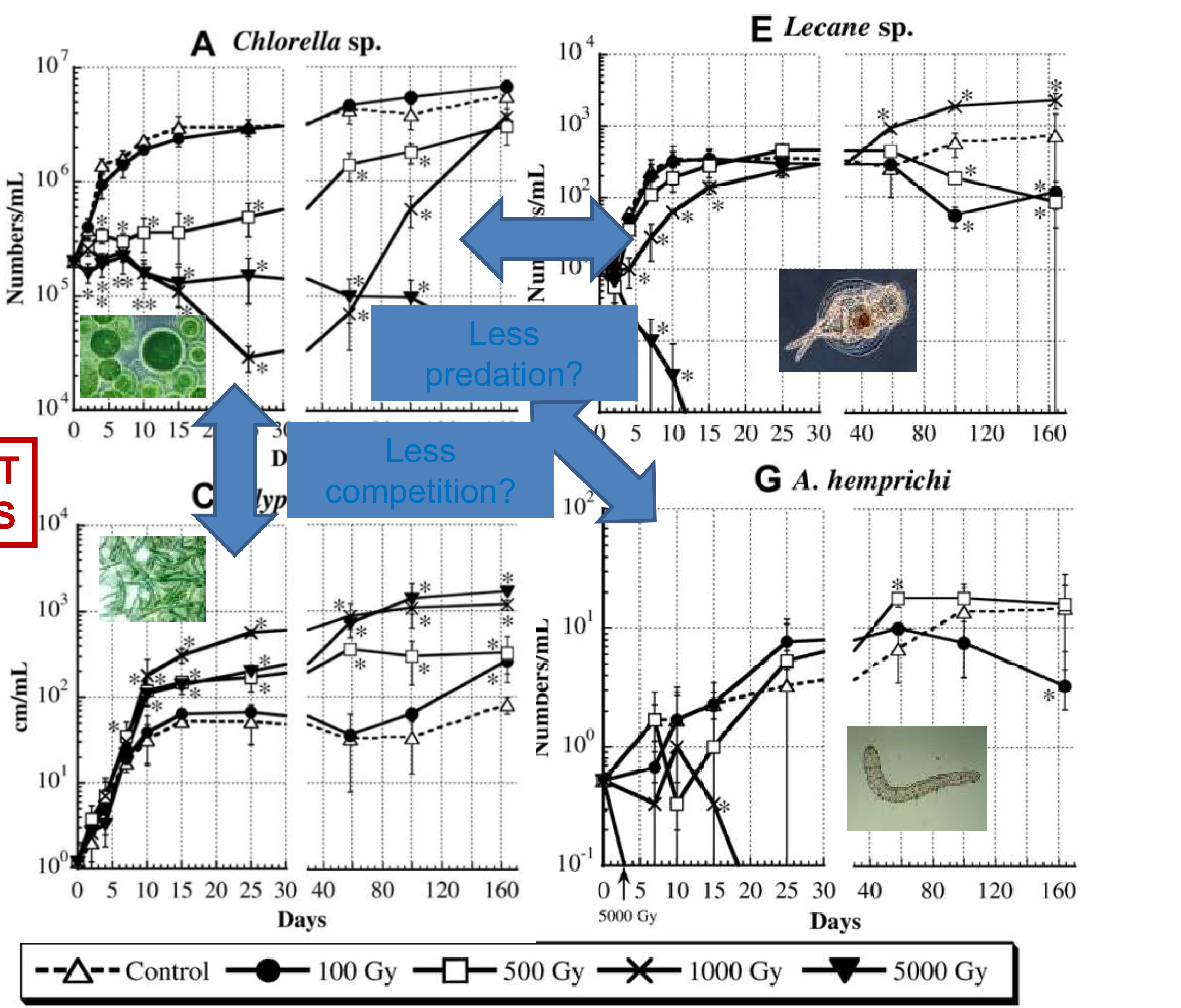




  - Decomposers: >4 species of bacteria, initially sustained on polypeptone



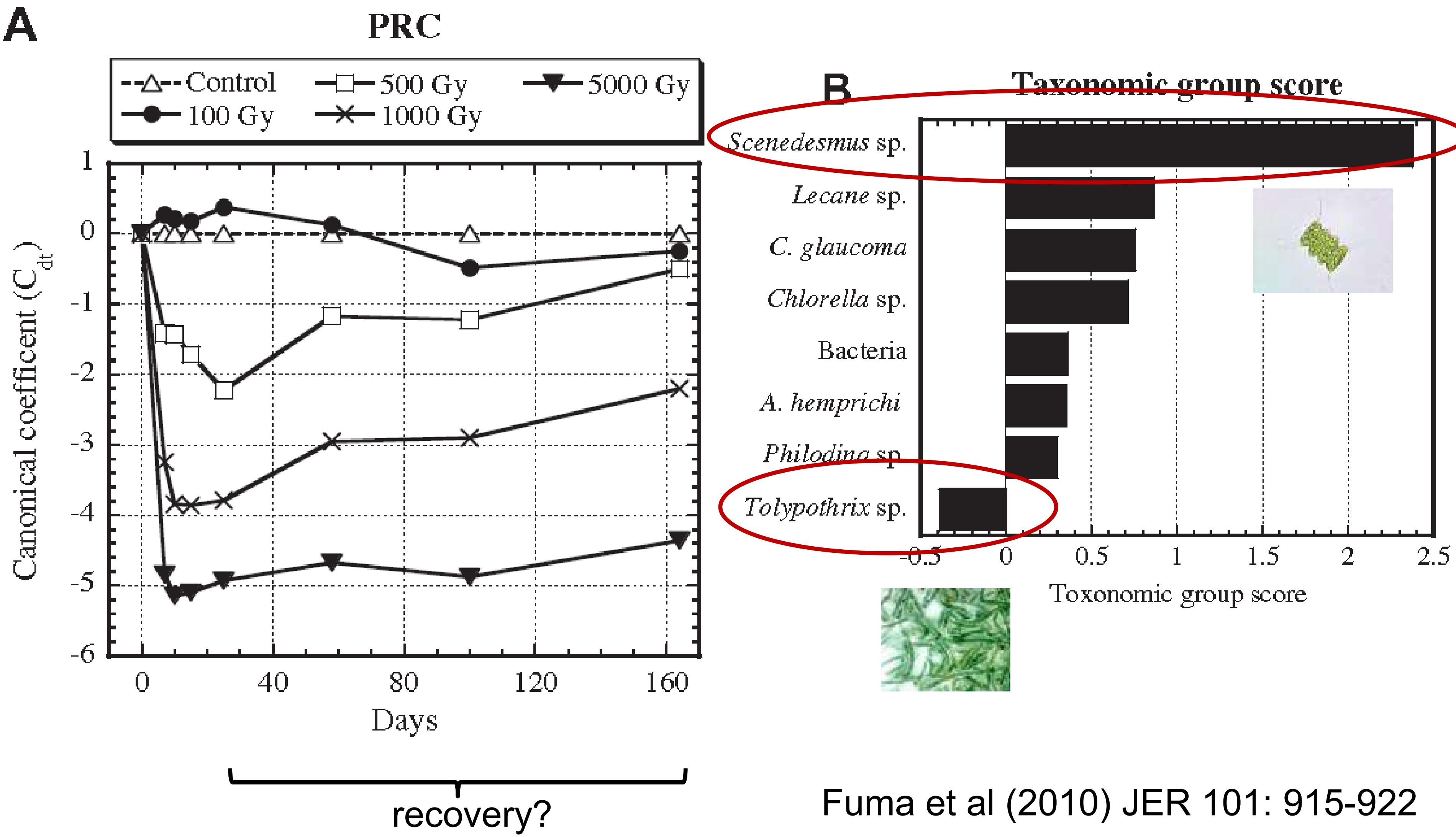
- Population changes were observed over 160 days after acute irradiation (100, 500, 1000, 5000 Gy at 31 Gy min^{-1}).

INDIRECT EFFECTS



Principle Response Curves

Multivariate method: overall change in community structure compared to control

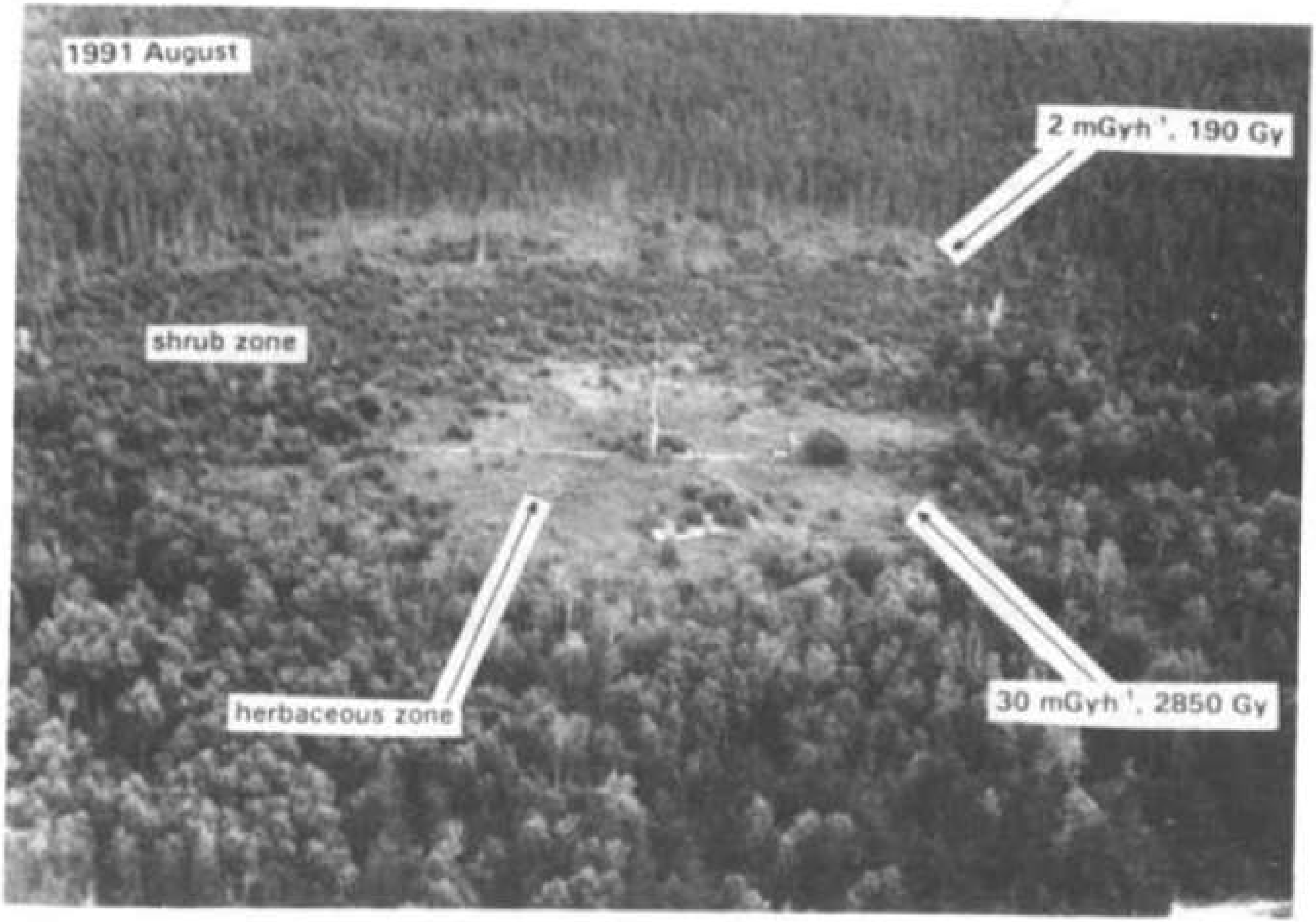


Fuma et al (2010) JER 101: 915-922

Indirect effects mediated by environmental changes

- Effects on organisms affects abiotic components which their turn affect organisms
  - particularly via keystone species or ecosystem engineers
- e.g. light penetration, temperature, nutrient concentrations, soil moisture, pH, O2…

Evidence from the field



14y chronic gamma irradiation of boreal forest, Canada
Amiro and Sheppard (1994)

Acute (8 day) high dose exposure, South Urals area – mixed pine and birch

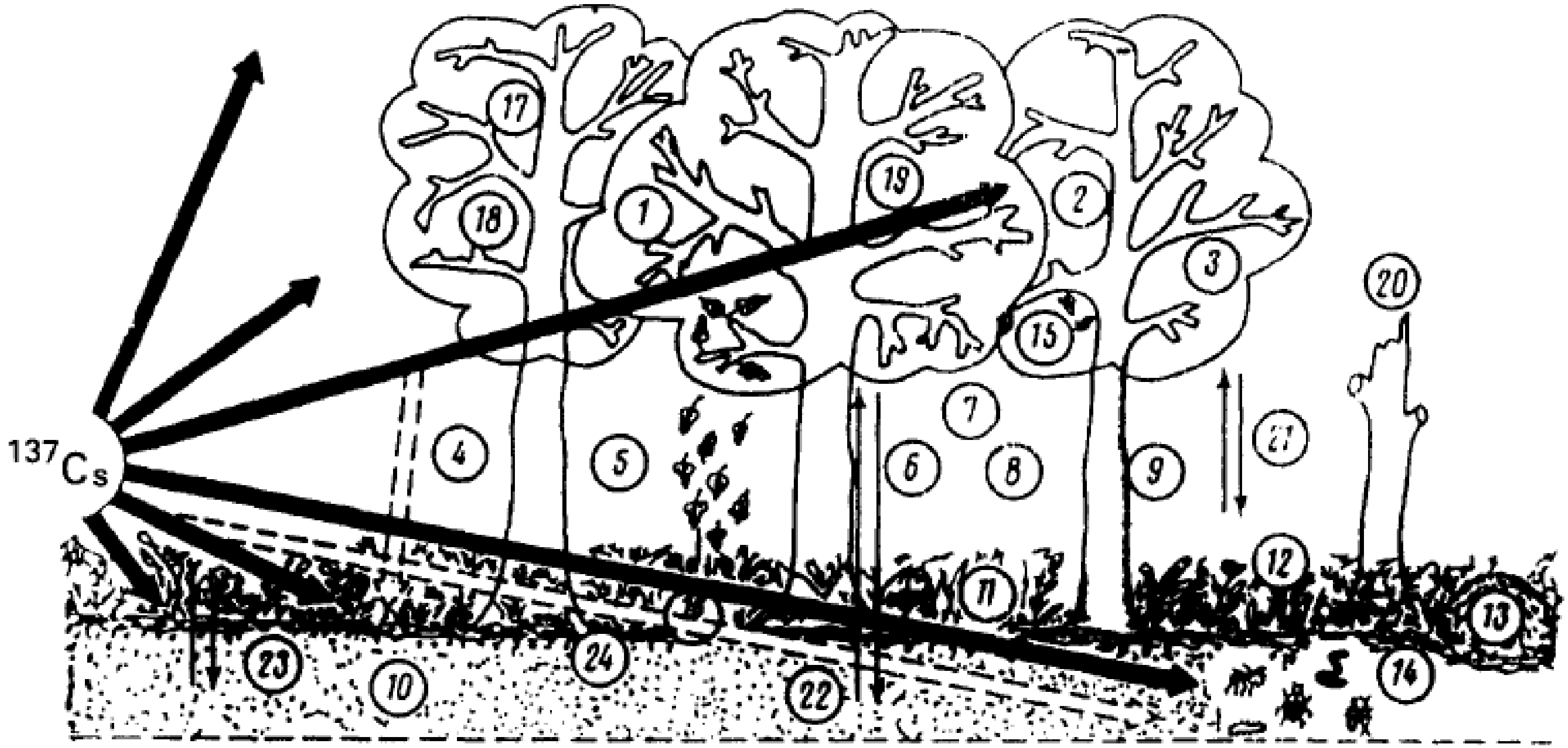


Fig. 2. General scheme illustrating major primary and secondary radiation reactions in the forest biogeocenosis. **1**, phenology; **2**, growth of the tip and side branches; **3**, leaf fall; **4**, precipitation; **5**, wind speed; **6**, temperature; **7**, light under canopy; **8**, humidity; **9**, annual wood ring; **10**, soil temperature; **11**, biomass and yield of grass seeds; **12**, structure and phenology of grass cover; **13**, ants; **14**, meso- and microfauna of soils; **15**, insects in canopy; **16**, forest litter; **17**, yield and quality of tree seeds; **18**, cytogenetic properties of buds and pollen; **19**, biomass of above ground parts of plants; **20**, damage and death of trees; **21**, tree and herb relations; **22**, tree and soil relations; **23**, grass and soil relations; **24**, yield and quantity of seeds in litter.

Alexakhin et al. (1994) Science of the Total Environment 157: 357-369

Ecosystem effects in forest field studies

- radiosensitivity: conifers > deciduous trees > shrubs
- altered microclimate (e.g. increased light, soil temperature) also favours shrubs and herbaceous species
- changes to moisture and C content of soil, and indirect effects on microbial communities
- increases in plant parasites in affected areas
- changes in litter turnover and organic matter decomposition

(note – external doses only)

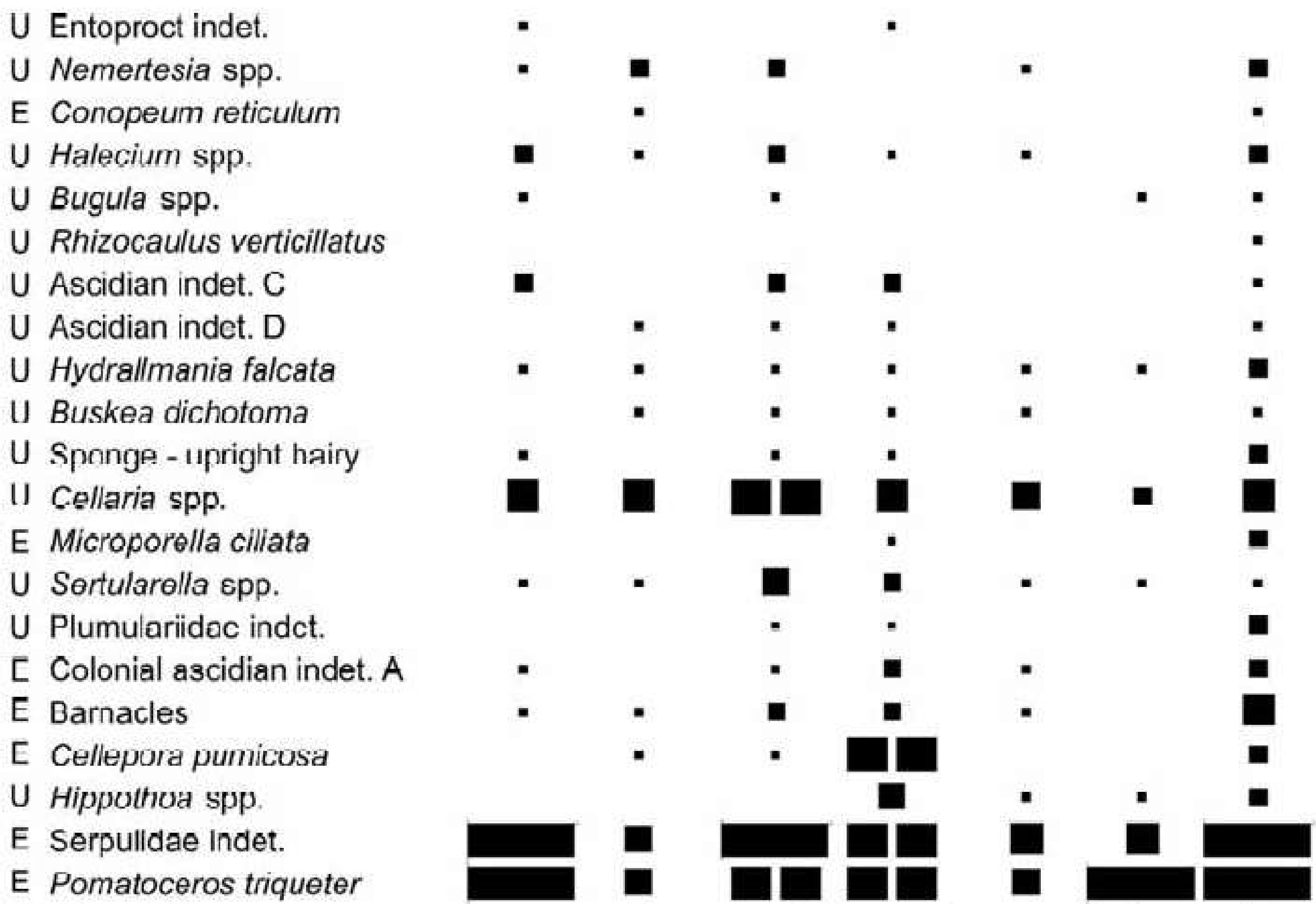
Why are indirect effects important to be aware of?

- May cause ‘positive’ effects (e.g. increases in numbers, increased rates of an ecological process)
- May mask or spuriously indicate direct contaminant effects
- May affect species that are resistant to the original stressor
- May have a larger effect than the original stressor
- Mechanisms may be hard to identify

Ecosystems as ecological networks

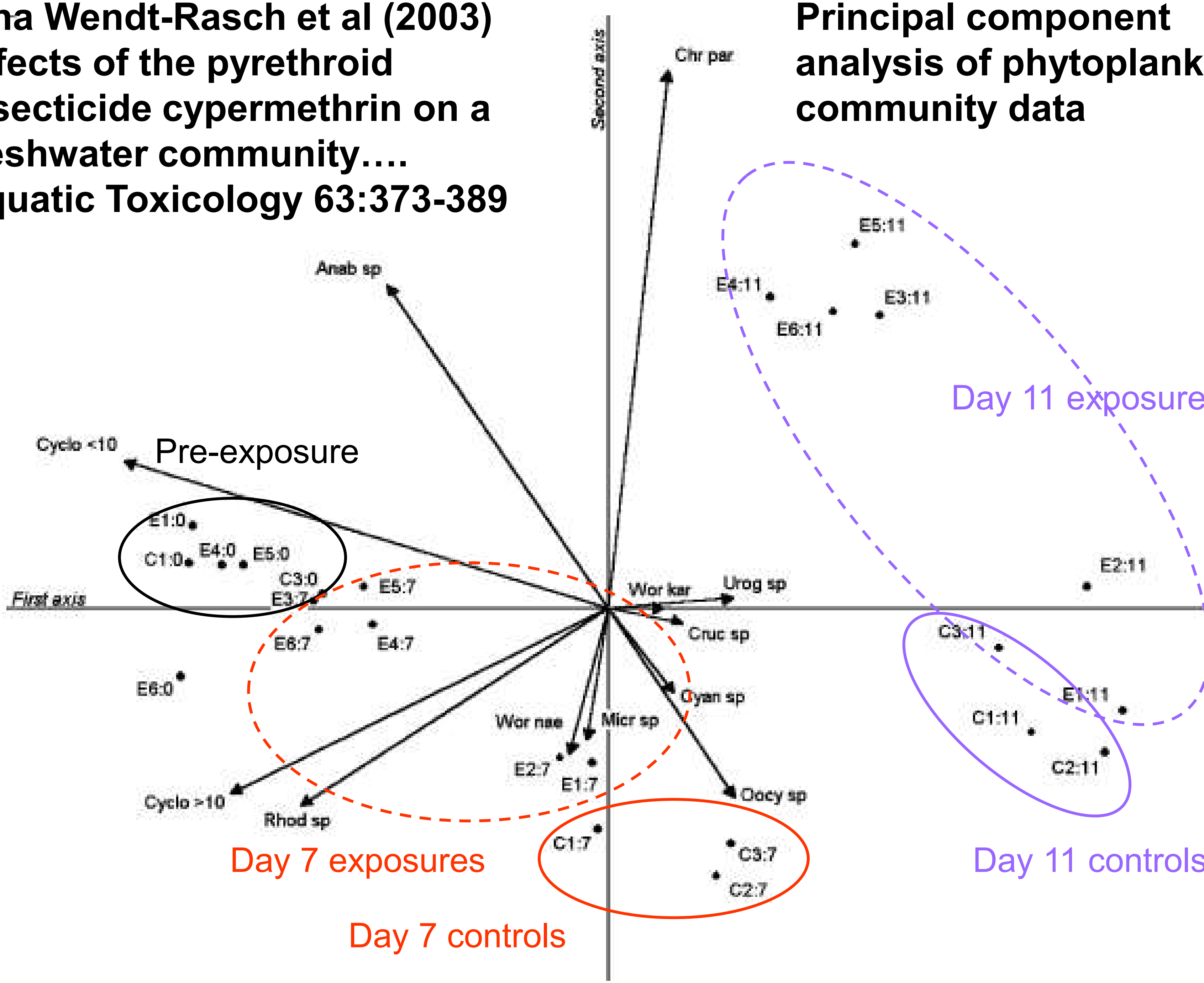
- More than just the organisms/nodes – also the connections between them (and their environment)
- Feedback loops (positive or negative)
- Complexity => resilience? (functional redundancy)
  - Complexity in terms of # of species or functional groups or traits
  - Complexity in terms of connectivity
- Networks, nodes and connectivity

Ecosystems/communities are often quantified in terms of taxonomic composition…

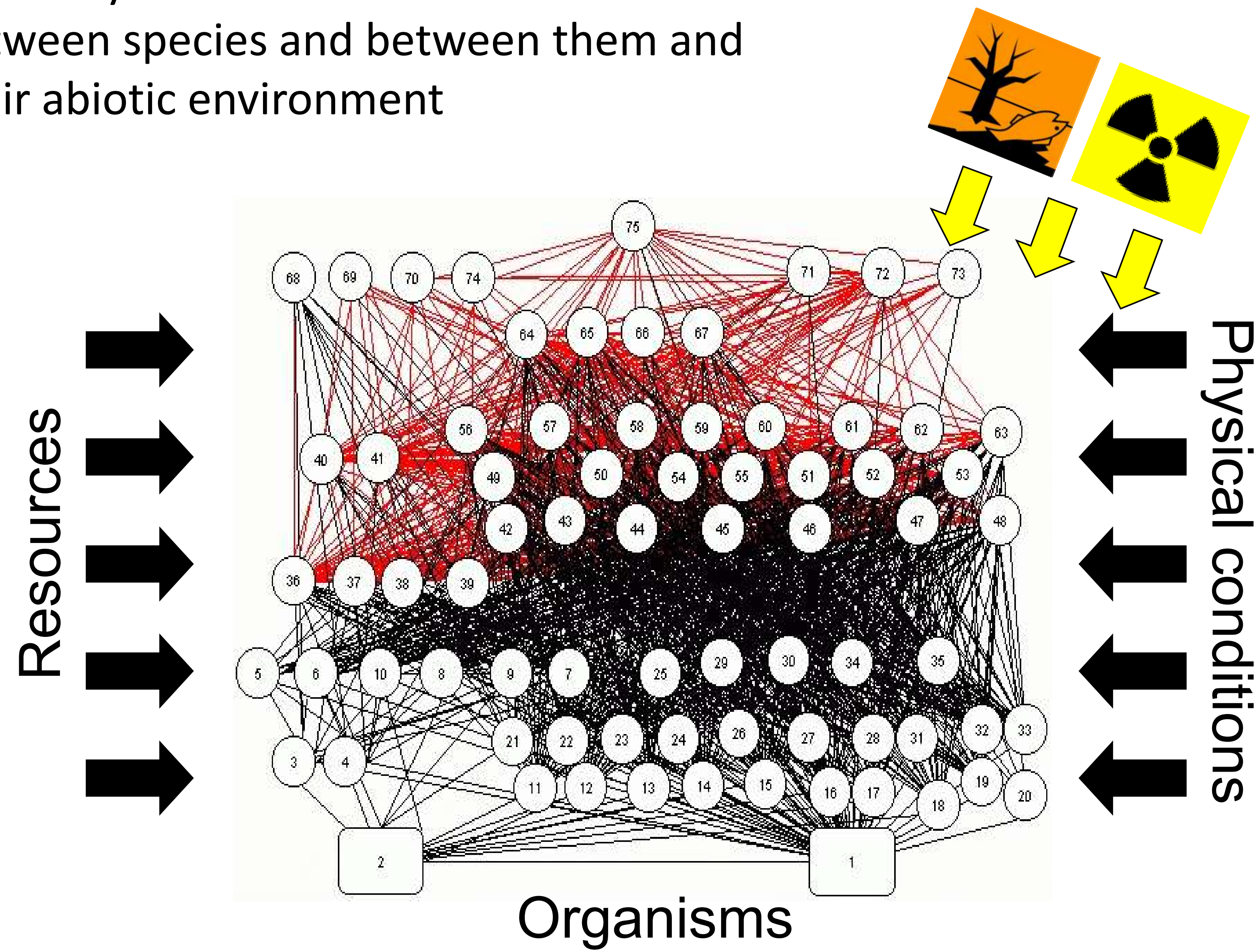


Lina Wendt-Rasch et al (2003) Effects of the pyrethroid insecticide cypermethrin on a freshwater community…. Aquatic Toxicology 63:373-389

Principal component analysis of phytoplankton community data



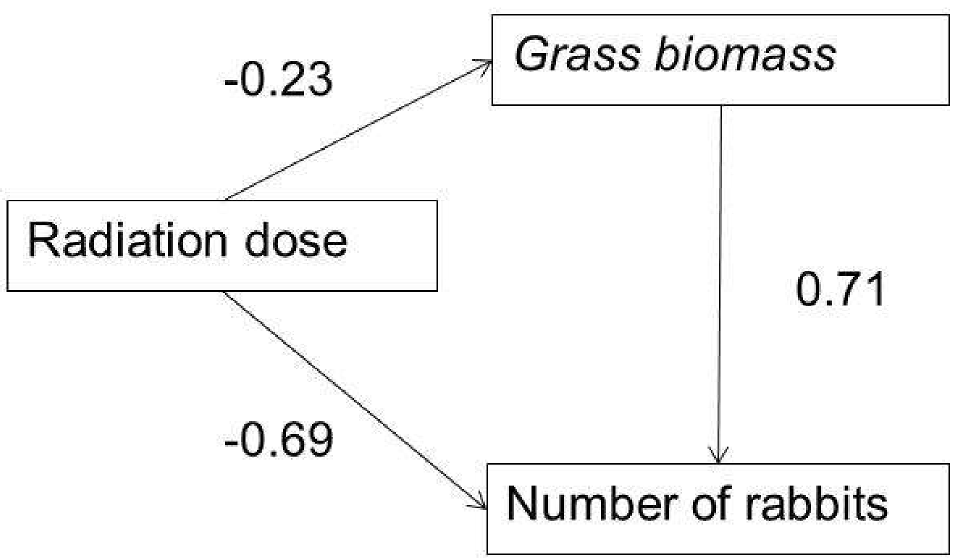
But ecosystems also include the **links** between species and between them and their abiotic environment



NW Atlantic Shelf Ecosystem adapted from Link et al (2002)

Path analysis

- A form of multiple regression focusing on causality
- Estimates the strength of interactions between species and e.g. pH, contaminants...
- Requires prior knowledge of these interactions



(Note: purely hypothetical example!)

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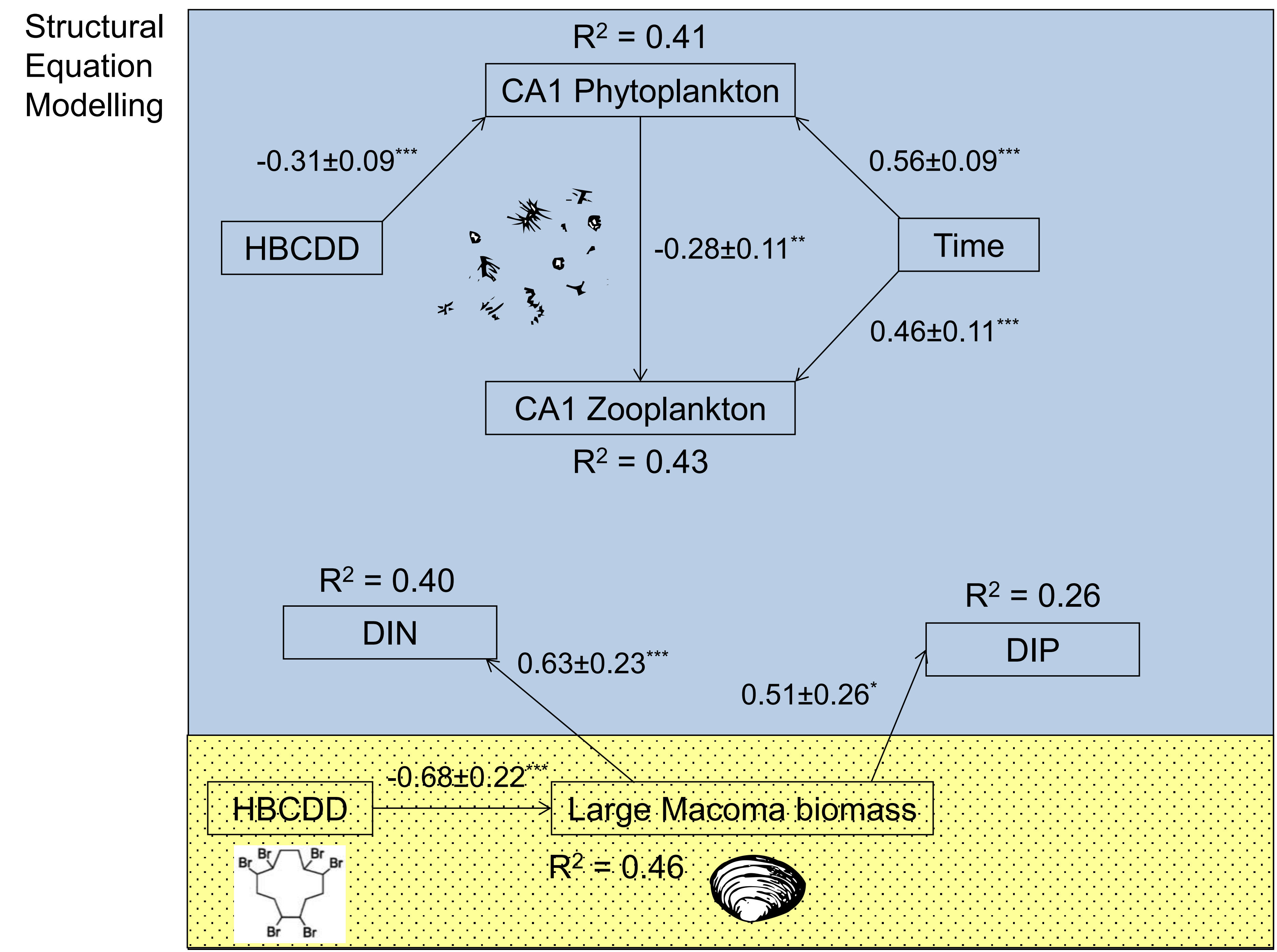
Volume 206
(2015): 306-314

Hexabromocyclododecane affects benthic-pelagic coupling in an experimental ecosystem

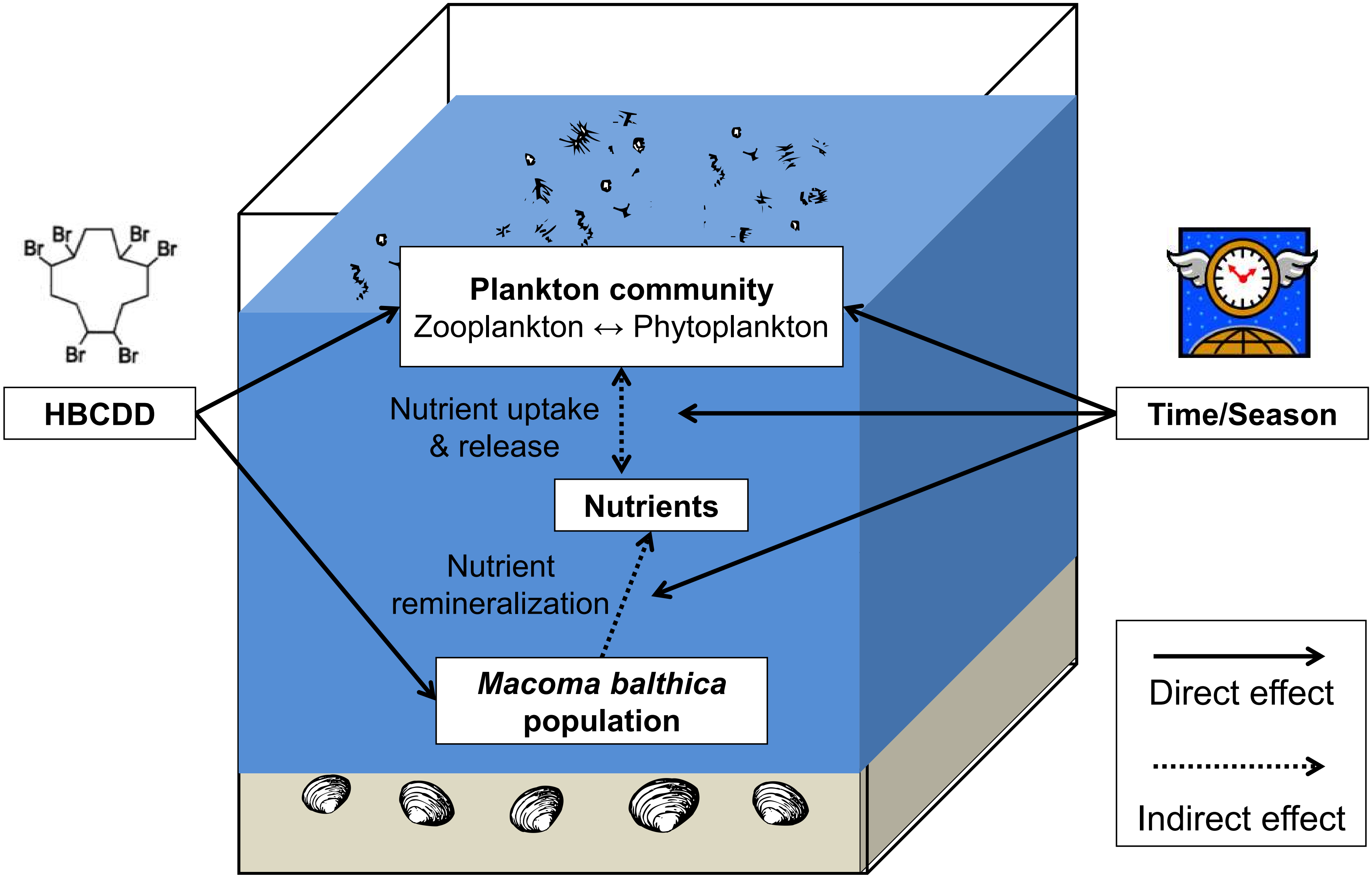
Clare Bradshaw [a,1,3], Johan Näslund [b,*,3], Joakim Hansen [b,2], Betina Kozlowsky-Suzuki [c], Bo Sundström [d], Kerstin Gustafsson [a]

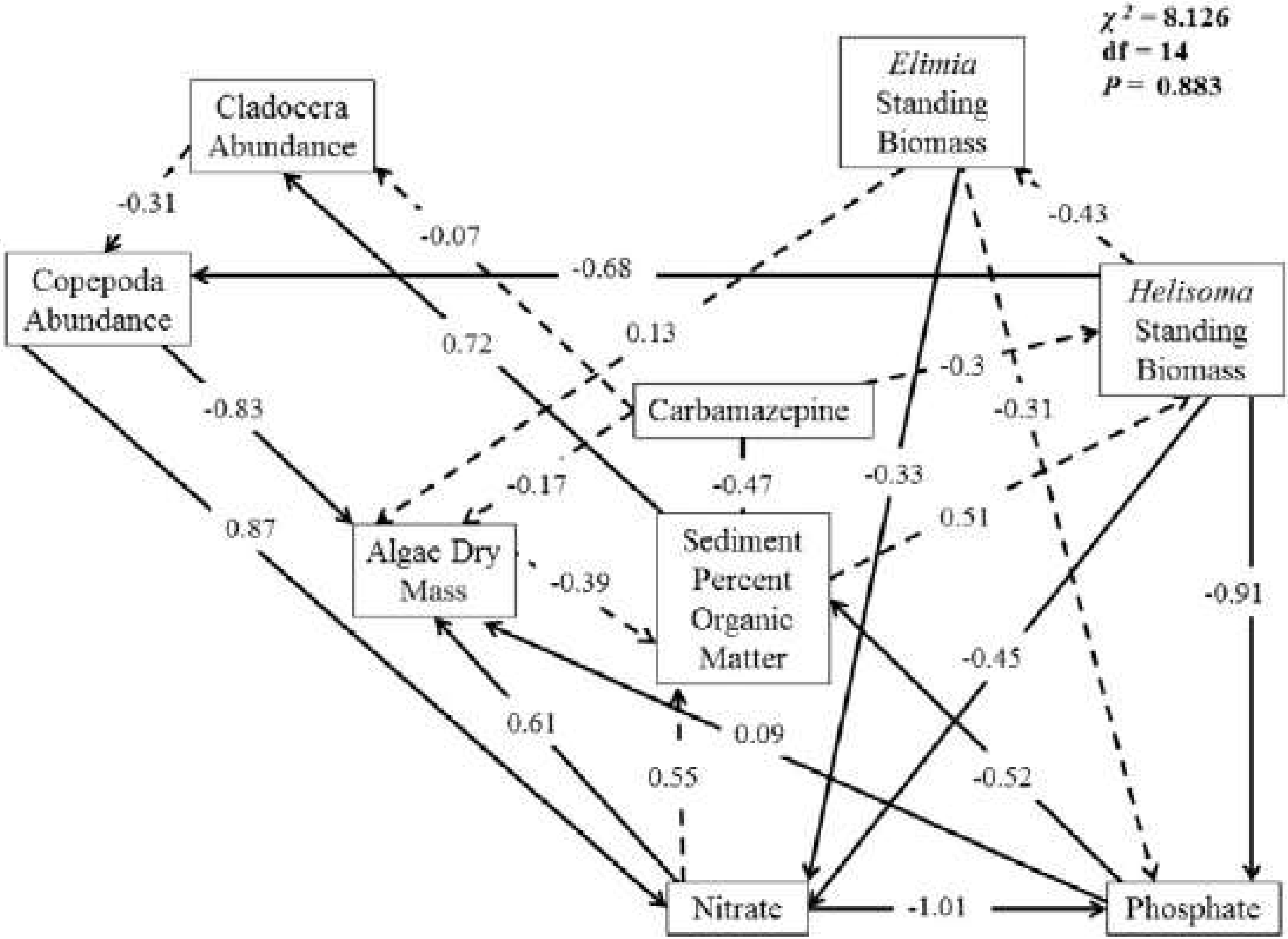
HBCDD = a flame retardant)

Gradient design


Structural
Equation
Modelling
R2 = 0.41
CA1 Phytoplankton
-0.31±0.09***
0.56±0.09***
HBCDD
-0.28±0.11**
Time
0.46±0.11***
CA1 Zooplankton
R2 = 0.43
R2 = 0.40
DIN
R2 = 0.26
DIP
0.63±0.23***
0.51±0.26*
-0.68±0.22***
HBCDD
Large Macoma biomass
R2 = 0.46
Br
Br
Br
Br
Br
Br

In summary: HBCDD affects benthic-pelagic coupling

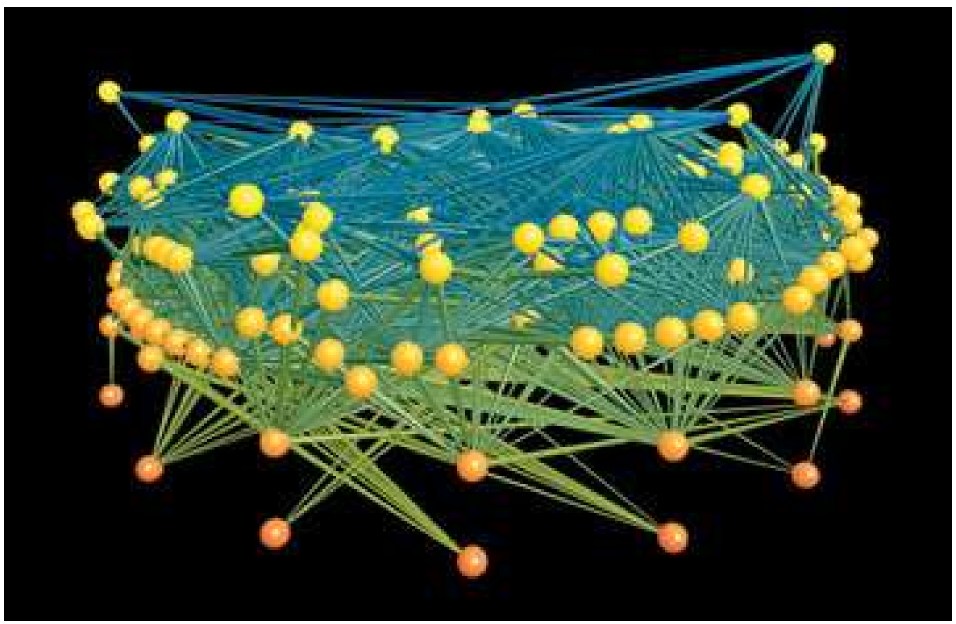




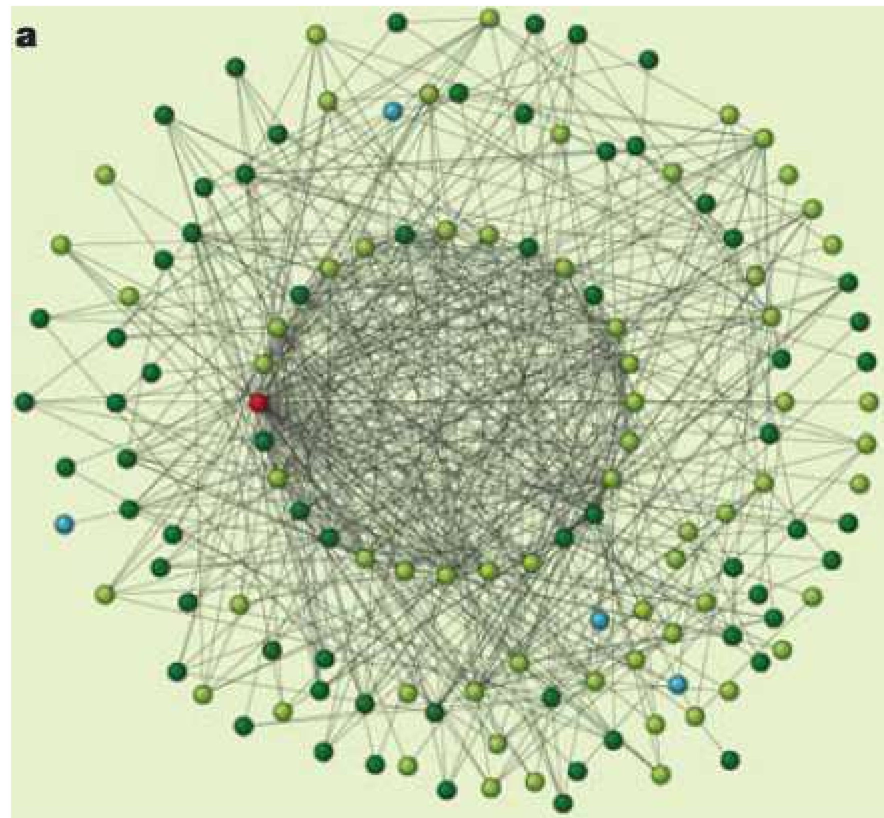
Jarvis et al (2014). The effects of the psychiatric drug carbamazepine on freshwater invertebrate communities and ecosystem dynamics. Sci Tot Env 496: 461–470

Ecological Network Analysis

A methodology to holistically analyse environmental interactions



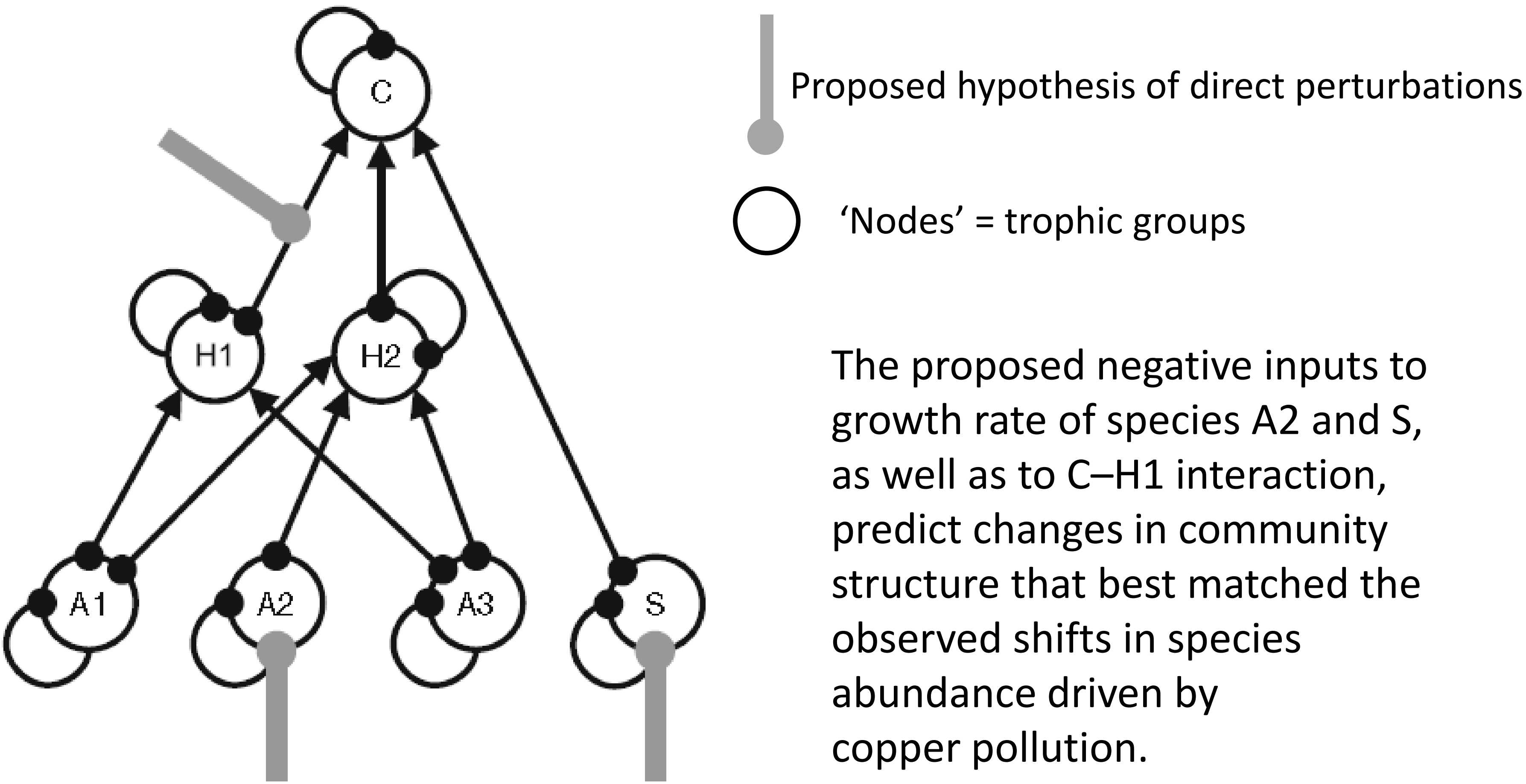
Aleutian Islands food web (noaa.gov)



Ythan estuary food web
Montoya et al (2006) Nature 442: 259-264

Ecological Network Analysis

(example from a copper-polluted intertidal community)



The proposed negative inputs to growth rate of species A2 and S, as well as to C–H1 interaction, predict changes in community structure that best matched the observed shifts in species abundance driven by copper pollution.

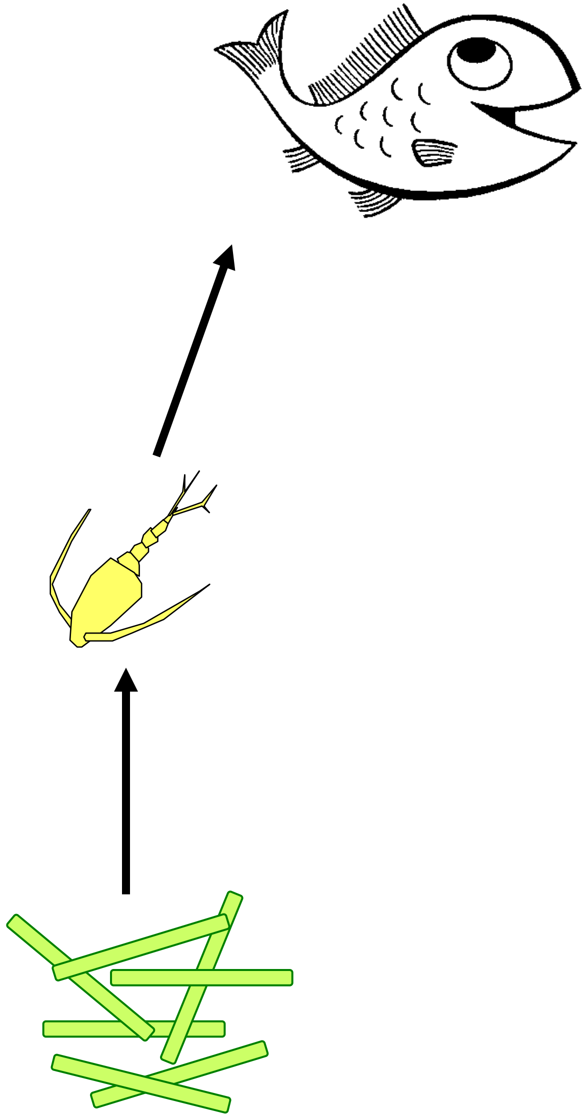
Ramos-Jiliberto et al (2012) Ecotoxicology 21:234–243

Ecological Network Analysis

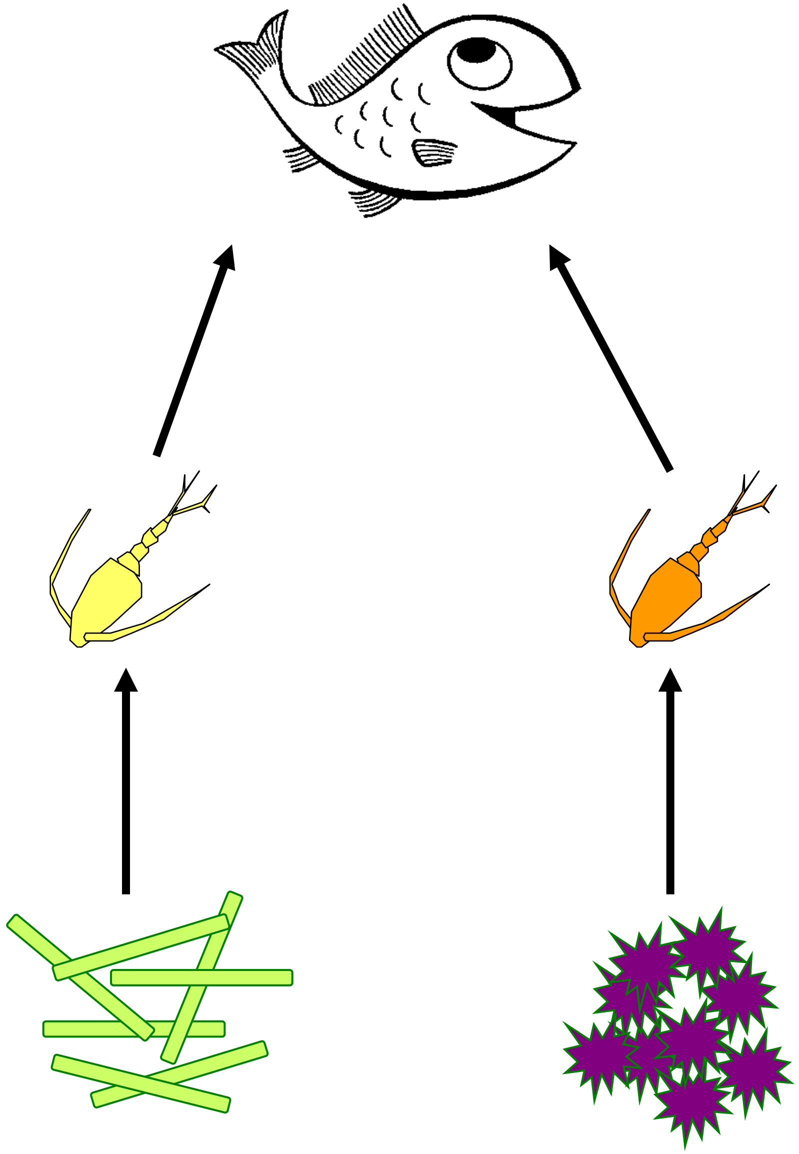
- Explore importance of
  - any one particular node
    - e.g. identification of keystone species - species that often determine network stability and vulnerability to cascading secondary effects
  - number of nodes (ie. diversity)
  - strength and degree of connectivity
    - high connectivity with redundancy = resilient to disturbance
- Identify particularly sensitive nodes or links
  - early warning indicators
- Identify feedback loops (positive or negative)

Fath et al (2007) Ecological Modelling 208: 49–55
Grey et al (2014) J. Applied Ecology 51: 1444–9
Montoya et al (2006) Nature 442: 259-264

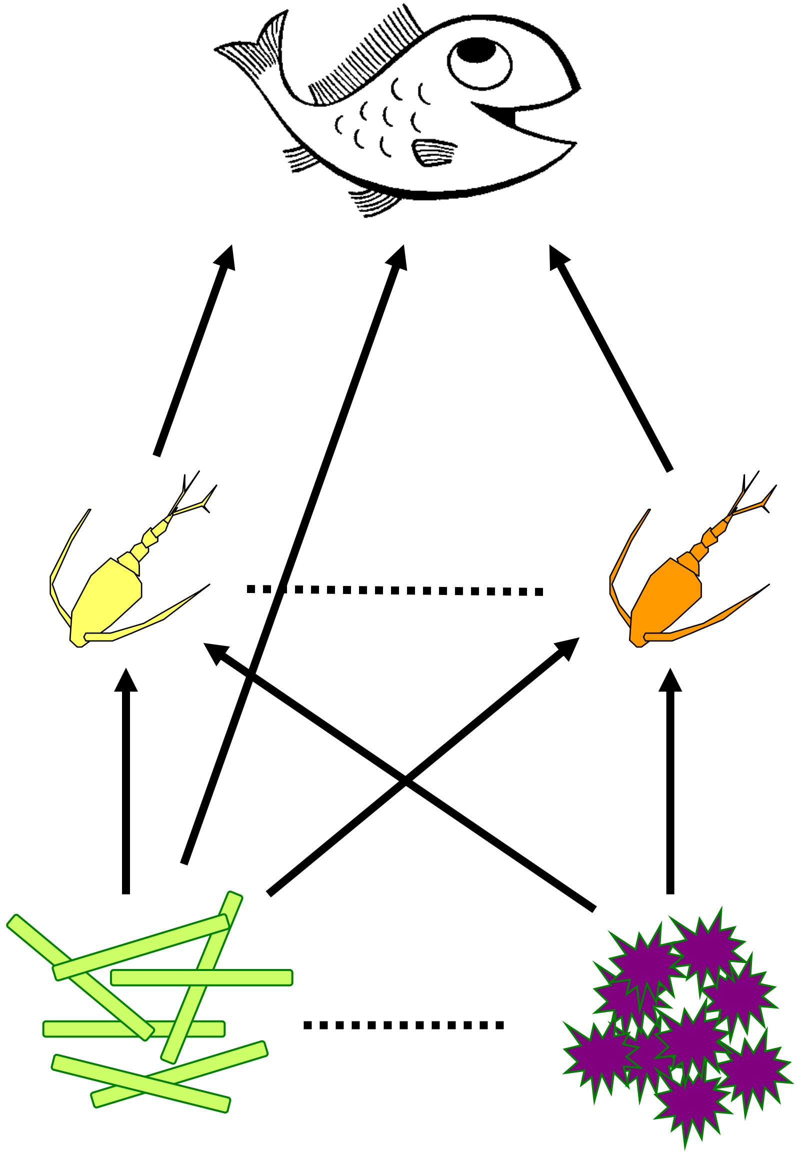
Simple linear system

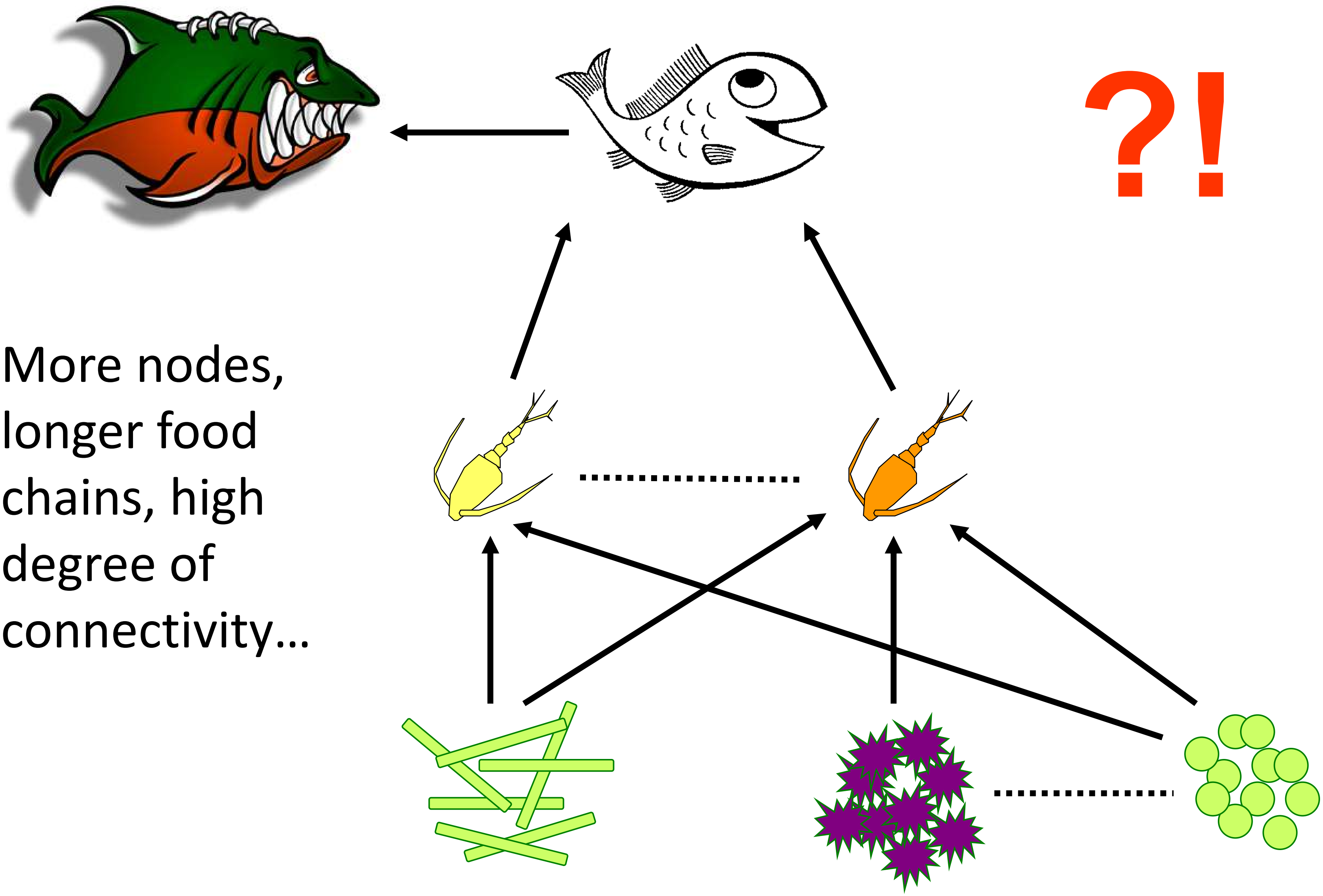


2 trophic pathways, little connectivity



Same number of nodes, but high degree of connectivity





More nodes, longer food chains, high degree of connectivity…

Ecosystem approach

Advantages

- ✓ enables implicit consideration of the net effects of contamination, integrating all direct and indirect effects (multiple stressors/ contaminants, species interactions, different responses to different types of radiation, spatial and temporal issues and natural variation)
- ✓ consistent and compatible with the Ecosystem Services concept
- ✓ consistent with most stated management objectives

Challenges

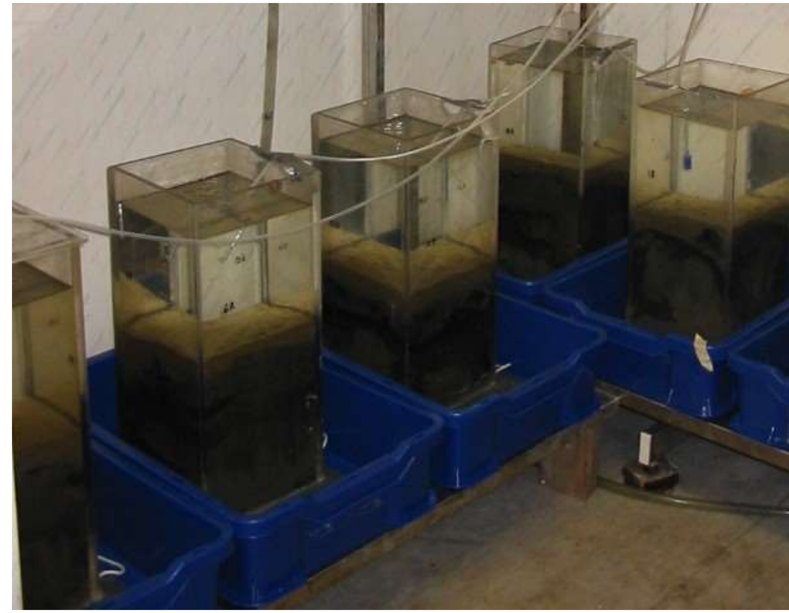
- ? lack of good experimental and field data to evaluate ecosystem-level effects
- ? multi-species dynamic models lacking
- ? ecosystem models require knowledge of many parameters that are not readily available
- ? modelling may need to explicitly consider ecosystem complexity and/or emergent properties
- ? ecological factors and variability can be more important than radiation effects – may need a different conceptual methodology?

What next?

- Start thinking more in networks rather than linearly
- Don't forget functional endpoints (processes)
- More manipulative ecosystem experiments?
  - enclosures, transplantations, radionuclide applications…etc
  - mesocosm experiments

Spares

accuracy, reliability



single species experiments

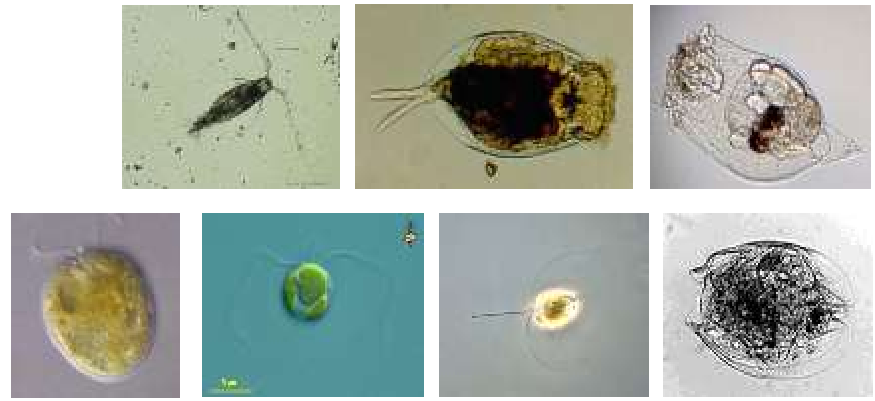
microcosm/ mesocosm/ model ecosystem studies

ecosystem / field studies

environmental relevance

What's different about ecology?

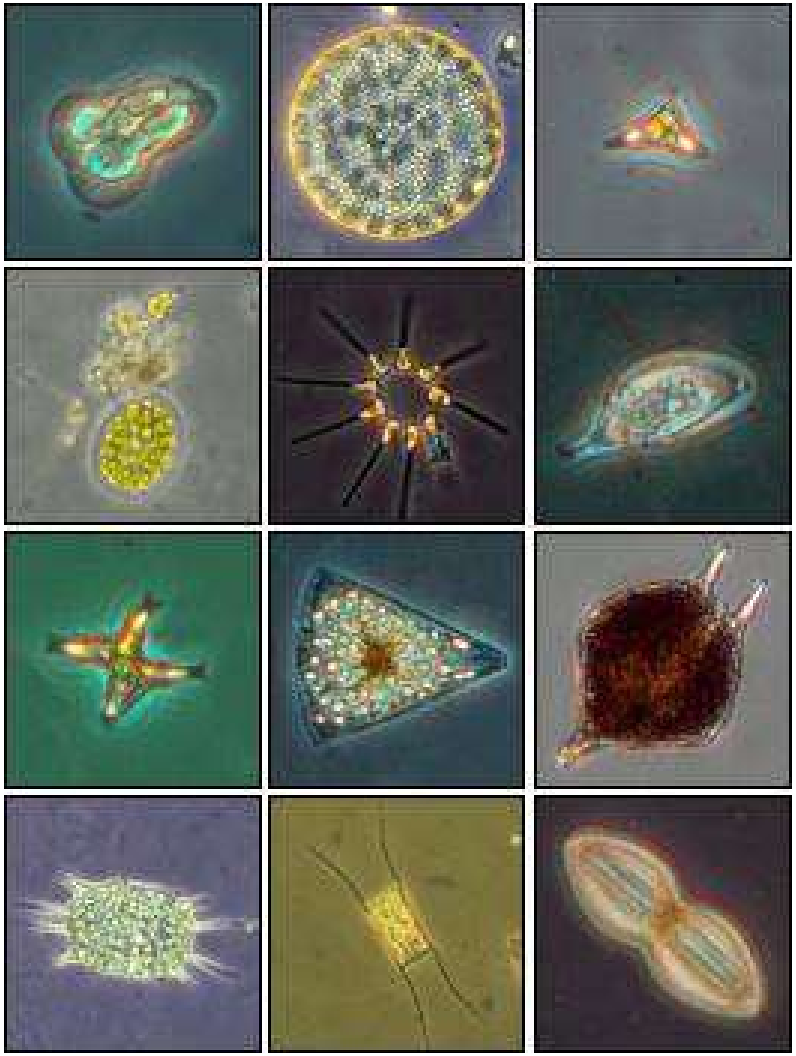
- Ecological processes
  - can strongly influence uptake and exposure to contaminants
  - Can cause indirect effects



Effects at 'higher' levels are complicated by:

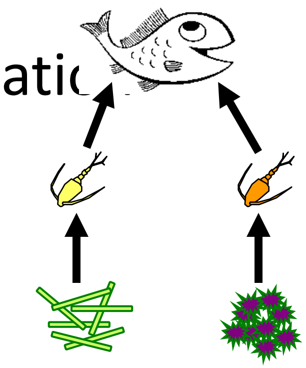
- Secondary (or indirect) responses
- Exposure dependencies
- Ongoing recovery and repair
- Spatial/temporal variations in exposure
- Seasonal differences in response
- Timing of damage expression

(but that's the reality…!)

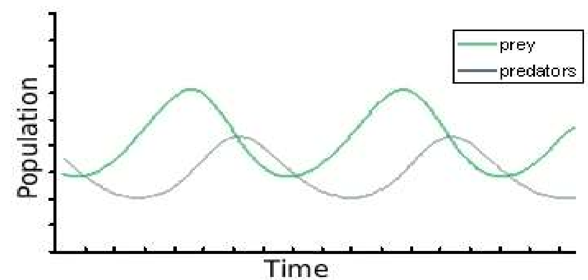


A short note on (ecosystem) modelling

- Foodweb models where contaminants affect population growth and thus food availability or feeding rates
  - Difficult to apply to complex systems
  - Assume consumption proportional to food supply



- Models of interacting populations
  - Difficult for >2 species



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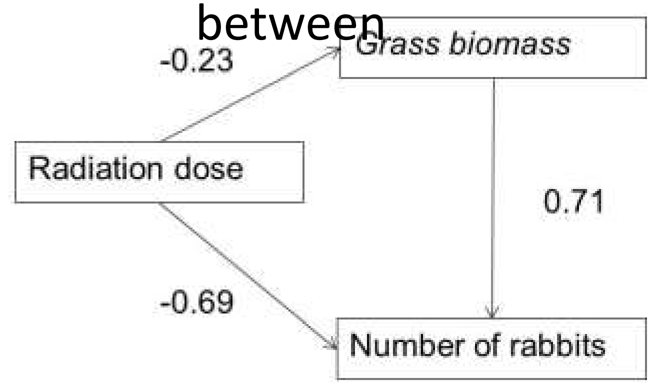


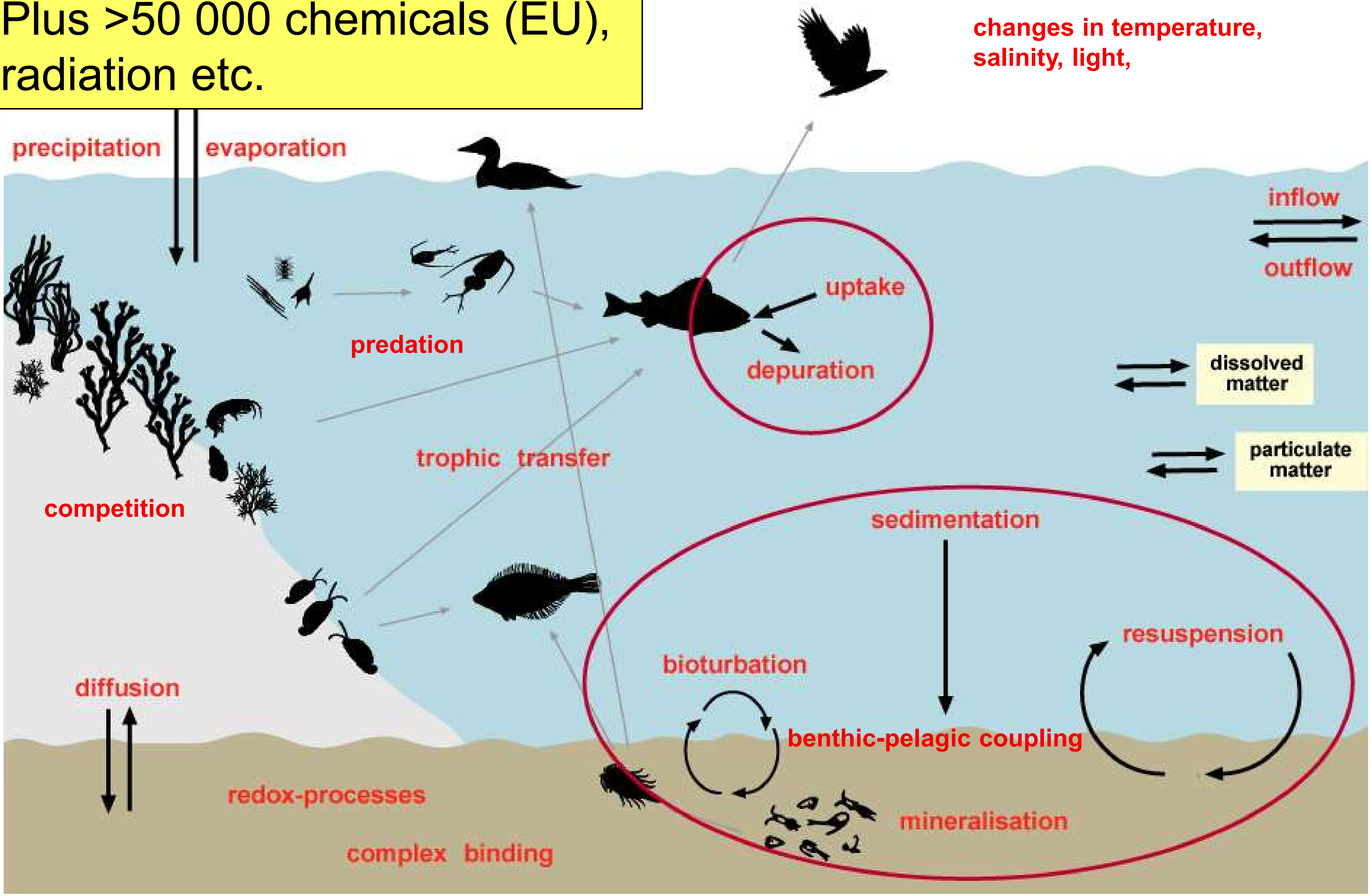
Ecosystem effects

- Structural
  - often a result of lethal effects
  - species composition
  - diversity
  - biomass

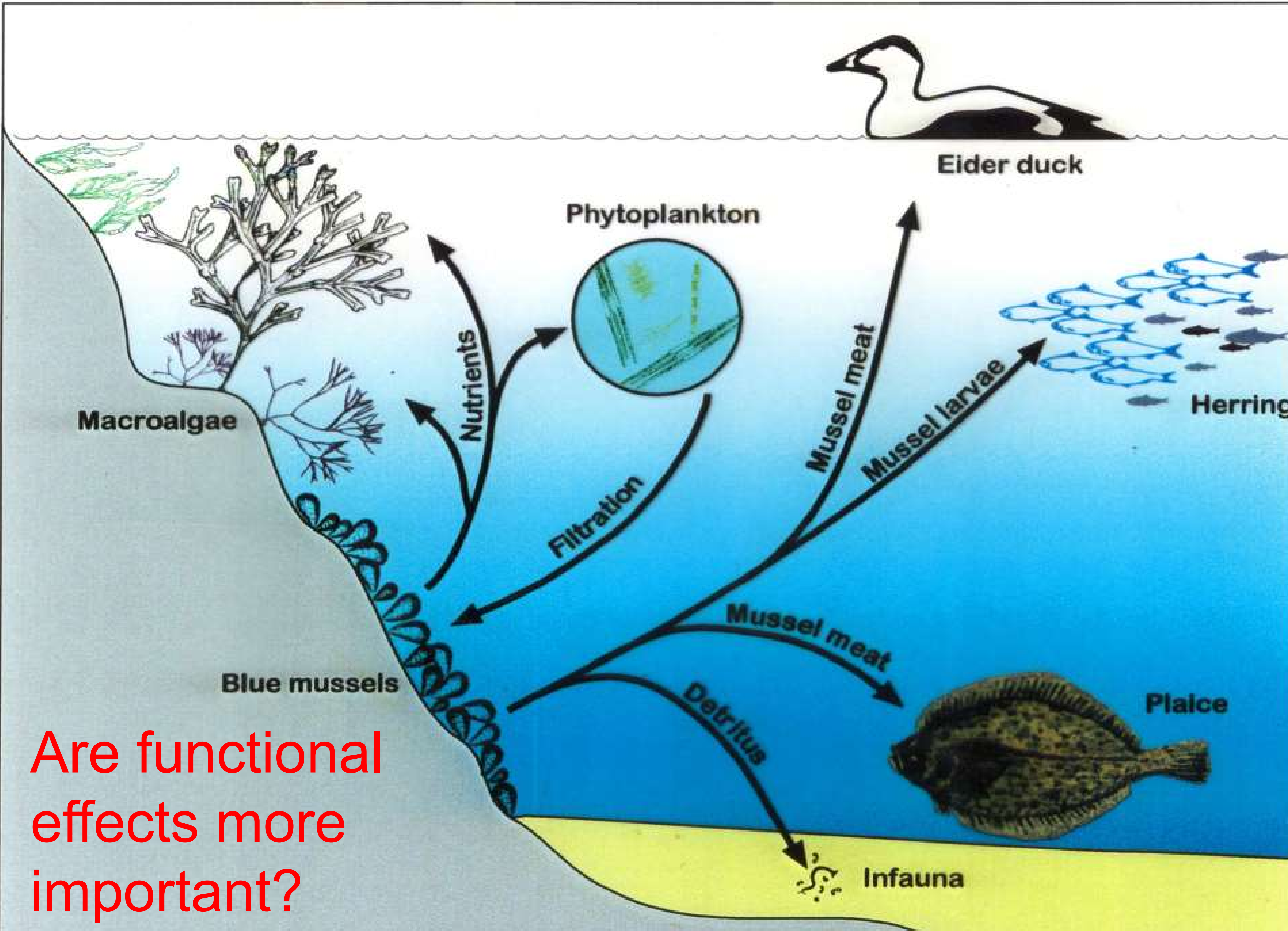
- Functional
  - often a result of sub-lethal effects
  - metabolism
  - “scope for growth”
  - energy flow
  - nutrient cycling
  - organic matter decomposition
  - behaviour
  - reproduction

Functional effects may appear first and be transient

Plus >50 000 chemicals (EU), radiation etc.

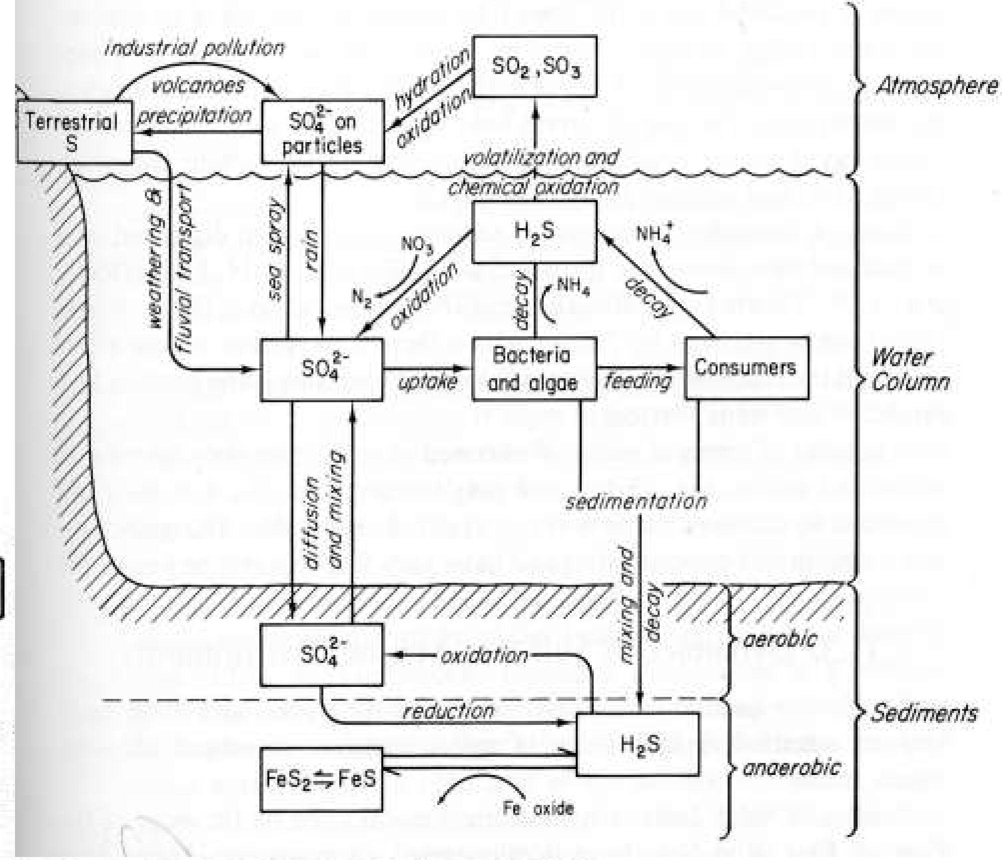


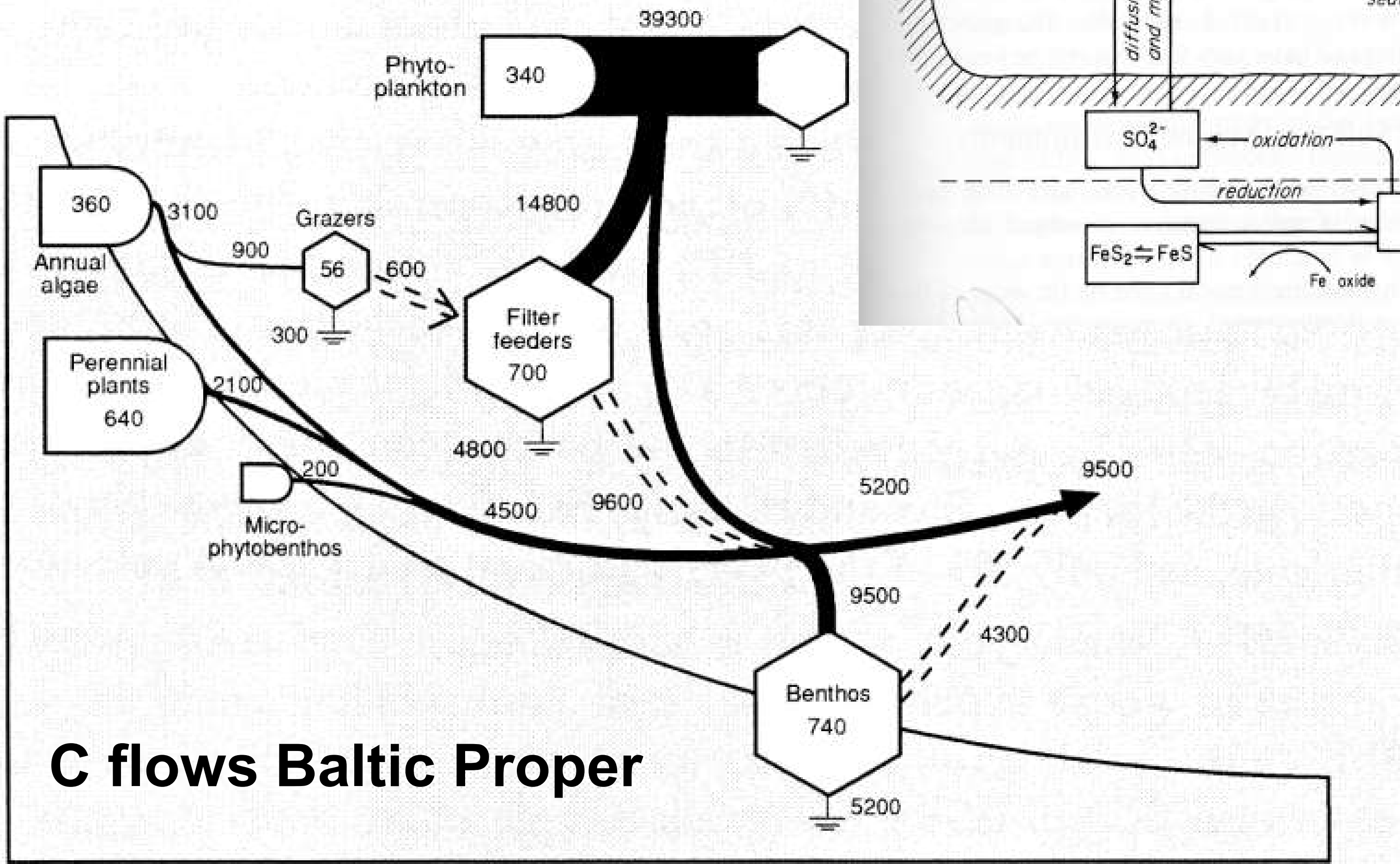
The function of the blue mussel



Are functional effects more important?

Generalised S cycle





C flows Baltic Proper

- Disturbance acts on a community through biological processes, for example by affecting competition
- Ecological interactions between organisms and their abiotic environment
  - may be affected by toxicant exposure
  - will themselves influence the effect caused by toxicant exposure