Challenges of Integrating Ecosystem Science into Radioecology

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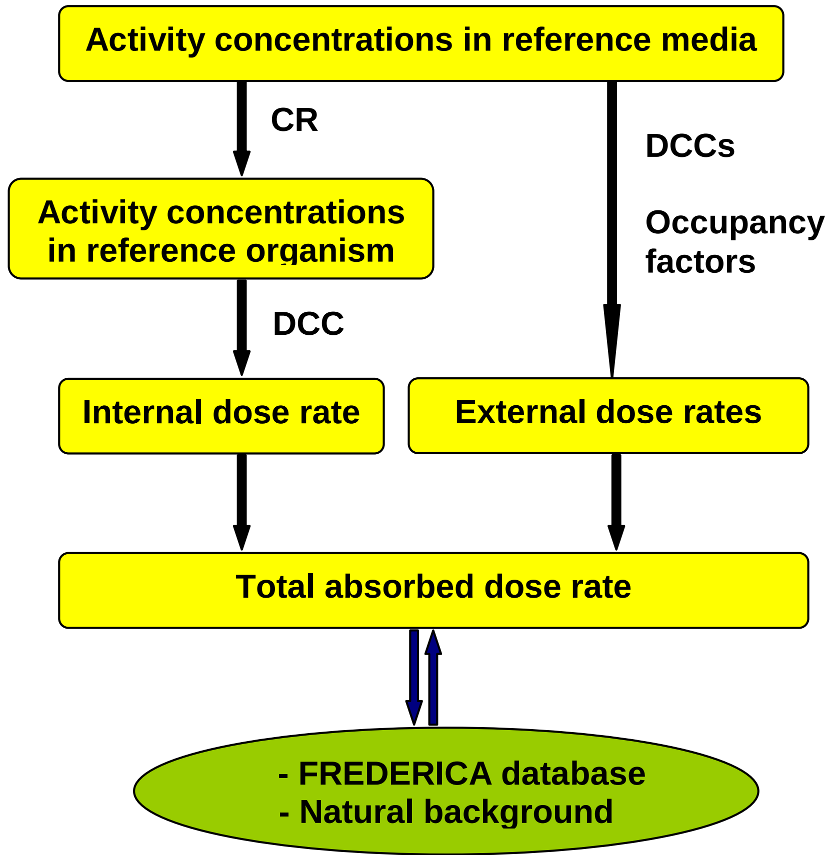
Historical and political challenges

- Strong influence of radiation protection frameworks
- Lack of ecologists
  - Recruit and collaborate with ecologists, adopt ecological approaches!
- Isolation of radiation as a stressor and radioecology as a science
  - But radionuclides / radiation are just one of many forms of ecological stress!

Radiation protection frameworks and the reference organism focus

- A selection of organisms that act as models for calculating exposure/dose/risk for effects
- Absorbed dose-rates calculated using simple dosimetric models using measured or derived activity concentrations of radionuclides in organisms and their habitat
- Risk assessed using dose rate bands within which certain effects have been noted, or might be expected
- Radiosensitivity assessed using individual organism-level endpoints: early mortality, morbidity, reproductive success, and mutation frequency

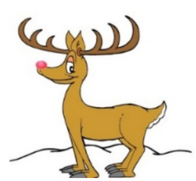










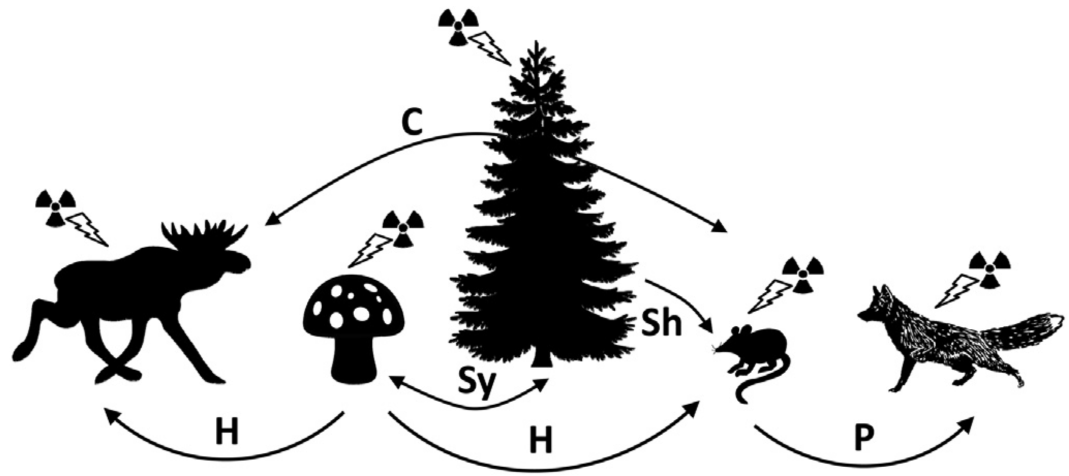



Pros and cons of the reference organism approach.

- Relatively simple, so convenient for risk assessment
- Maybe OK if they are the most sensitive and/or most exposed

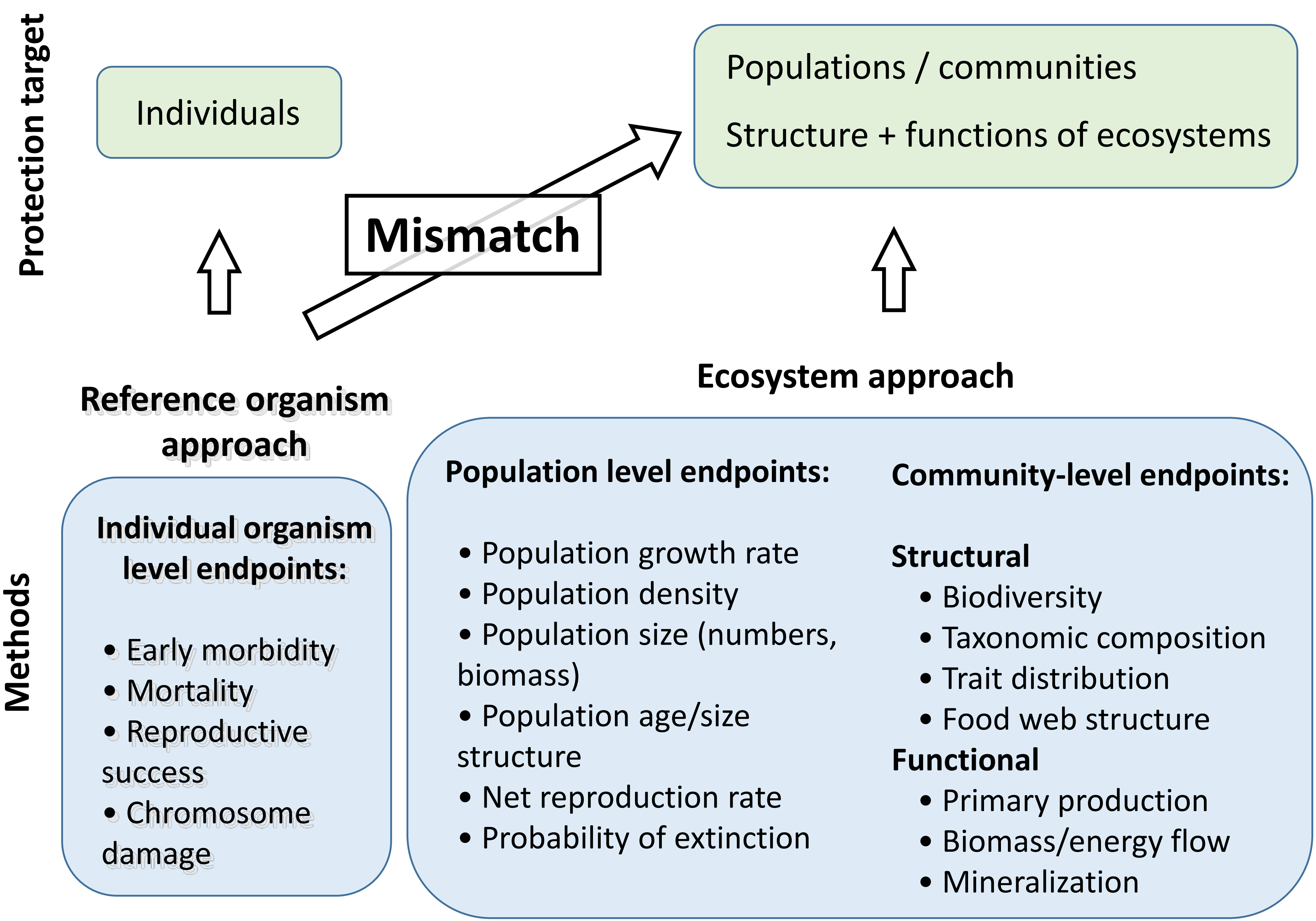
BUT

- The approach does not include ecological interactions
- There can be non-linear changes in ecosystem structure and function that cannot be predicted from effects on individual organisms.
- So this approach cannot guarantee the protection of all components of an ecosystem.



C = competition
P = predation
H = herbivory
Sy = symbiosis
Sh = shelter

Bradshaw et al (2014)



Bradshaw et al (2014)

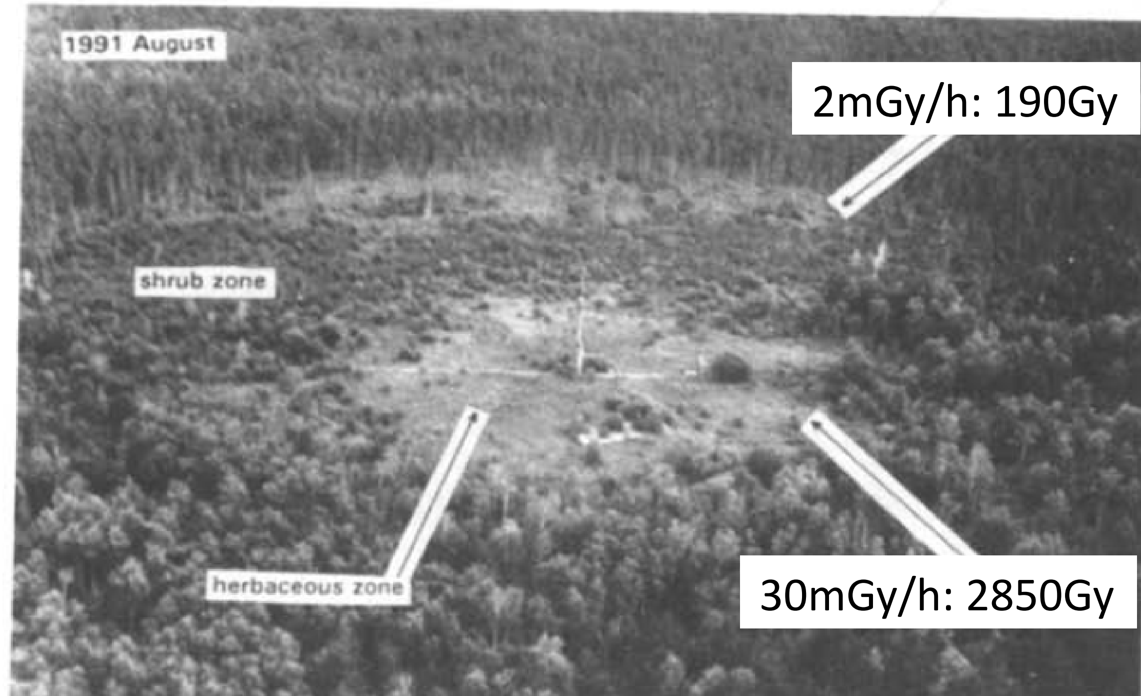
Scientific Challenges

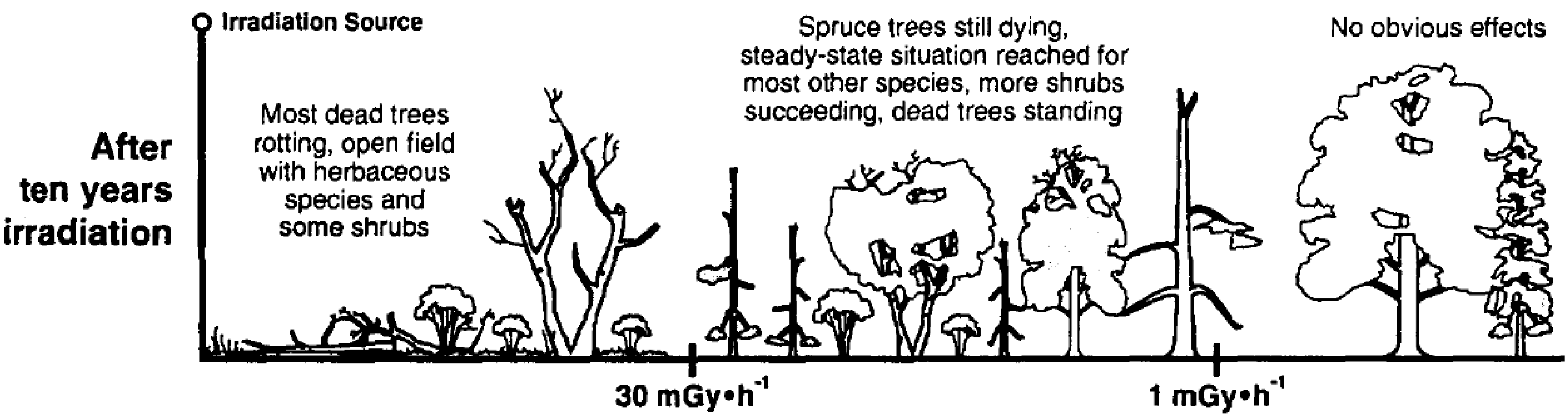
1. Lack of convincing experimental and field evidence for ecosystem effects of radiation at environmentally relevant doses / dose rates
    - Most evidence is from high dose experiments (field and lab)
2. Lack of agreement over results of field studies
    - Partly due to poor dosimetry
    - Partly due to poor design of experiments / field studies
    - Partly due to lack of agreement with single species lab results
3. Natural variability and the influence of other factors than radiation need to be better dealt with
4. Non-linear and indirect effects, complexity are common! (and rarely considered in radioecology)
5. Need models that adequately/explicitly deal with ecosystem complexity

1. Lack of good experimental and field data to evaluate ecosystem-level effects of radiation

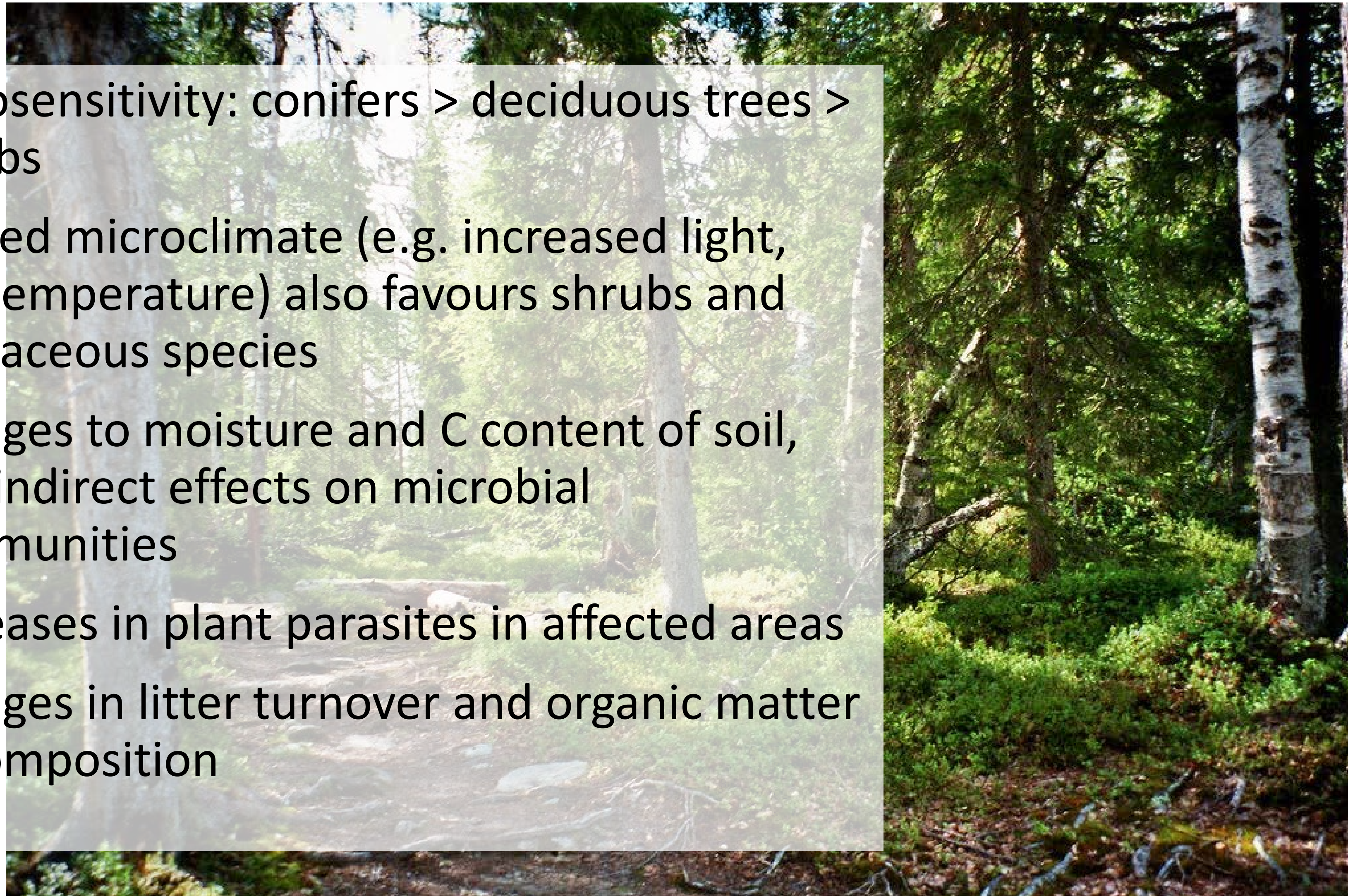
Much of the evidence is from high dose experiments

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





Indirect effects – example from forest field studies



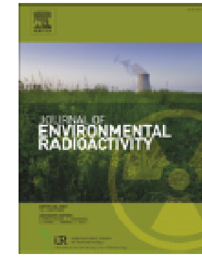
- radiosensitivity: conifers > deciduous trees > shrubs
- altered microclimate (e.g. increased light, soil temperature) also favours shrubs and herbaceous species
- changes to moisture and C content of soil, and indirect effects on microbial communities
- increases in plant parasites in affected areas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

(note – based mostly high dose experiments, external doses only)

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

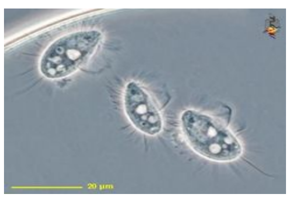


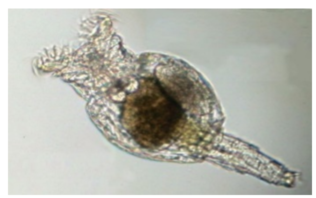
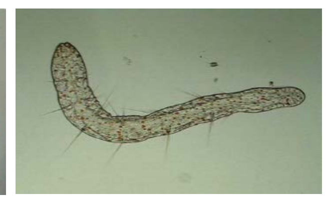
JER 101: 915-922

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

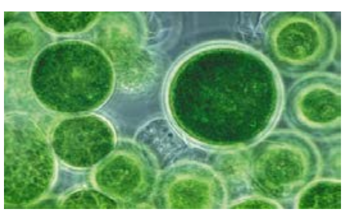
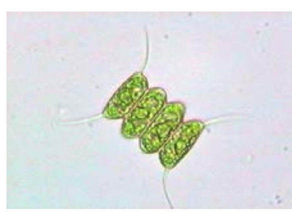
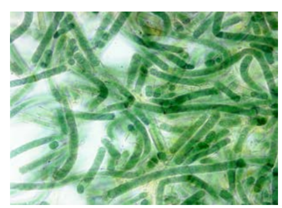
Shoichi Fuma [a,*], Nobuyoshi Ishii [a], Hiroshi Takeda [a], Kazutaka Doi [b], Isao Kawaguchi [b], Shuichi Shikano [c], Nobuyuki Tanaka [d], Yuhei Inamori [e]

Consumers: a ciliate protozoan, 2 rotifers and an oligochaete



Primary producers: 2 green algae and a blue-green alga

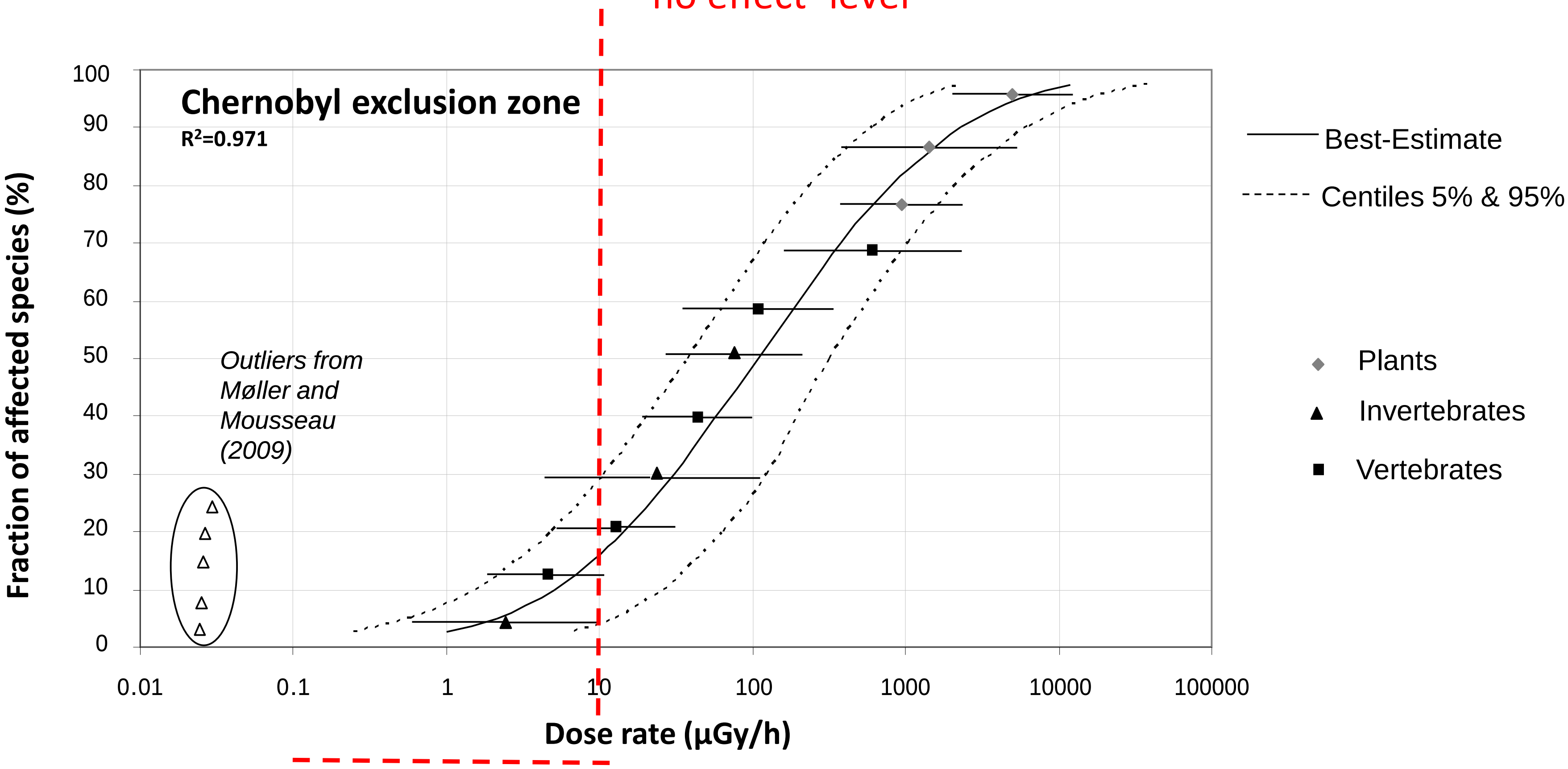




Decomposers: >4 species of bacteria

- 160 days of acute irradiation (100, 500, 1000, 5000 Gy at 31 Gy min^{-1})
- Both negative and positive population changes seen

2. Lack of agreement on field results

10µGy/h = ERICA expected 'no effect' level

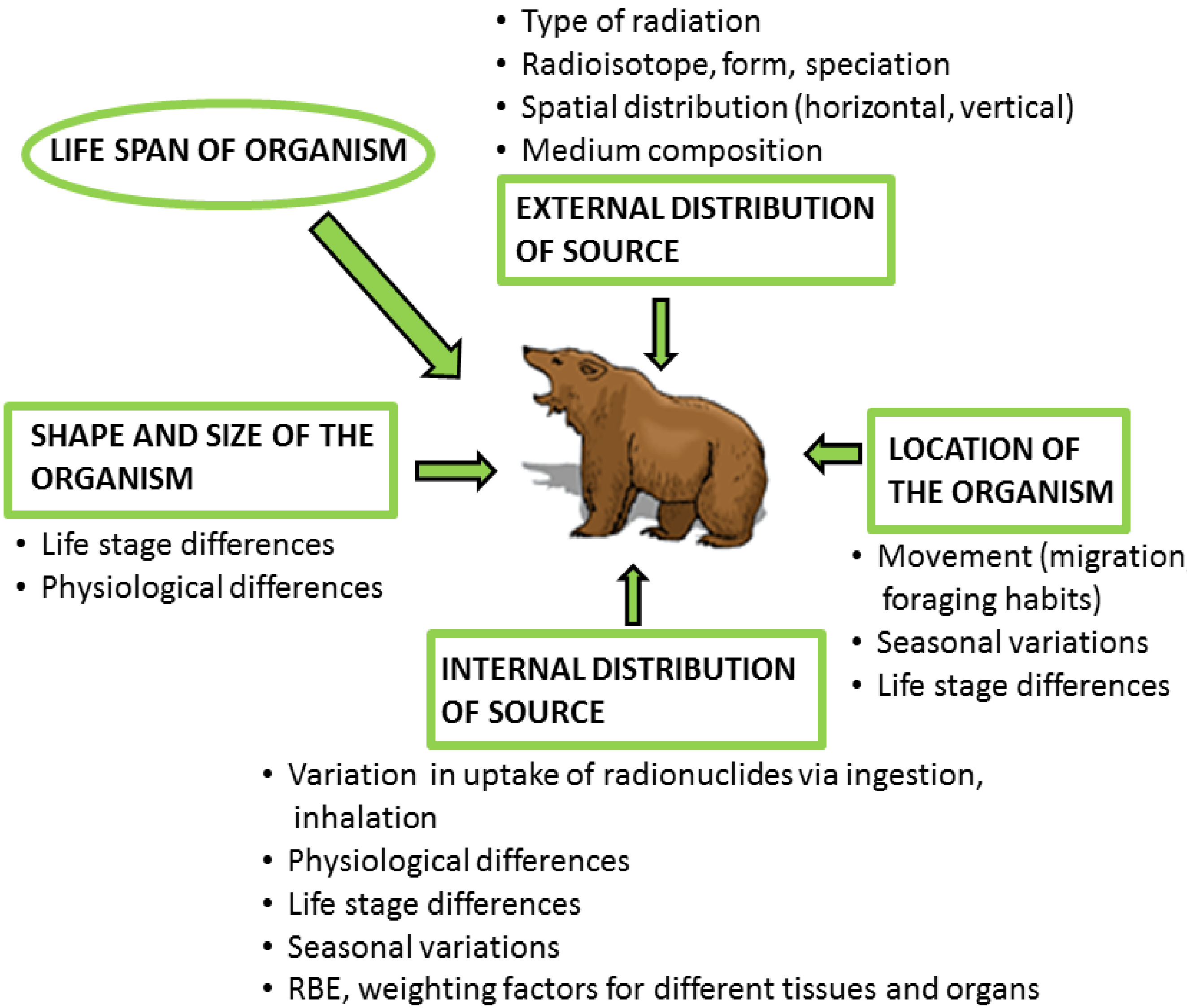


Range of natural background radiation in UK

Adapted from Garnier-Laplace et al (2013)
With thanks to Nick Beresford for UK data

The challenge of accurately estimating of dose (rate)s

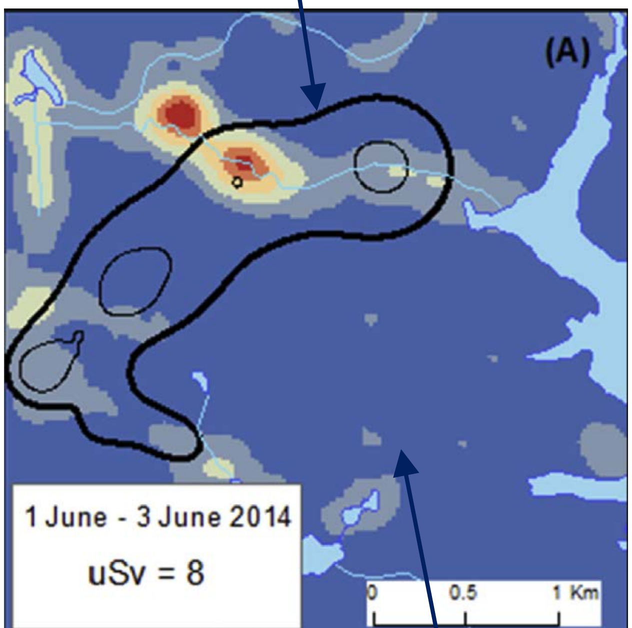
- Dose (rate)s have not always been well quantified.
- Increased awareness of the importance of this.
- E.g.: Recalculation of dose rates to birds in Fukushima (Garnier-Laplace et al., 2015):
  - ambient dose rate 0.16 - 31 µGy/h, recalculated dose rates 0.3 - 97 µGy/h
  - observed effects more in line with what would be expected using recalculated dose rates.



From Stark et al (in prep).

New efforts to quantify doses to mobile organisms in heterogeneous habitats

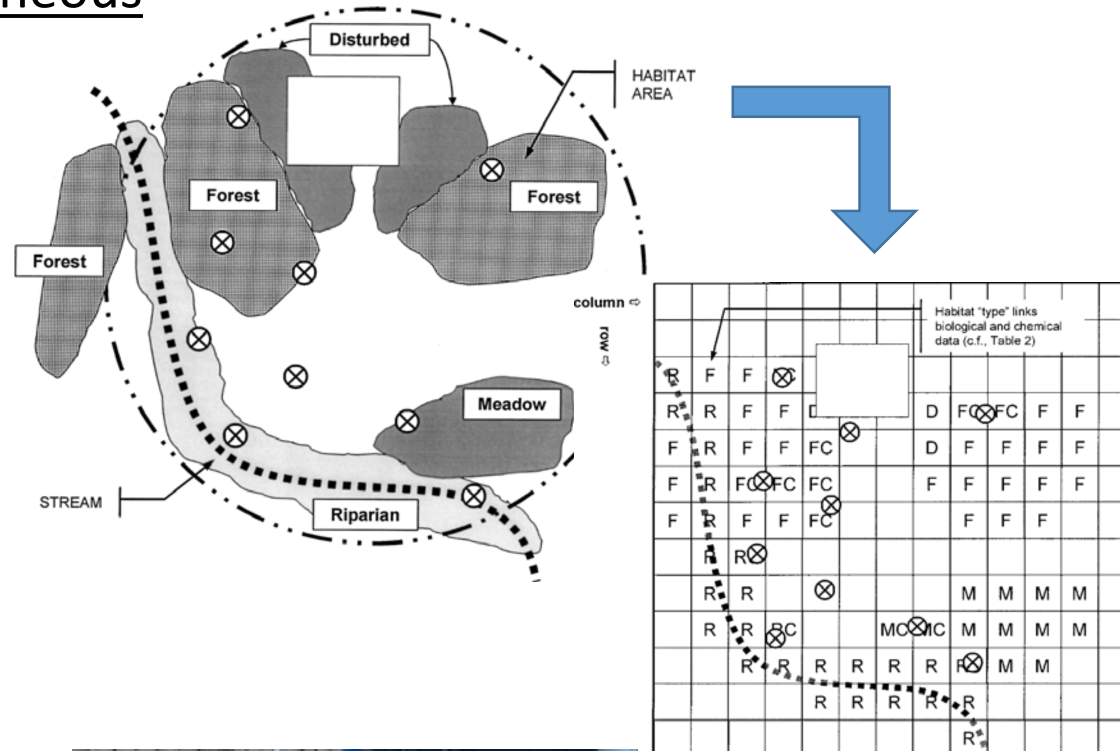
Area where an adult wild pig spent 95% of its time



Cs-137 contamination from aerial survey

Hinton et al (2015) JER 145: 58-65

Modelling approaches to predict habitat utilisation and exposure (dose)



Hope (2005) Hum Ecol Risk Ass v.11

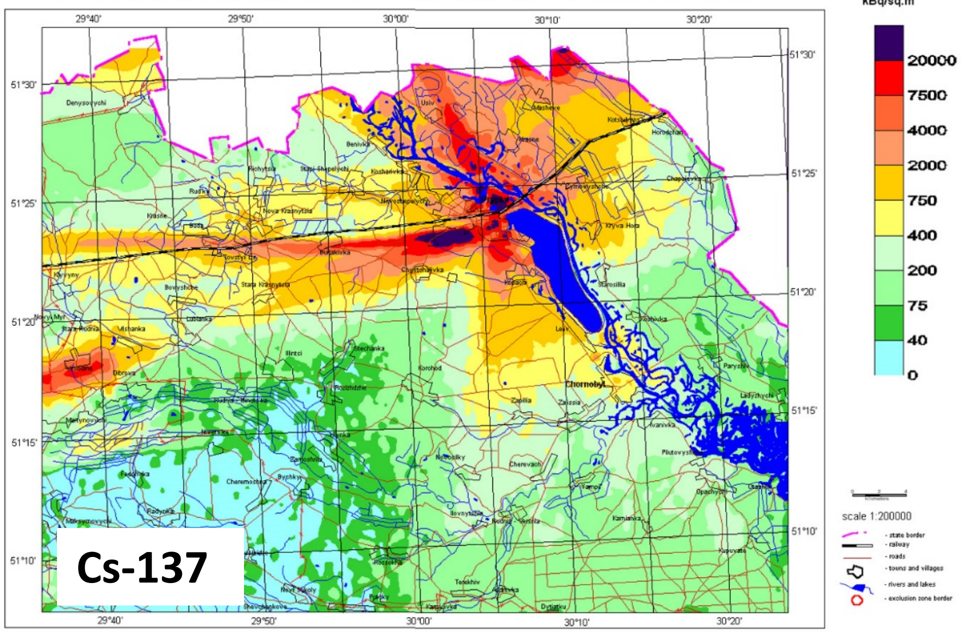
GPS+dosimeter on reindeer, Norway. Photo: Lavrans Skuterud

3. Natural variability and the influence of other factors than radiation

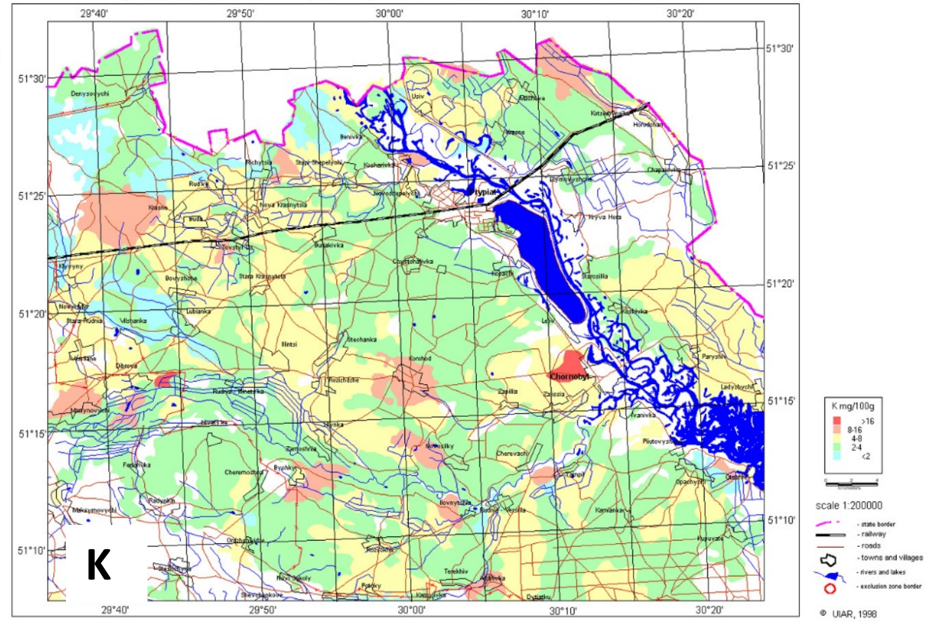
Source: airbusds.com

- Ecological factors and variability can be more important than radiation
- At accident sites, removal of humans may be the most important factor
- Some factors co-vary, others do not
- Habitat ’history’ is important
- Far better quantification of ’other’ parameters is needed, as well as robust statistics
- Mechanisms / causality often hard to determine, or not investigated (more descriptive studies are more common)

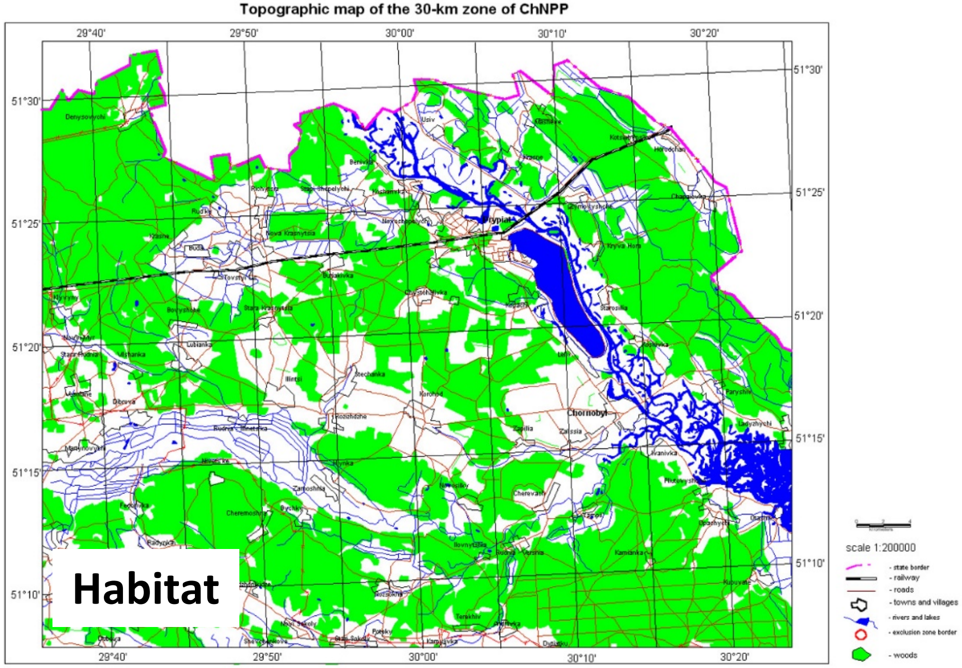
The map of the 30-km Chernobyl zone terrestial density of contamination with cesium-137 (on 1997)



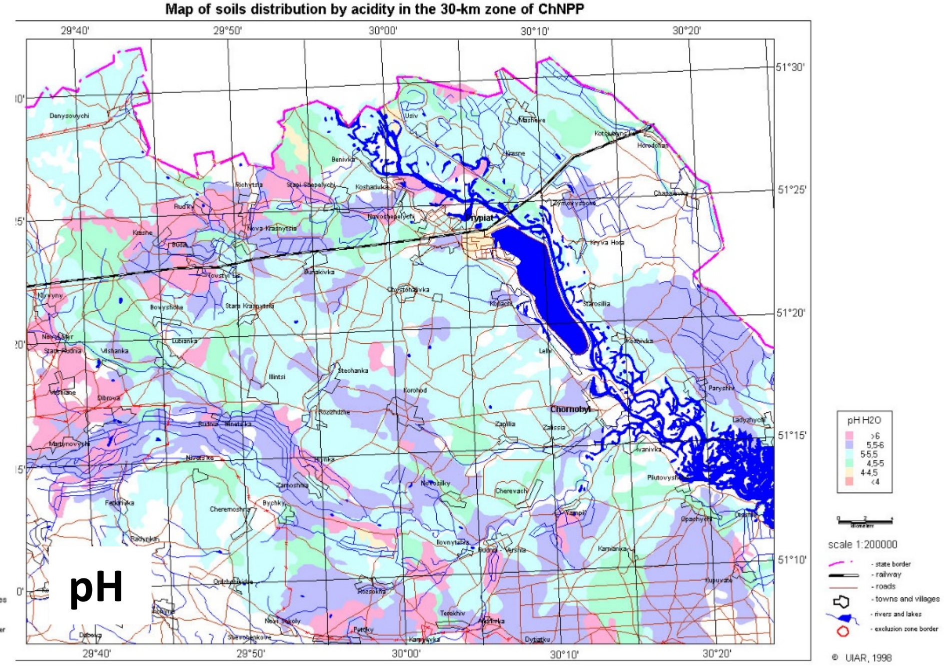
Spatial distribution of soils by mobile potassium contents in the 30-km zone of ChNPP



Topographic map of the 30-km zone of ChNPP

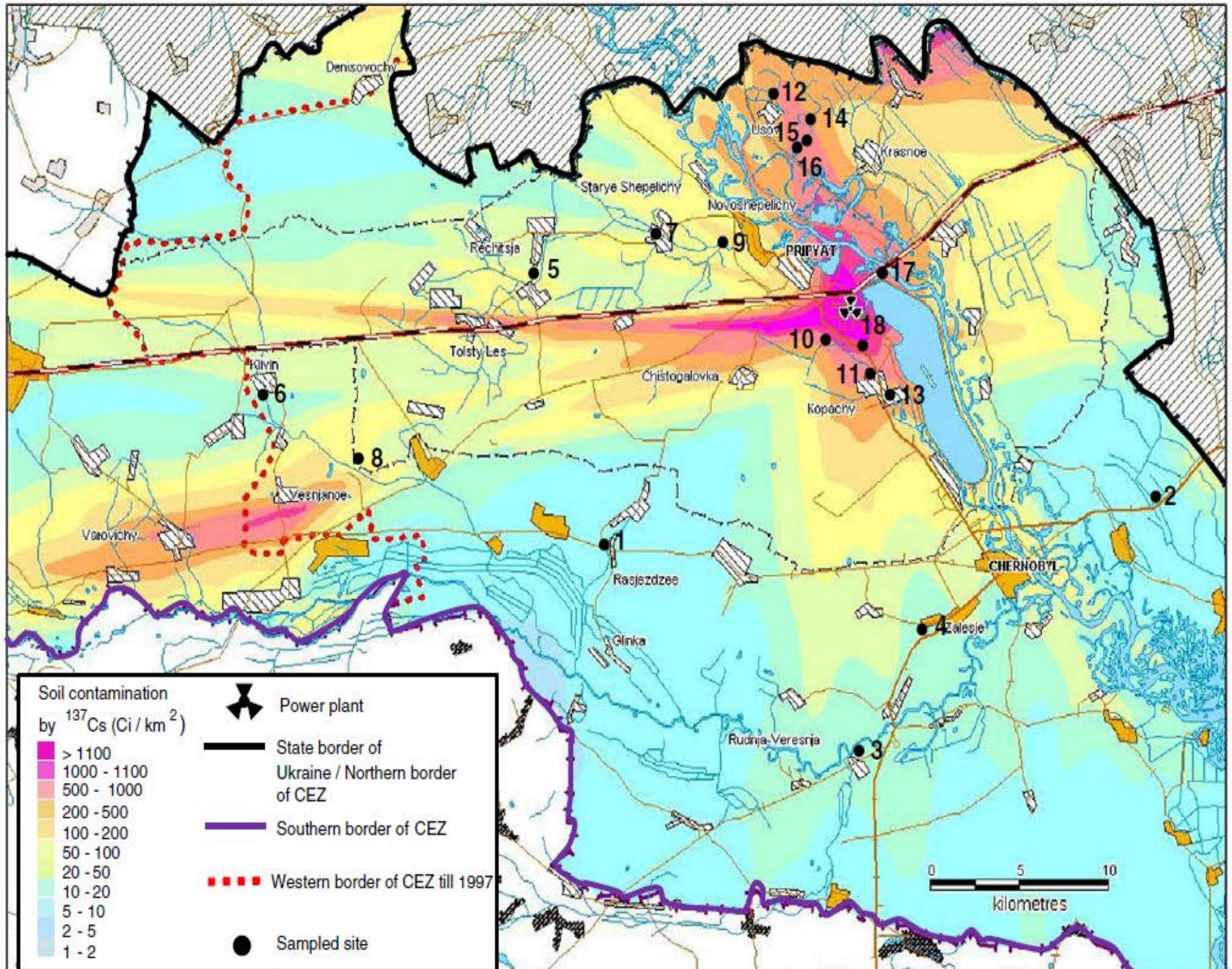


Map of soils distribution by acidity in the 30-km zone of ChNPP



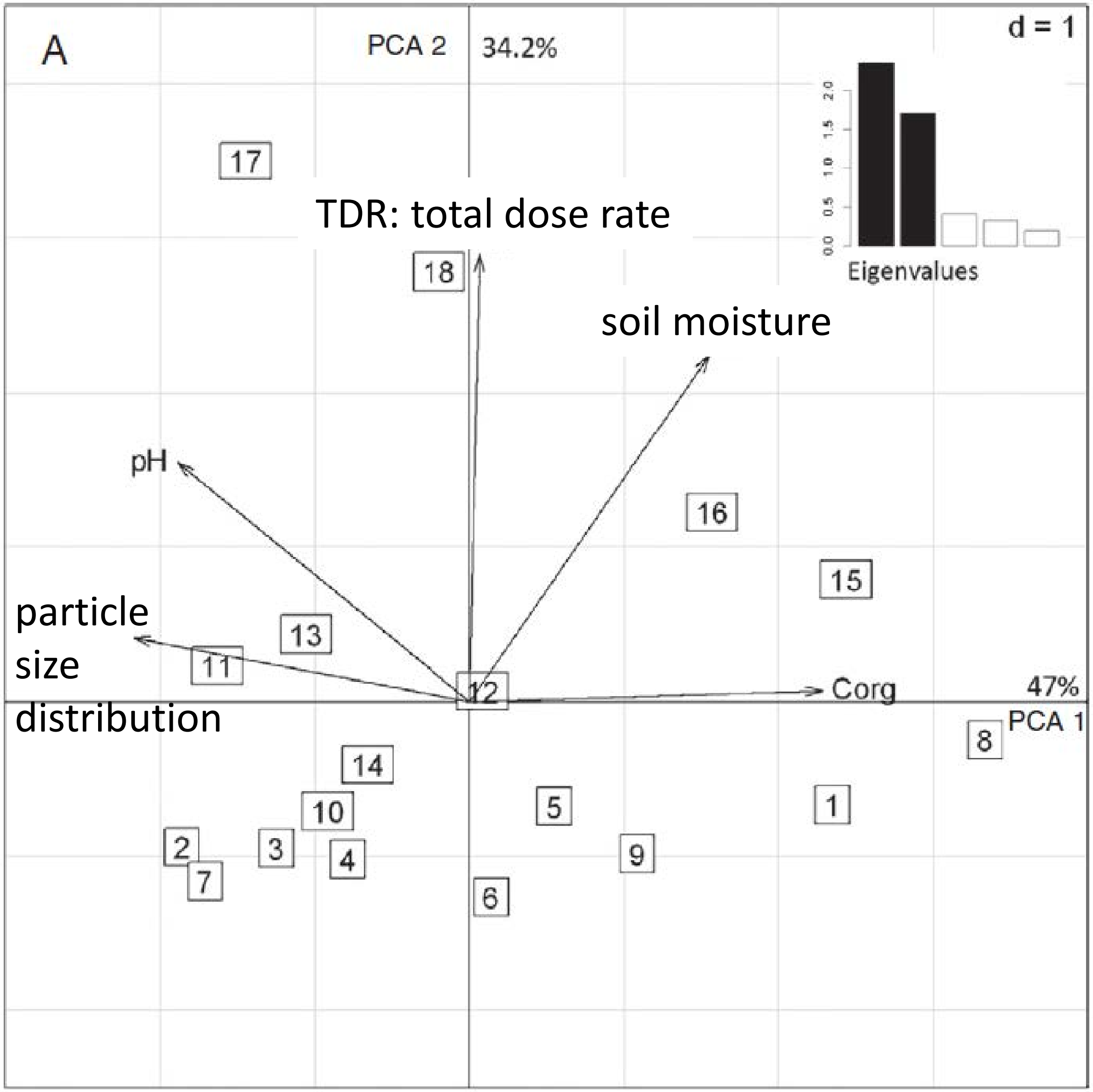
Source: PROBA database

Nematode communities in forest sites in the Chernobyl Exclusion Zone



- Shannon diversity
- Maturity index (MI): based on on life strategies (colonisers-persisters), shows the degree of soil disturbance
- Nematode channel ratio (NCR): indicates the relative importance of the bacterial- and fungal-feeders (ie functional response)
- Quantified total dose rate (internal+external)
- Related their results to both total dose rate, and soil properties (PCA, multiple linear regression)

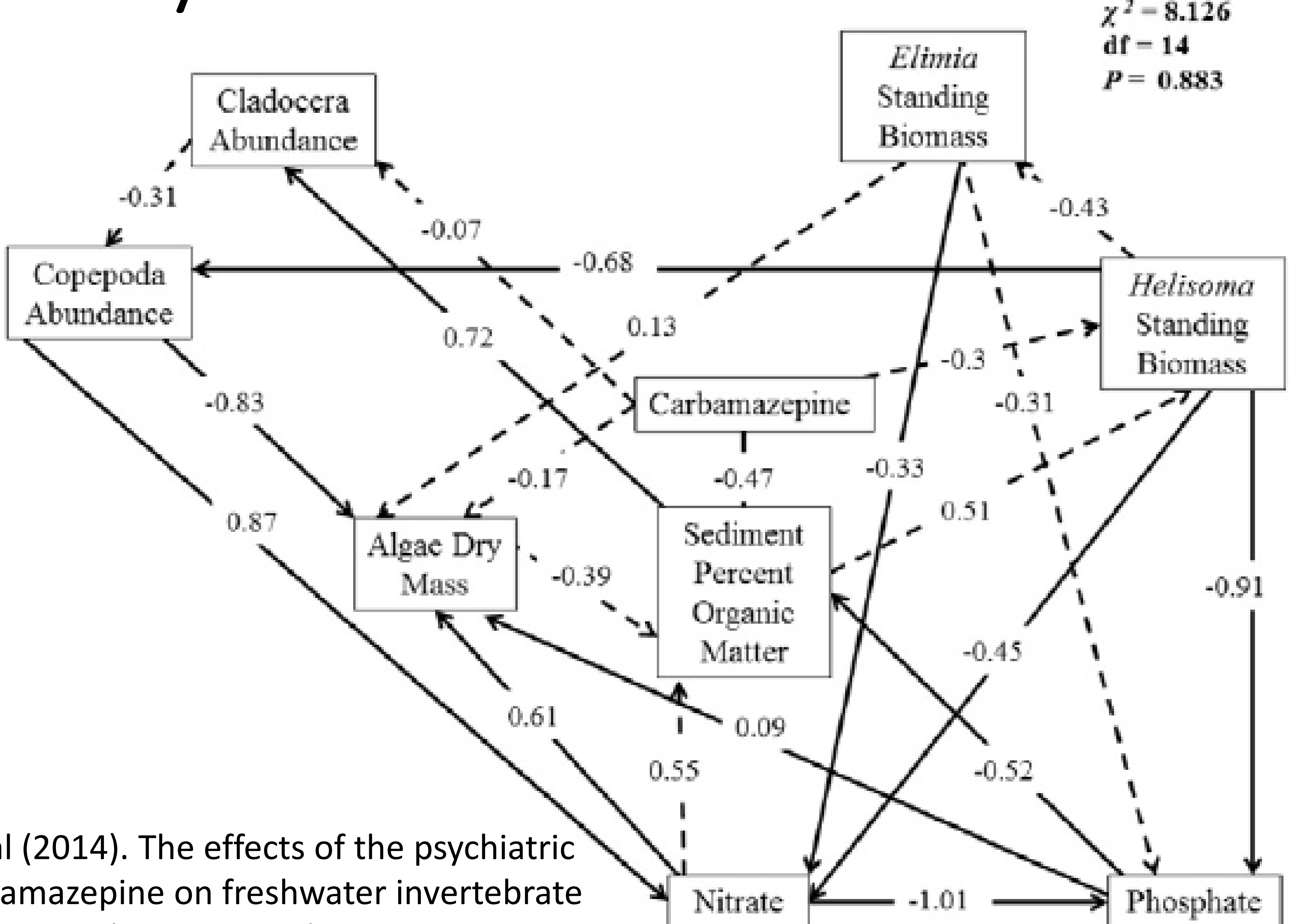
Lecomte-Pradines et al. (2014) STOTEN 490: 161-170



Principal Component Analysis of soil abiotic parameters. Numbers = sites. (Lecomte-Pradines et al., 2014)

- Few 'disturbance-sensitive' species at any site
- Generally low diversity (due to low nutrient soils?)
- No significant effect of radiation or any other measured factor on Shannon diversity
- NCR was significantly affected by TDR: reduced relative abundance of bacterial vs fungal feeding nematodes
- Maturity index (MI)(ie. disturbance) significantly affected by TDR and *also* by pH and orgC

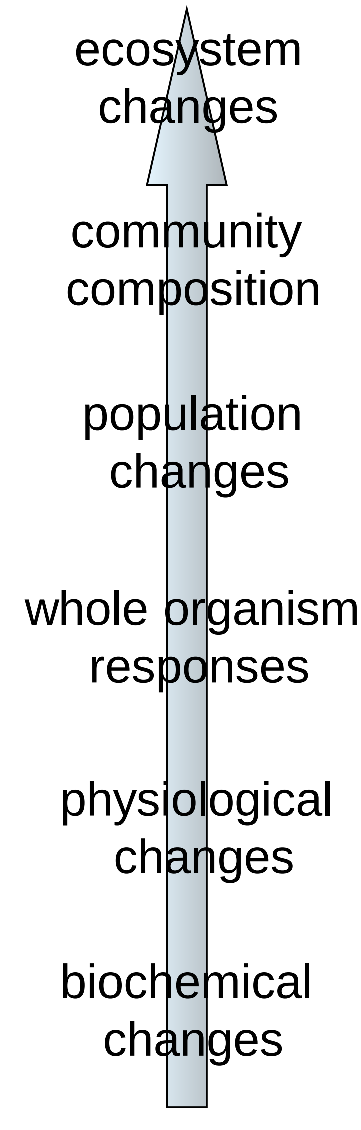
Path analysis



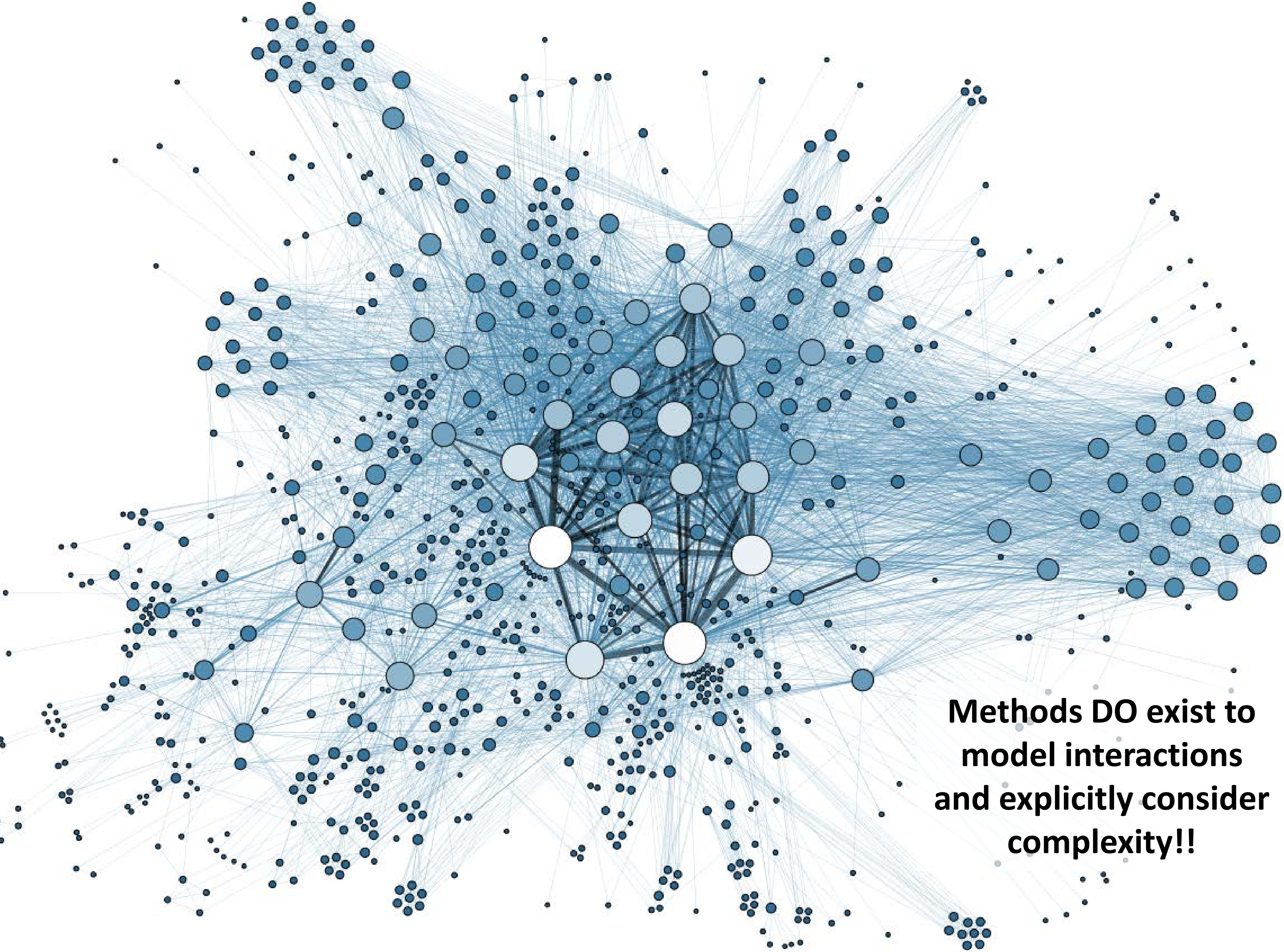
Jarvis et al (2014). The effects of the psychiatric drug carbamazepine on freshwater invertebrate communities and ecosystem dynamics. Sci Tot Env 496: 461–470

4. Non-linear and indirect effects

- Such effects are common at the ecosystem level!
  - Often due to interactions
- Effects at 'higher levels' of organisation cannot necesarily be predicted from lower level one
  - Populations can be more radiosensitive than individuals (Alonzo et al., 2016*: modelling study) - several slight effects at the individual level combined into a larger effect at the population level
- Systems can have different properties than their components
  - Regime shifts, resilience, emergent properties
- Radioecology needs to think in a more 'systems'-based way and accept complexity...
  - Both in experimental work and in modelling



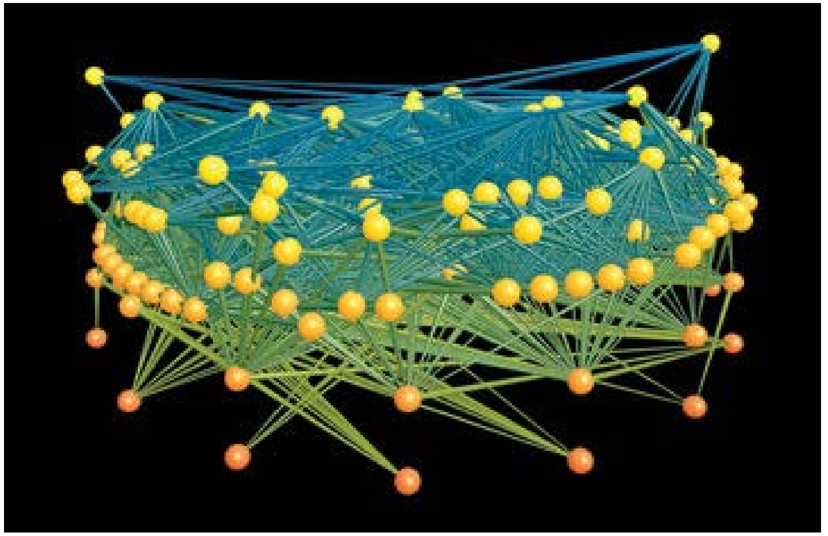
* JER 152: 46-59



Methods DO exist to model interactions and explicitly consider complexity!!

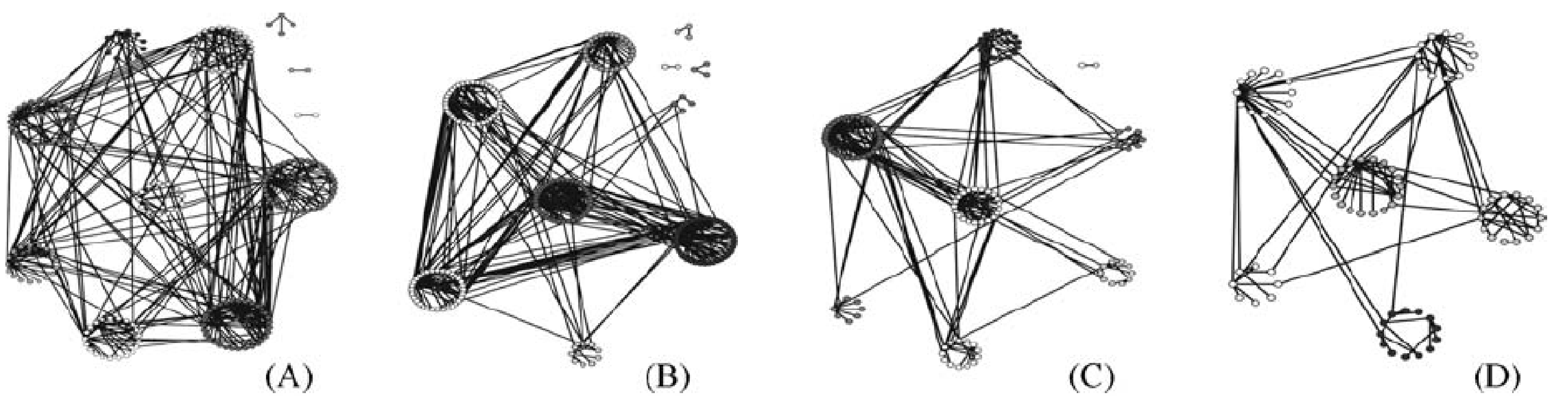
(Ecological) Network Analysis

- A methodology to holistically analyse interactions
- Explore importance of
  - any one 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 sensitive nodes or links
  - early warning indicators
- Identify feedback loops (+ or -)



Aleutian Islands food web (noaa.gov)

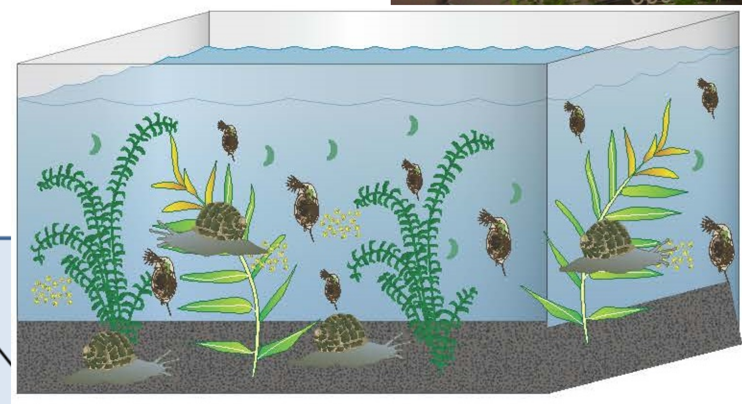
- Network complexity may be altered by stress
  - Number and relative strength of nodes may change
  - Type and amount of connectivity may change

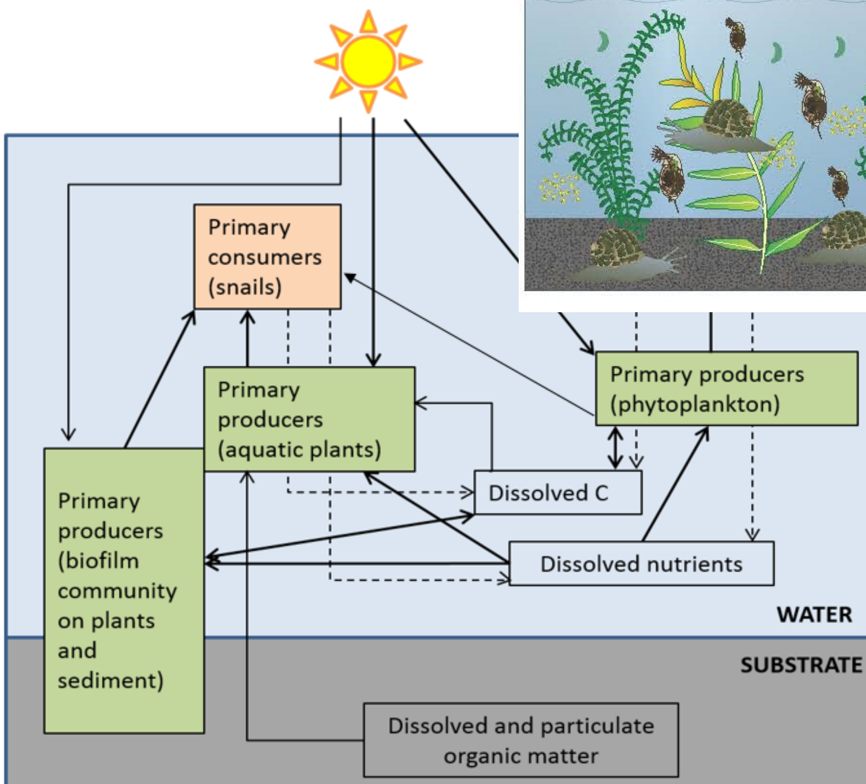


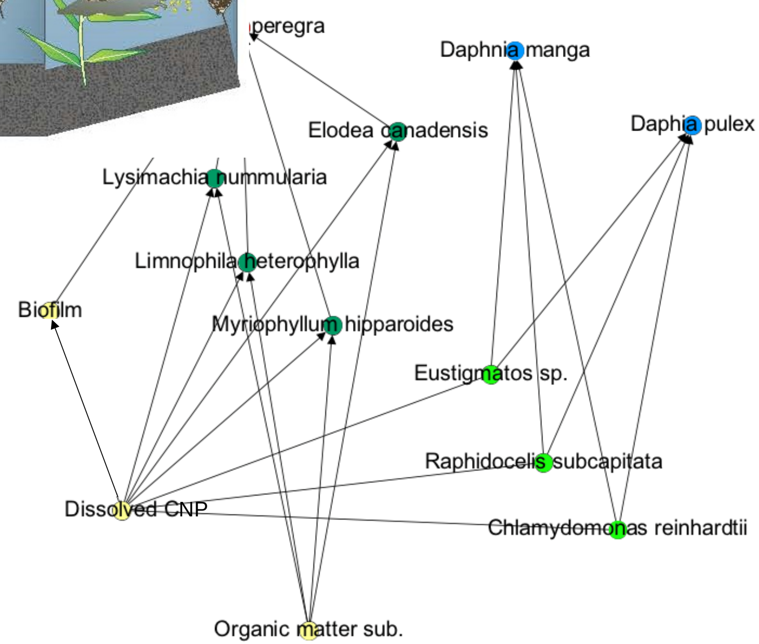
Low altitude (low stress) → High altitude (high stress)

Ramos-Jiliberto et al (2010)
(terrestrial ecosystems)

Multispecies irradiation experiment starting soon (9-31 Oct) in Norway!!







The silver lining!

- IUR taskgroups on Ecosystem Approach since early 2000s
- IUR joint taskgroup with Centre for Environmental Radioactivity, Norway)
    - Review of ecosystems-relevant modelling approaches
    - Literature review on the use of cosms in radioecology/ecotoxicology
    - Cosm experiments with gamma irradiation (9-31 October)
    - CERAD is also doing a lot of field work at NORM and accident sites
- Increased interest in field research?
    - Fukushima
    - UK TREE project (Chernobyl)
    - EU STAR/COMET project in Fukushima and Chernobyl and field data workshops
    - GPS & dosimeters on animals in the field (also modelling – IAEA MODARIA)
- (EU) Strategic Research Agenda for Radioecology
    - ”determine ecological consequences under the realistic conditions that organisms are exposed”