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## Ecosystem approaches in radioecology

Rodolphe Gilbin

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# ECOSYSTEM APPROACHES IN RADIOECOLOGY

ICRER 2024 – refresher Course

**Rodolphe GILBIN**

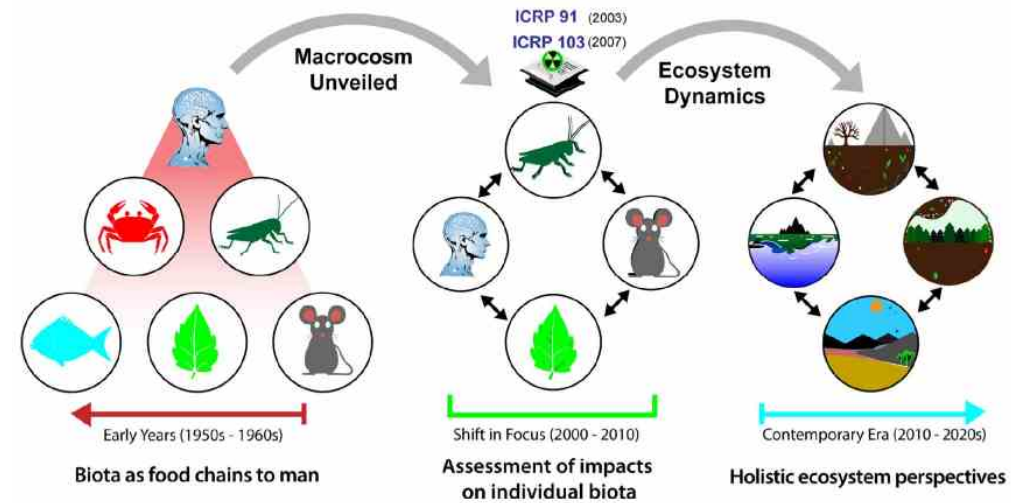
with help and inspiration from **IRSN** and **ALLIANCE** colleagues

# Introduction

## Context and Background

# Chronological journey of radioecology

Matarèse et al. (2024) *Radiation Research* 202(2)

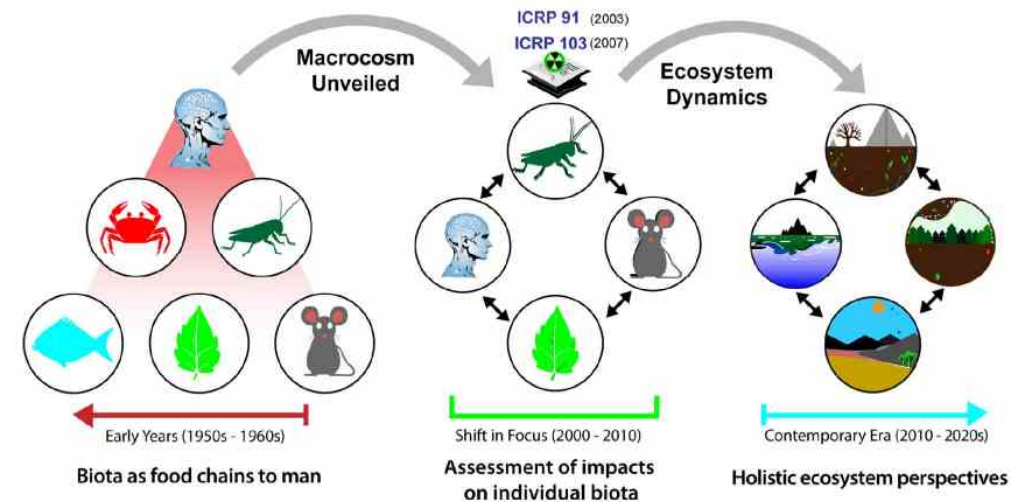


## Context and Background before 2000

- Radioecology emerged during the Cold War, focus on RNs pathways to humans, influenced by nuclear testing and regulatory frameworks (ICRP 60)

## Chronological journey of radioecology

Matarèse et al. (2024) *Radiation Research* 202(2)



# Context and Background

## 2001 - 2009

- **Recognized limitations of human-centric approaches**
  - 2001: First IUR Publication on Protection of the Environment from ionising radiation
  - 2002: IAEA Tecdoc on Ethical Considerations
  - 2005 : ICRP’s Committee 5 dedicated to the protection of environment
  - 2008 : ICRP “Reference animals and plants (RAP)” approach

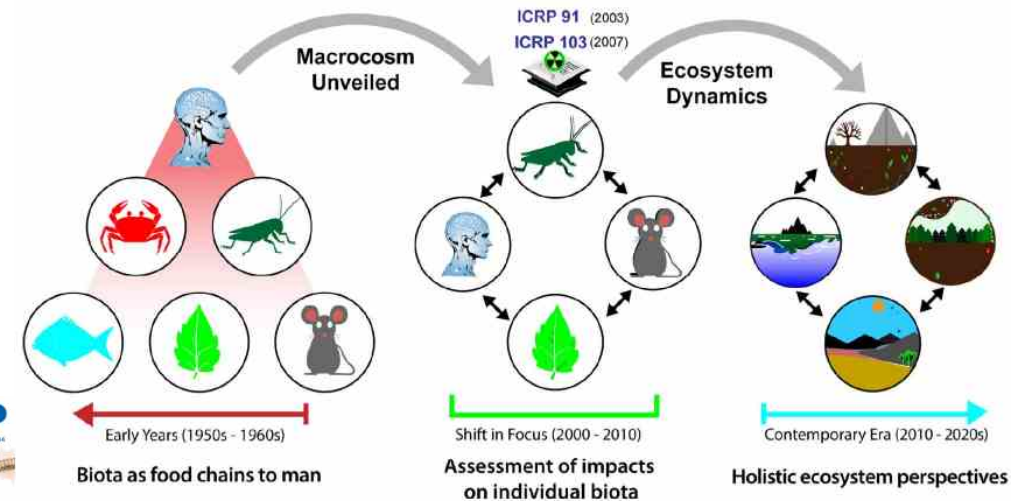
**Now Available!**

**Publication 148**  
Radiation Weighting for Reference Animals and Plants

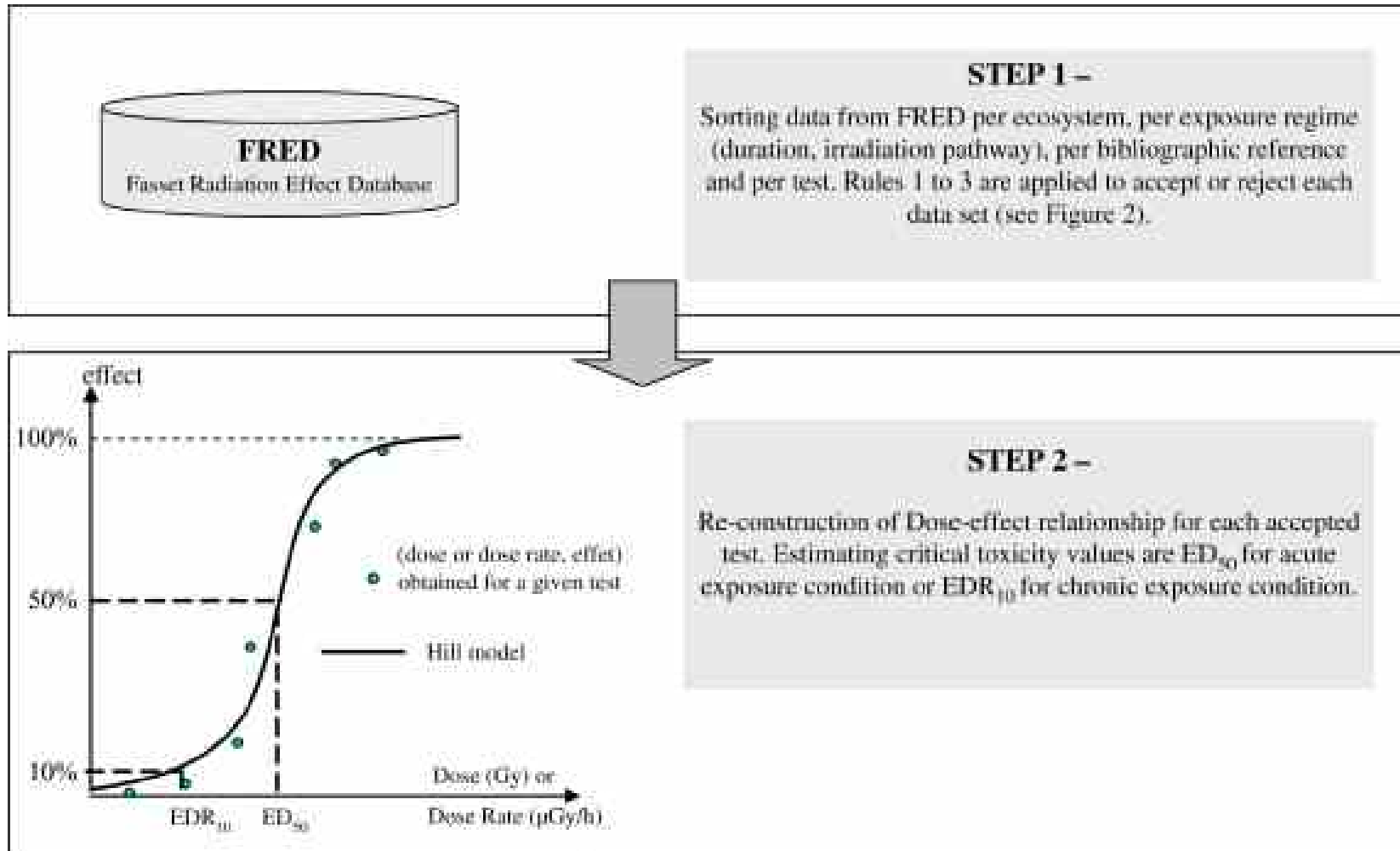
ICRP  
INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

# Chronological journey of radioecology

Matarèse et al. (2024) Radiation Research 202(2)



## Derivation of ERICA PNEDR: First steps (from raw data to EDR10)



## Derivation of ERICA PNEDR: Last steps (from EDR10 to HDR5)

$R^2 = 0.9513$

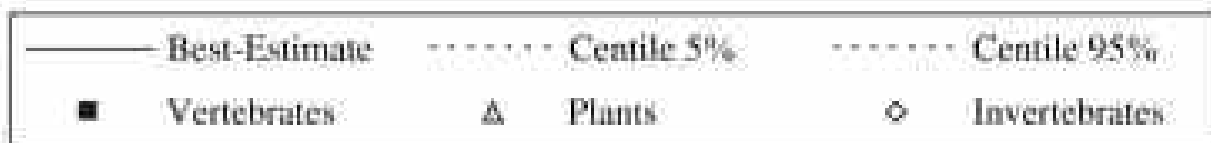
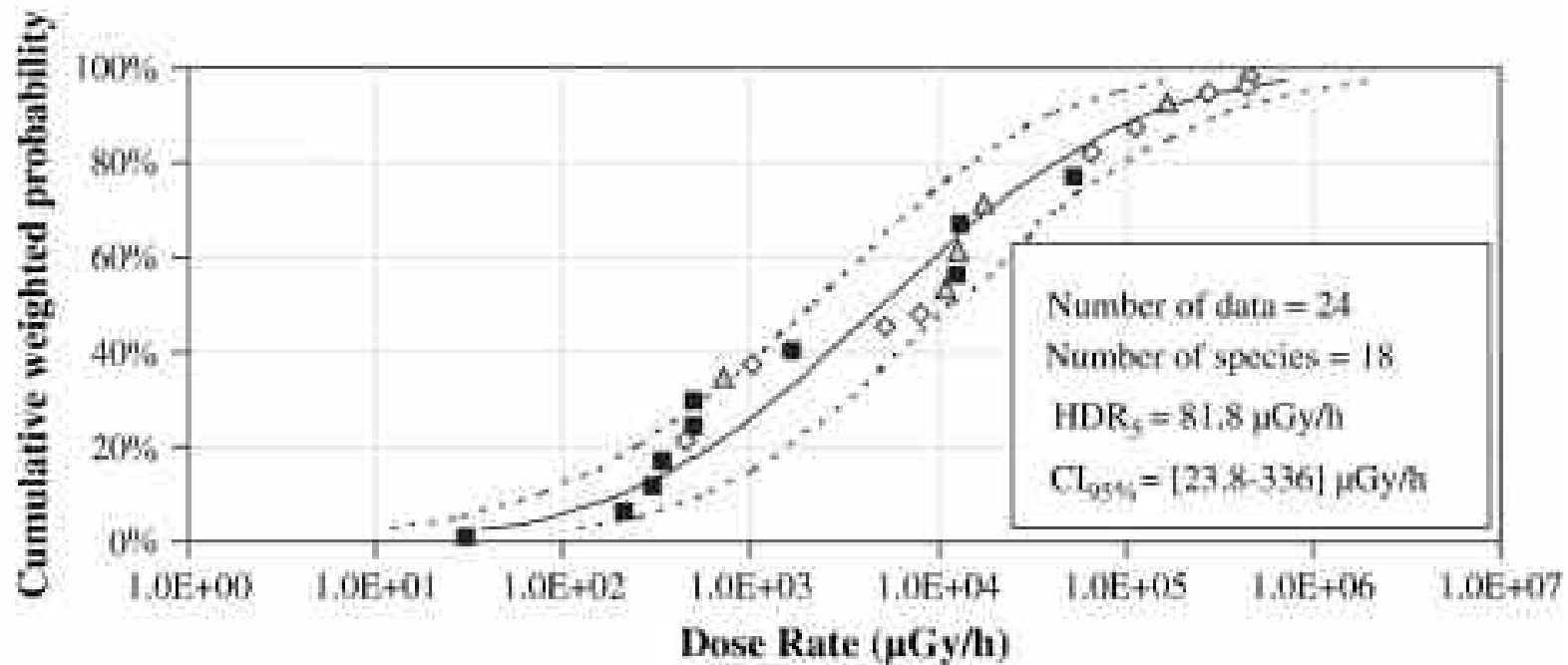
KSpvalue = 0.500

Log Normal – Generic Ecosystem (SW+FW+TER)

Sp = weighted; TW: none

wm.lg = 3.71

wsd.lg = 1.09



Garnier-Laplace et al. (2008)



# ICRP Approach to Environmental Radiation Protection

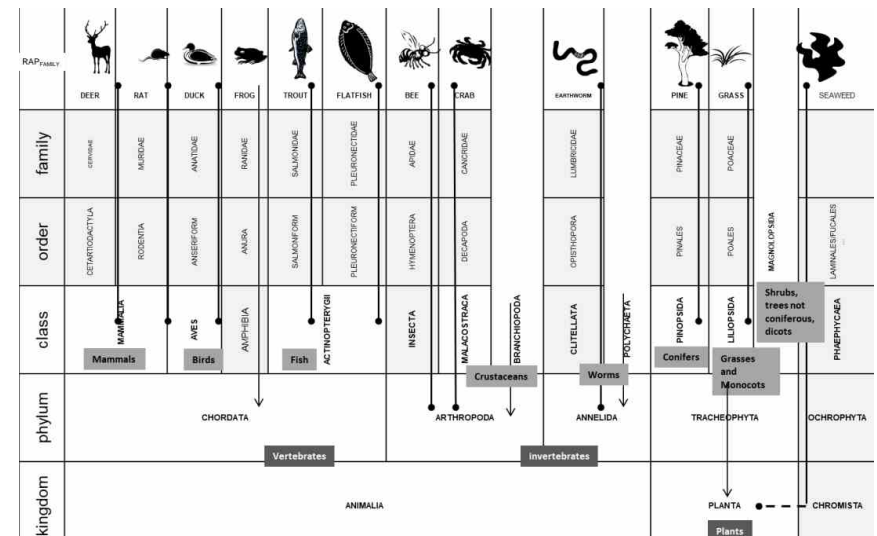
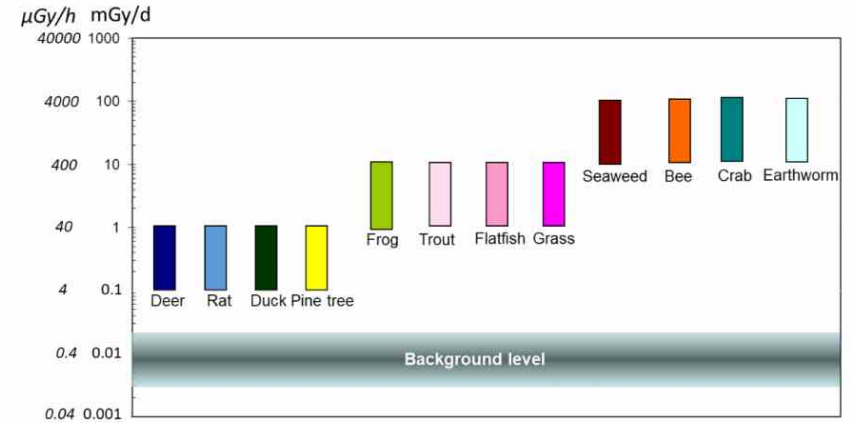
## RAP and related DCRLs

- Simplified exposure pathways for generic groups, not specific species
- Derived Consideration Reference Levels (DCRLs) to assess radiological impact

## Recent evolutions

- Incorporating current knowledge on radiation effects on non-human species
- Ensuring practicality for planned, emergency, and existing exposure situations
- Employ transparent and taxonomic group-based references

→ Refresher Course Environmental Risk Assessment  
 – D Coplestone (Thu 28/11 8:00)

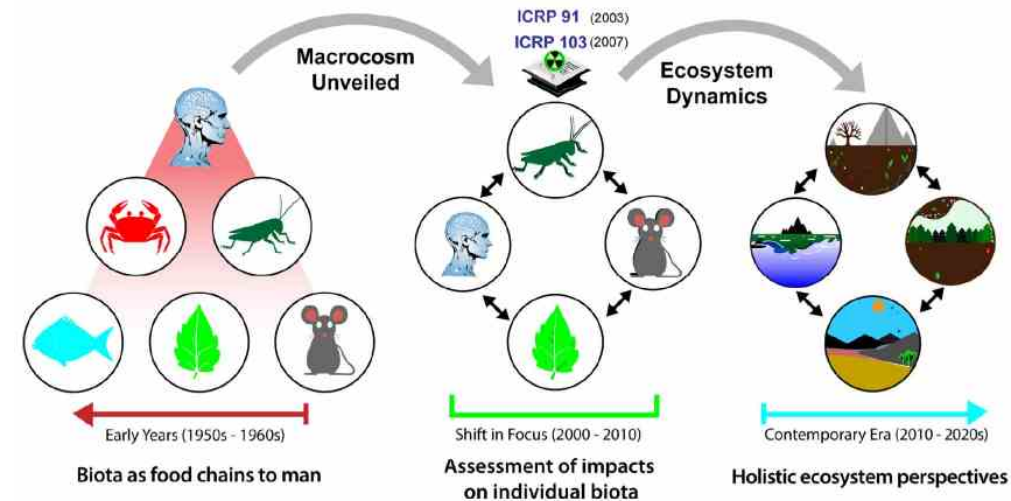


## Context and Background

- **Need for integrating ecological, radiobiological, and environmental sciences** to address complex interactions and cumulative radiation impacts.
  - 2014 : IAEA recommendation to “protect ecosystem services (...) and prevent the effects of ionizing radiation on non-human biota”
  - 2021: ICRP draft recommendation : “more global considerations of environmental protection”

## Chronological journey of radioecology

*Matarèse et al. (2024) Radiation Research 202(2)*



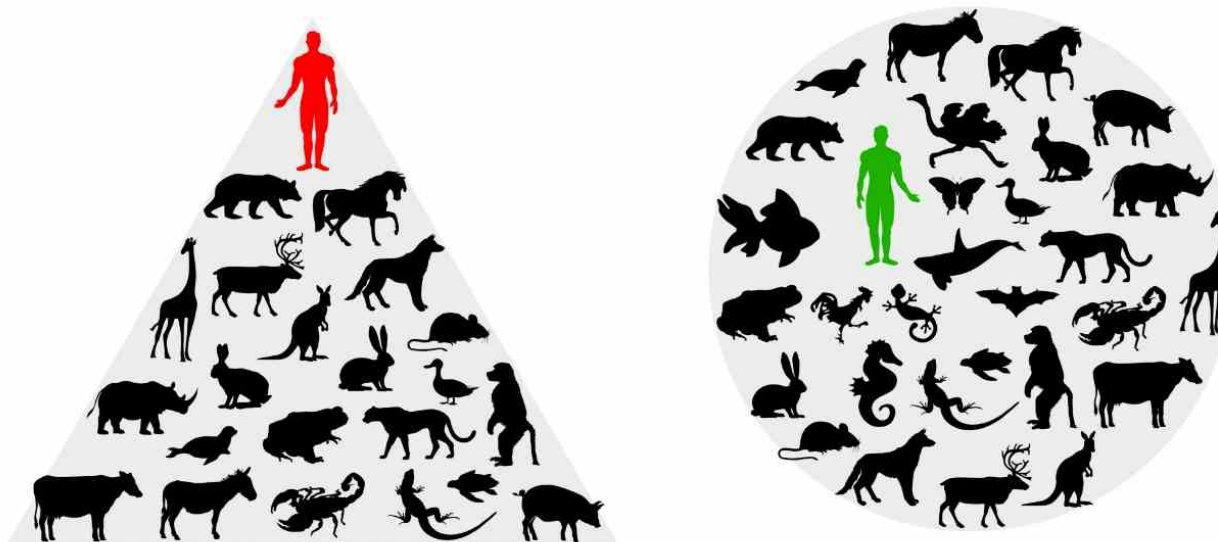
## Context and Background

## Chronological journey of radioecology

*Matarèse et al. (2024) Radiation Research 202(2)*



# From EGO to ECO



## Objectives

From EGO to ECO... how to proceed ?

- Discuss the challenges of adopting ecosystem approaches
- Explore broader impact assessment possibilities
- Share a vision on research needs

# Challenges in Ecosystem Approaches to Radioecology

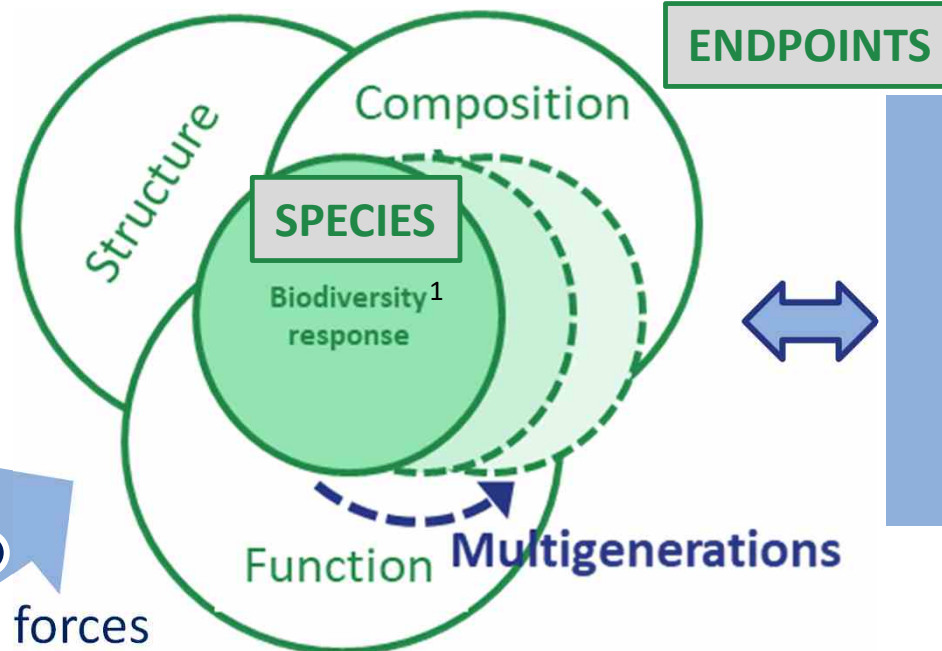
## Ecosystem Health Complexity: beyond individual responses

**EXPOSURE : chronicity<sup>2,3</sup>, long-term<sup>4</sup>, multi-stress**

Persistence of radiocontaminants

Multiples Stressors (chemicals, climate change,...)

Evolutionary forces (Hereditary effects, migrations, etc)



**ORGANISATION: life stage, individual, population**

<sup>1</sup> Noss 1990, <sup>2</sup> Dubois et al 2019, <sup>3</sup> Pereira et al 2011 <sup>4</sup> Sreetharan et al 2024

# Broadening Impact Assessments: Frameworks and Opportunities

## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

- [ **BETTER USE OF AVAILABLE DATA**
- [ **DEFINE INTEGRATIVE METRICS**
- [ **ACQUIRE KNOWLEDGE ON ECOSYSTEM PROCESS AND BIODIVERSITY**



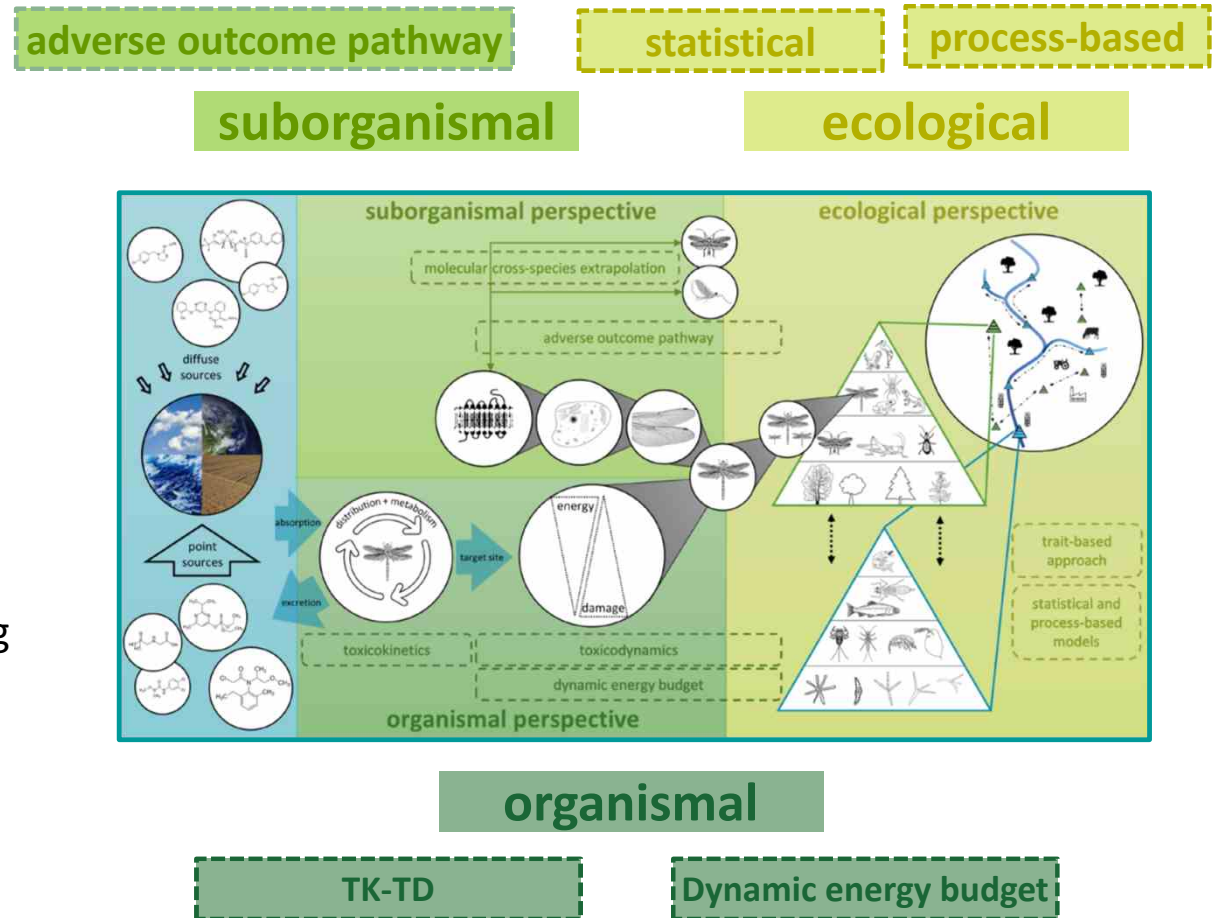
## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

### [ BETTER USE OF AVAILABLE DATA

- AOPs adverse effects at ecosystem (populations and communities)
- modelling for extrapolation to populations

## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

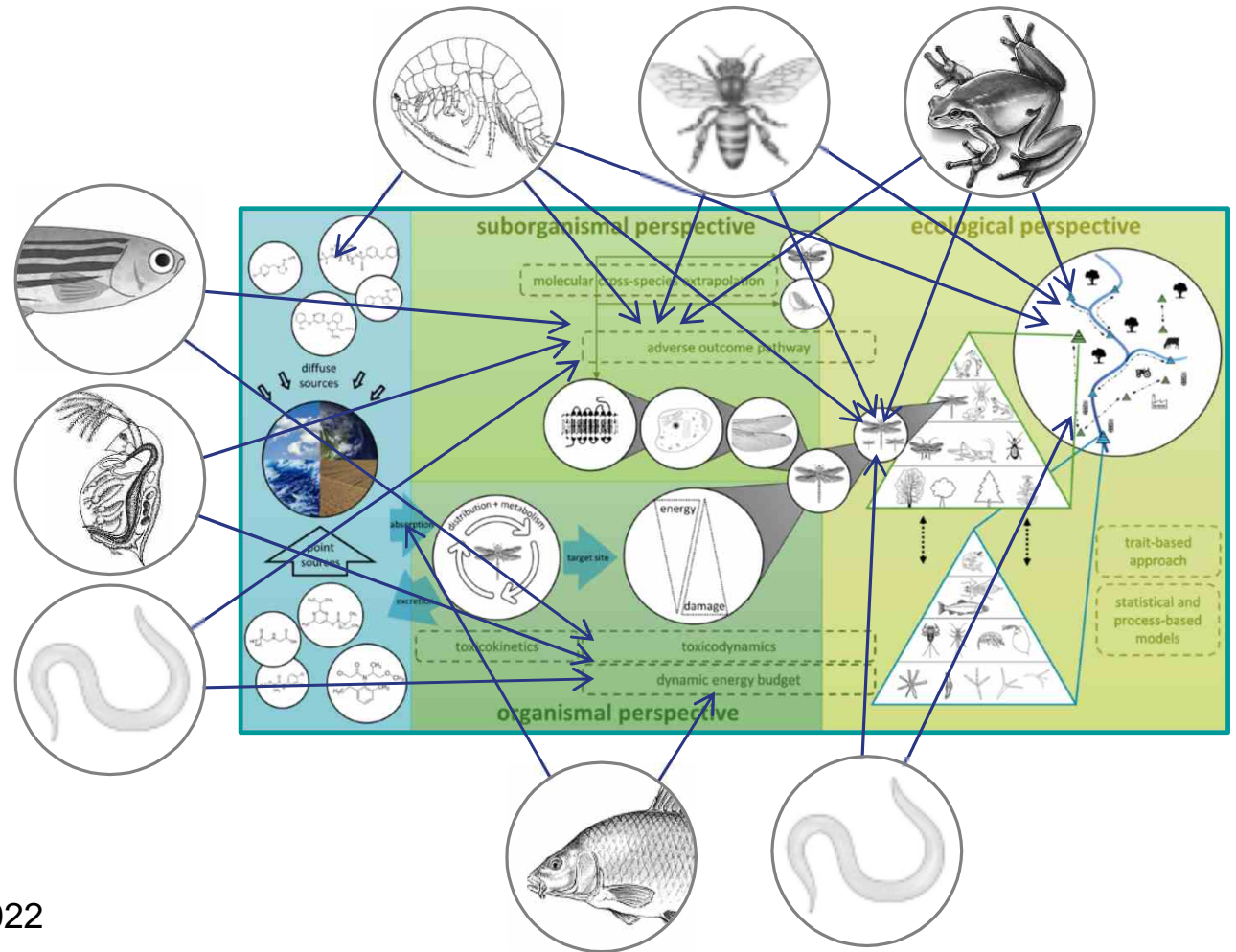
- Idealized representation that illustrates the different biological scales, their interrelationships and associated approaches and tools.
- Predictive modelling of effects and extrapolation among species
- A major challenge: data sets simultaneously covering different biological levels, as well as across varying temporal and spatial scales



Schneeweiss et al, *Glob Change Biol* 2022

## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

- Experiment on model species addresses effects at the different biological scales with various studied species
- A brief overview of recent advances

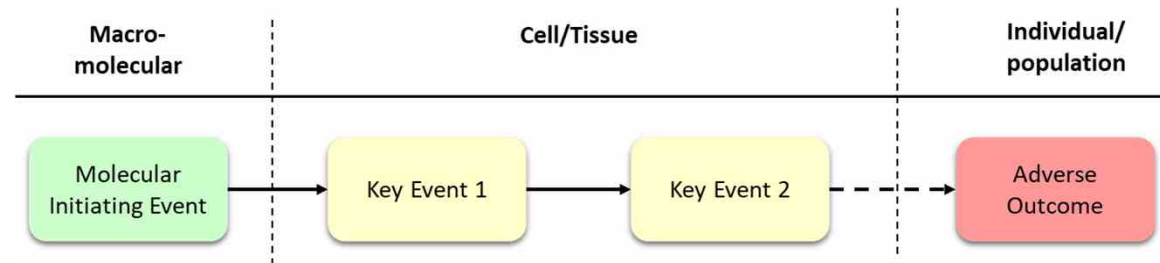


Schneeweiss et al, *Glob Change Biol* 2022

# THE ADVERSE OUTCOME PATHWAY (AOP) FRAMEWORK

**AOP<sup>1</sup> = Tool for data structuration: from an initiating event (MIE) to an adverse outcome (AO), mostly phenotypical (individual, population), used for ERA**

27 with IR<sup>2</sup>,  
2 endorsed



**AOP framework enables:**

- Linking different biological levels, with WoE assessment
  - Main steps leading to an Adverse Outcome and relative knowledge gaps
  - Possible use of molecular data
- Common tool between radiations and other stressors (AOP networks),
- Sharing common tool between researchers and regulators<sup>3</sup>

<sup>1</sup> Ankley et al 2010, <sup>2</sup>IJRB Special Issue 2022, <sup>3</sup> Chauhan et al 2022

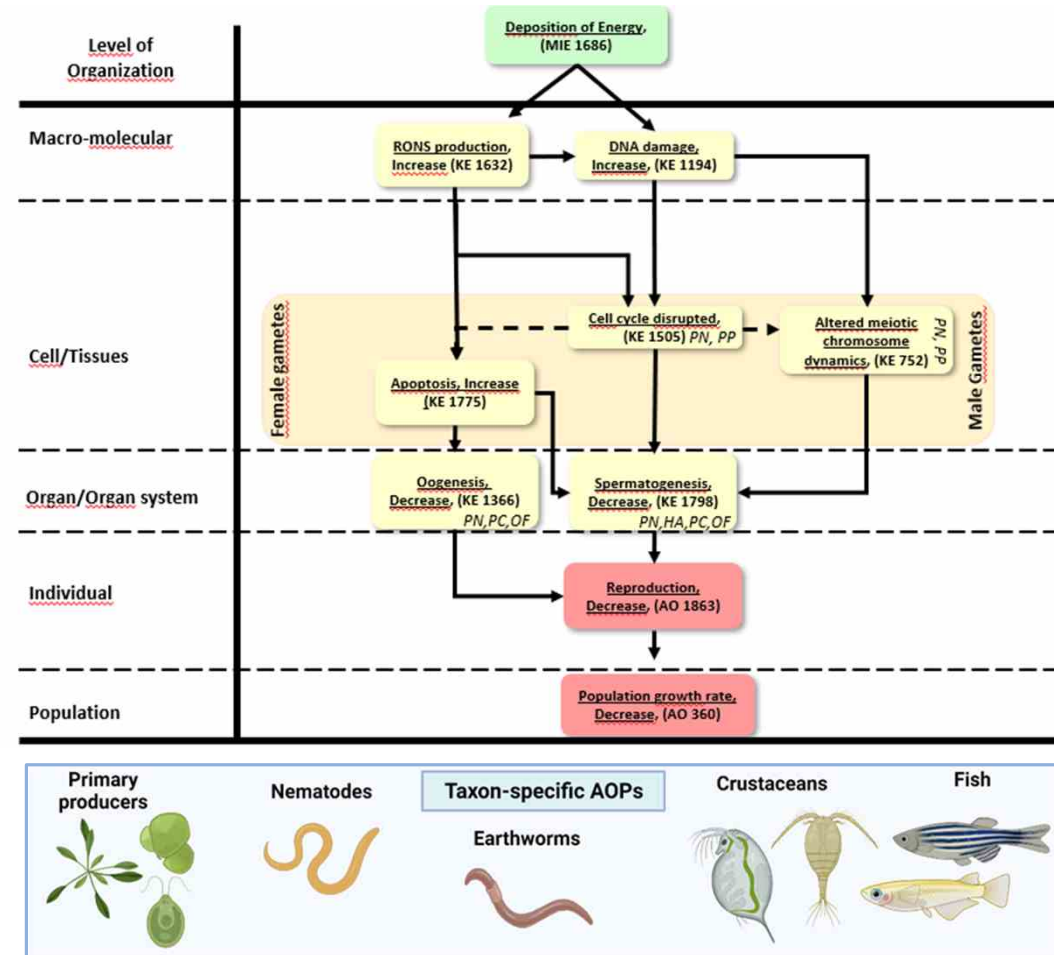
# DEFINITION OF ECOLOGICALLY RELEVANT DESCRIPTORS (KE, AO)

| Type/Level of Organisation | Event  | AOP wiki ID | Parameter analysed / Ref   |
|----------------------------|--|-------------|--|
| KE/Population structure    | <b>Sex ratio, skewed</b>   | <b>#417</b> | Sex ratio measurement over population exposed <sup>1</sup>   |
| „                          | <b>Adaptive potential, decrease</b>                                |             | Affiliation rate, increase <sup>2-3</sup>  |
| KE/Population composition  | <b>Mutation rate, increase, Mutations, increase</b>                | <b>#185</b> | Population genetic inference (genetic diversity) <sup>4-8</sup>  |
| „                          | <b>Nuclear Genetic diversity, decrease</b>                         |             | Genetic markers (e.g., mitochondrial), SSRs, SNPs <sup>2-3</sup>   |
| AO/Population KE/Ecosystem | <b>Population size, decrease / Population demography, decrease</b> | <b>#997</b> | Standard counts (e.g., bird point counts, track analysis, motion activated camera traps, etc.) <sup>5,9-13</sup> |
| AO/Population KE/Ecosystem | <b>Abundancy, decrease/increase</b>                                |             | Modelling, Fruit tree numbering (indirect; pollinator and bird disturbance), Tracks analysis <sup>9-13</sup>     |
| AO/Ecosystem               | <b>Pollination, decrease</b>                                       |             | Indirect; pollinator disturbance <sup>14-15</sup>  |
| AO/Ecosystem structure     | <b>Organic matter cycling, increase/ decrease</b>                  |             | Indirect; litter detritivore numbering <sup>12-13</sup>  |
| AO/Ecosystem composition   | <b>Biodiversity richness decrease</b>                              |             | <i>All previous parameters/upcoming eDNA methods</i>   |

<sup>1</sup>Quevarec et al. 2022, <sup>2</sup>Car et al. 2023, <sup>3</sup>Shimalina et al. 2020, <sup>4</sup>Baker et al., 2017, <sup>5</sup>Car et al. 2022, <sup>6</sup>Ellegren et al. 1997, <sup>7</sup>Goodman et al. 2022, <sup>8</sup>Møller & Mousseau 2015, <sup>9</sup>Bonzom et al. 2016, <sup>10</sup>Deryabina et al., 2015 <sup>11</sup>Moller & Mousseau 2007, <sup>12</sup>Mousseau et al 2014, <sup>13</sup>Møller et al 2012, <sup>14</sup>Burrows et al 2022, <sup>15</sup>Raines et al 2020, <sup>16</sup>Sakauchi et al., 2021

# CONSENSUS ADVERSE OUTCOME PATHWAYS FOR RADIO-INDUCED REPROTOXIC EFFECTS IN ENVIRONMENTAL SPECIES

- Link molecular-, cellular- and organ-level events to adverse outcomes (relevant for population dynamics): survival, growth and reproduction
- Find common events and differences among species, differing in trophic positions, reproductive strategies, life history (lifespan, age of reproduction, number/size of offspring)
- Compare radiotoxicity with other stressors
- Identify knowledge gaps



Tollefsen *et al.*, *Int J Radiat Biol* 2022

## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

### [ BETTER USE OF AVAILABLE DATA

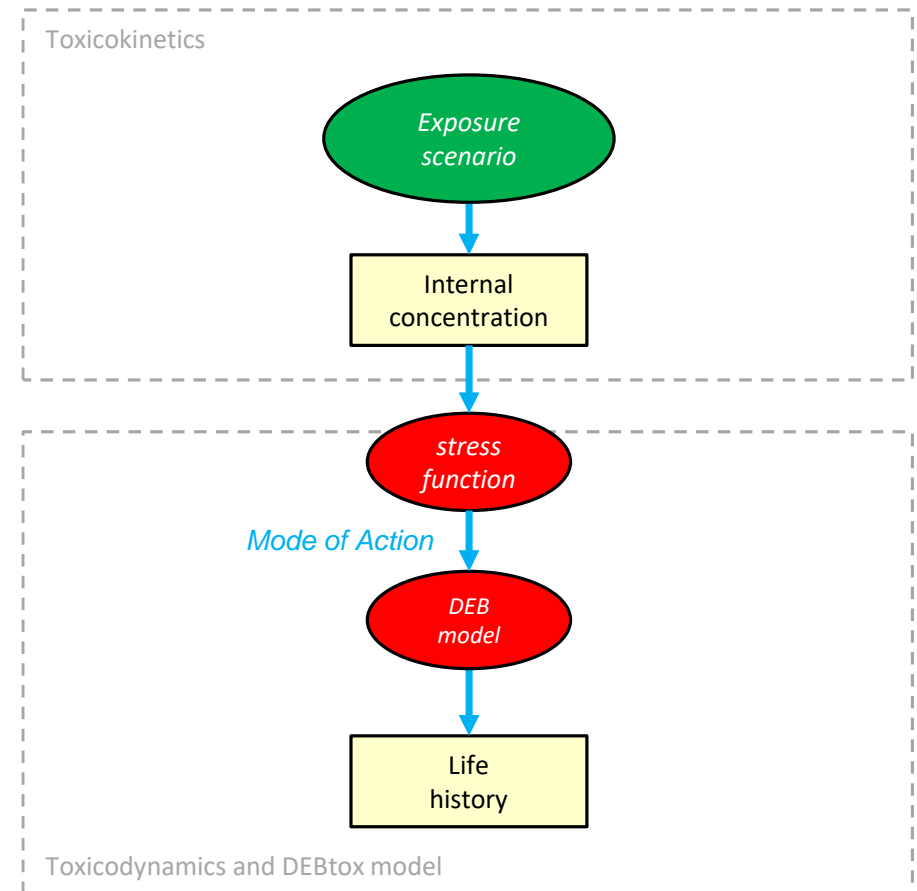
- AOPs adverse effects at ecosystem (populations and communities)
- **modelling for extrapolation to populations**

# DYNAMIC MODELING OF EXTERNAL GAMMA RADIATION EFFECTS IN THE NEMATODE *C. ELEGANS*

- Changes in toxic effects over time can be analyzed using the mechanistic TK-TD approach
- In TK-TD models (GUTS, DEBtox), lethal or sublethal effects are dynamic processes
- Describe how organism internal concentration changes over time and how this affects survival and reproduction through a physiological mode of action
- An approach originally developed for chemical contaminants, more recently applied to external gamma radiation in *Caenorhabditis elegans*

Jager & Zimmer, *Ecol Model* 2012

Lecomte-Pradines *et al.*, *J Toxicol Env Health* 2017

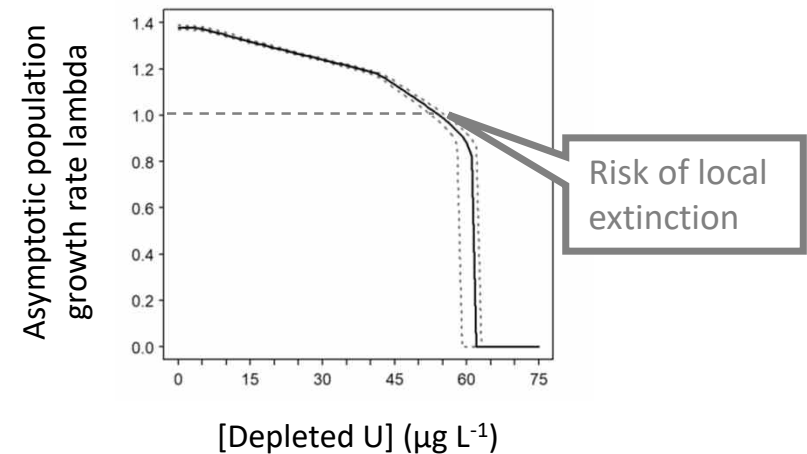
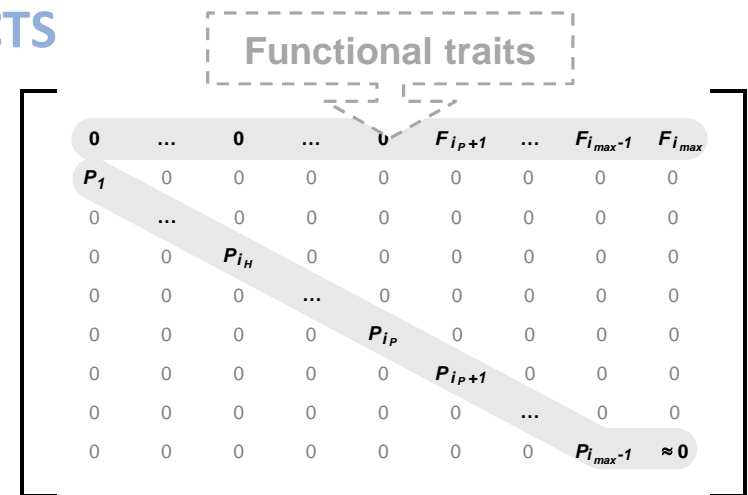




# POPULATION MODELLING OF RADIONUCLIDES EFFECTS APPLIED TO FUNCTIONAL ECOLOGY

- Population models need to integrate organism-level effects over a whole life cycle, to mathematically extrapolate to population-level responses
- Population matrices, a powerful algebraic tool
- Previously used to integrate survival and reproduction effects and calculate consequences for population dynamics
- Integration of organism functional traits to calculate consequences for ecological processes (primary consumption, secondary production...)

Biron et al., *Environ Sci Technol* 2012  
 Alonzo et al., *J Environ Rad* 2016  
 On-going GGP-Env Project (with EDF R&D)



## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

[ BETTER USE OF AVAILABLE DATA

[ **DEFINE INTEGRATIVE METRICS**

■ Ecosystem services

■ EQS (integration man-env...)

■ Consider Radiation protection among other stresses (chemicals, climatic change and heat, habitats transformation...)

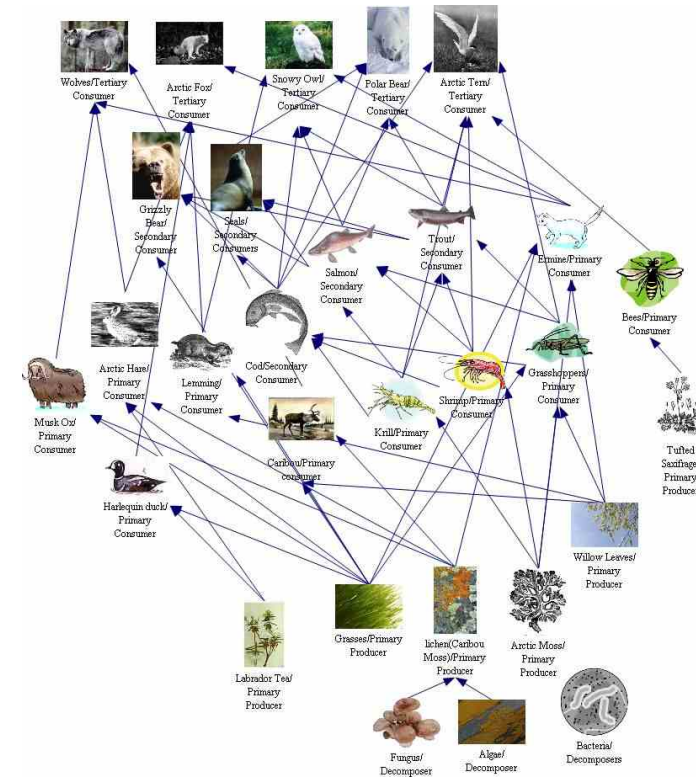
# Ecosystem Approach and Sustainability

Appreciation of the **interdependency of humankind and the environment**

.... focus on the **inherent value of ecosystems, habitats and organisms**

Move from a purely anthropocentric view to one that encompasses an ecocentric ethic perspective.

Sustainability needs to address more than physical and economic considerations, recognise societal and cultural impacts, and acknowledge the dilemmas that can arise from interactions between sustainable development goals.



## UN Sustainable Development Goals



17 interlinked global **Sustainable Development Goals** (SDGs) designed to be a "blueprint to achieve a better and more sustainable future for all".

*See Sarah Donaher's talk O5-01 about ICRP TG125 on Thursday*

# UN Sustainable Development Goals



17 interlinked global **Sustainable Development Goals** (SDGs) designed to be a "blueprint to achieve a better and more sustainable future for all".

See Sarah Donaher's talk O5-01 about ICRP TG125 on Thursday

## Ecosystem services (see Sarah Donaher's talk O5-01 about ICRP TG125 on Thursday)

“the conditions and processes through which ecosystems and species that make them up sustain and fulfill human life” (Daily, 1997)

“Ecosystem services” as a phrase was popularized by the Millennium Ecosystem Assessment (2005), although science around from the 1980s

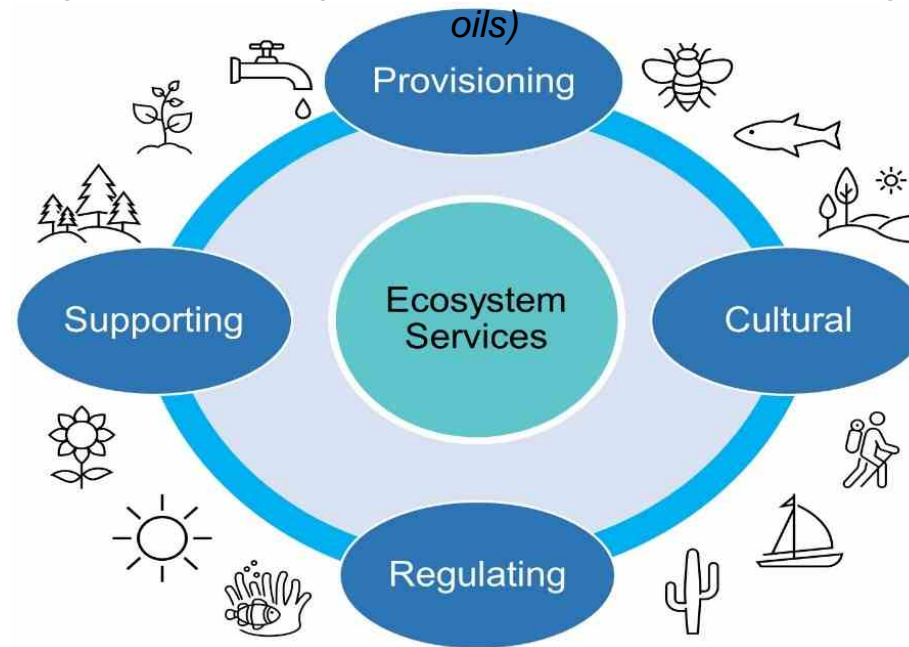
Ecosystem services (ES) refer generally to the benefits humankind derives from the workings of the natural world, i.e., from ecosystems.

## Ecosystem services

### **Direct products of ecosystems**

(e.g., food, drinking water, timber, wood fuel, natural gas,

oils)



### **Processes that sustain ecosystems**

(e.g., photosynthesis, nutrient cycling, soil creation, water cycle)

### **Non-material benefits**

(e.g., creativity inspired by nature, recreation)

### **Processes that moderate natural phenomena**

(e.g., pollination, decomposition, water purification, erosion control)

MEA (2005); Martinez et al (2022)

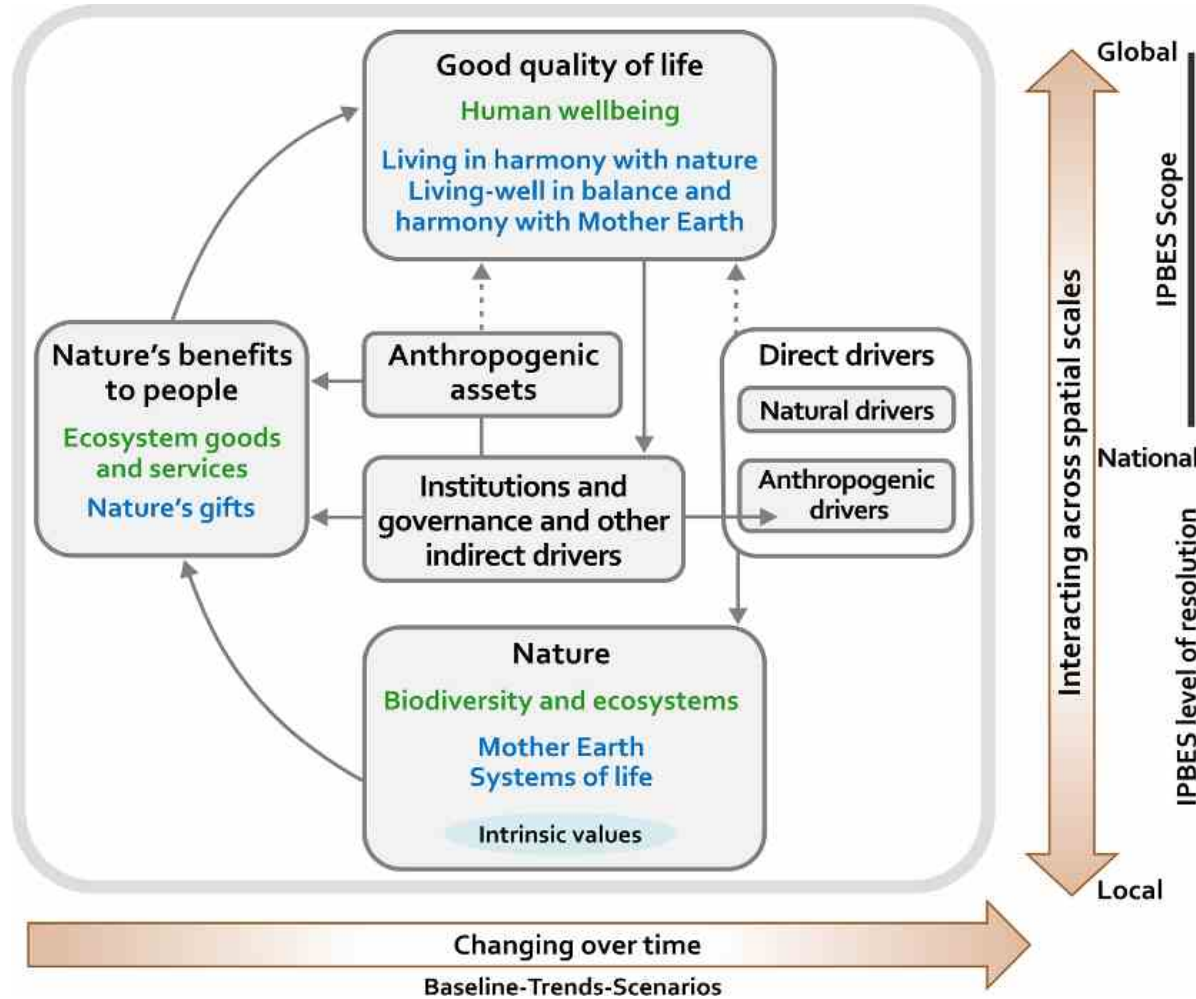
## Ecosystem services

- Since the most recent ICRP recommendations, the pace of change in **global socio-economic challenges and environmental degradation** has accelerated.
- It is important that the system RP provides for an **appropriate level of protection** without unduly limiting desirable human actions and without adversely affecting sustainable development or resulting in unintended consequences.
- There has been increasing interest in incorporating ecosystem services monitoring and assessment in many contexts related to environmental protection and policy making

An ecosystem services approach is **not intended to replace** any part of the current approach to environmental radiological protection. Rather, ES has potential as a tool for communication and decision-support in our goal of robust protection.



# Ecosystem services



The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Conceptual Framework (Diaz et al 2015 PLoS Biol 13(1)) <https://doi.org/10.1371/journal.pbio.1002040>

## Ecosystem services

### US EPA operationalization

#### ➤ An Ecosystem Services Portal

## Ecosystem Services Portal

Ecosystem services assessment tools help you describe, quantify, and sustain the benefits nature offers humans and weigh the impact of decisions. This tool portal helps select the best tools for your scenario. Choose a path below and follow the steps to find the tools that match your needs.

I'm looking for help with...



Choose this path if you are:

- Evaluating the possible impact of environmental stressors such as chemicals, disease, or invasive species.
- Predicting the likelihood of future effects.
- Using an Ecological Risk Assessment in Remedy Decisions.
- Preparing and/or reviewing Ecological Risk Assessments.



Choose this path if you are:

- Doing a preliminary assessment or investigation of a contaminated site.
- Planning or engaged in cleanup or reuse of a contaminated site.
- Working with a Contaminated Site process or model.



Choose this path if you are:

- Working towards a goal that isn't ecological risk assessment or contaminated site cleanup (for example, natural resource management, park and recreation planning, habitat restoration, and stormwater management).
- Have a general interest in ecosystem services.

*Ecosystem Services Portal (US EPA)*

<https://www.epa.gov/eco-research/ecosystem-services-portal#/paths>

## Ecosystem services

### ■ US EPA operationalization

- An Ecosystem Services Portal
- FEGS [final ecosystem goods and services]
  - Focusing on direct beneficiary (person, industry, organization) and how they interact and/or appreciate their environment
  - Final ecosystem goods that are clearly understood
  - Discrete ecosystems with operational boundaries
- US EPA has identified 200 potential metrics for 45 beneficiaries across 7 ecosystems
- Selected biophysical metrics of FEGS must meet four criteria: measurability, interpretability, applicability, and comprehensiveness
- Metrics are not “contaminant” specific, rather specific to the ecosystem and beneficiary in question; largely used in the context of impact of “deltas” or changes in policy

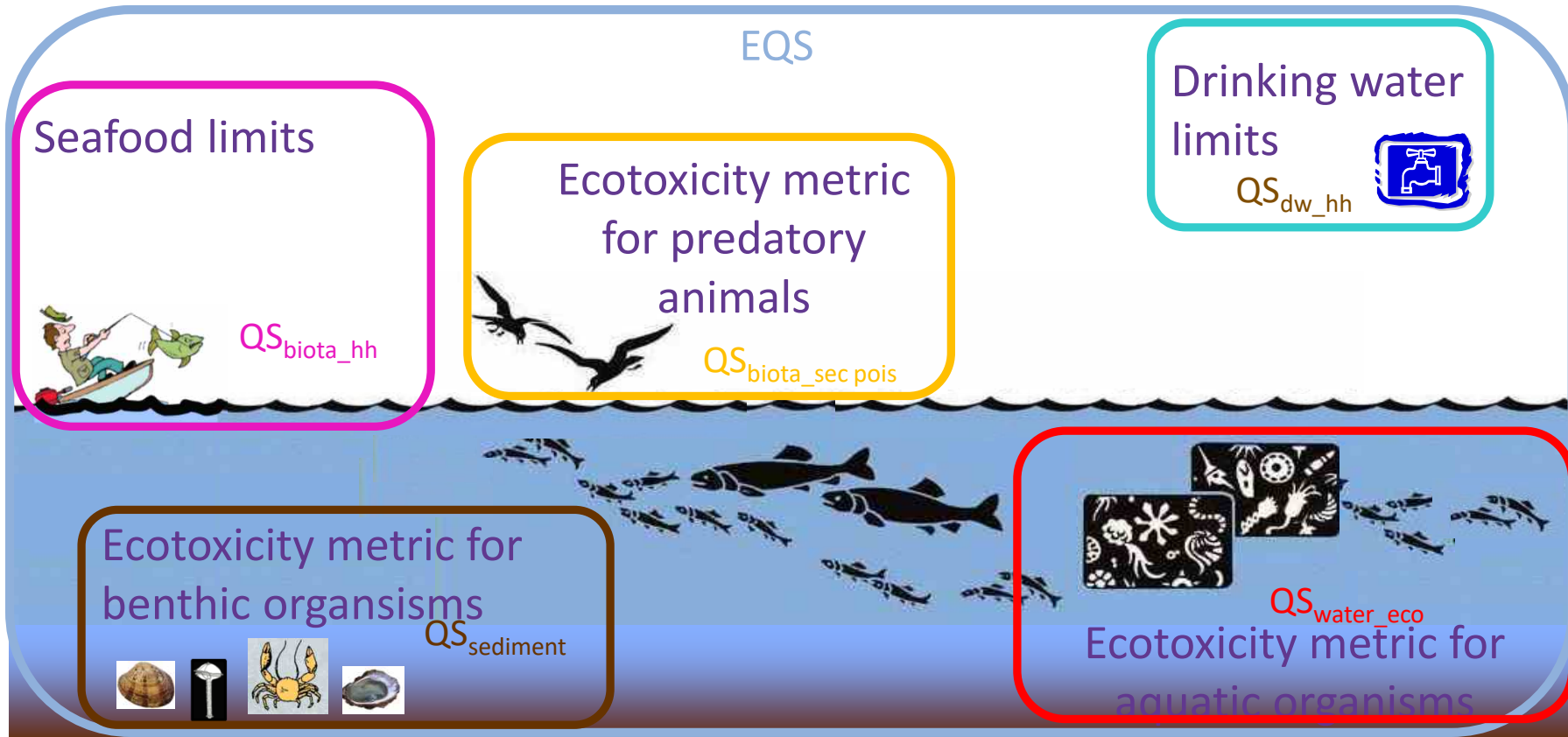
## Ecosystem services

Table 11. Available FECS Metrics for Beneficiaries of Agricultural Systems

| 1                           | 2                                    | 3                   | 4                     | 5   | 6                 | 7                | 8                |
|-----------------------------|--------------------------------------|---------------------|-----------------------|---|-------------------|------------------|------------------|
| Beneficiary Subclass        | Specific Beneficiary                 | Attribute Category  | Attribute Subcategory | Available FECS Metric                                 | Suggested Source  | Remotely sensed? | Model available? |
| Farmers                     | Non-pollinator Dependent Crop Farmer | Soil/Substrate      | Soil quality          | Generic Productivity Index                            | USDA & MSU        | Yes              | Yes              |
|                             | Pollinator-dependent Crop Farmer     | Fauna               | Pollinating fauna     | Population of wild bees                               | National Websites | Yes              | Yes              |
| Residential Property Owners | Farmland property owners             | Water               | Water quality         | Contamination of water                                | State Websites    | No               | No               |
|                             |                                      |                     | Water quantity        | Groundwater surveys                                   | State Websites    | No               | No               |
|                             |                                      | Composite           | Site appeal           | Natural Amenities Index                               | USDA              | Yes              | Yes              |
|                             |                                      |                     | Extreme events        | Risk of flooding (Flood Maps for 100 year flood risk) | FEMA              | Yes              | Yes              |
| Atmosphere                  | Air quality                          | Air monitoring data | State Websites        | No  | No                |                  |                  |

# Environmental quality standards

$$EQS = \min (QS_{water\_eco}, QS_{sediment}, QS_{biota\_sec\ pois}, QS_{biota\_hh}, QS_{dw\_hh})$$



## 2/3 Broadening Impact Assessments: Frameworks and Opportunities

- [ BETTER USE OF AVAILABLE DATA
- [ DEFINE INTEGRATIVE METRICS
- [ **ACQUIRE KNOWLEDGE ON ECOSYSTEM PROCESS AND BIODIVERSITY**

COVID-19's devastating march through the body p. 356

Watching skyrmions on the fly p. 386

Visualizing the radical transfer path in a protein complex p. 424

# Science

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## INSECT DECLINE

Scattered gains, widespread losses pp. 368 & 417

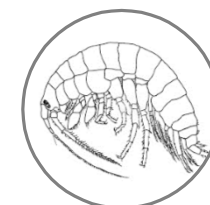
IRSN



EUROPEAN RADIOECOLOGY ALLIANCE

## Some presentations at ERPW on effects of IR at ecological level

- P5-15 (Q Lember, IRSN): "Soil trophic interactions under radio contamination: an in-situ study in the Fukushima Prefecture cedar forests" investigates ecological functions such as **organic matter recycling** and how **biodiversity and soil functionality** are affected by radio-caesium contamination.
- P5-07 (F Alonzo, IRSN): "Population modelling to compare risks for fitness and function in a secondary consumer exposed to radionuclides over multiple generation" uses **population-level risk assessments** to link fitness traits to ecological functions, focusing on Daphnia species.
- O5-08 (DP Techer, IRSN): "An integrative study of ionizing radiation effects on fitness and ecological function of a keystone planktonic secondary consumer" evaluates the **ecological role of secondary consumers** under ionizing radiation.
- P5-12 (S Frelon, IRSN): "Ionizing radiation of Gammarus fossarum affects their reproduction but not their food consumption" highlights how radiation impacts reproduction, and **links between population dynamic and ecological functions** like detritus processing.
- O5-14 (L Dasque, IRSN, France): "Environmental radioactivity impacts bioenergetics in tree frog of Fukushima" investigates the effects of radiocontamination on **energy metabolism and physiological processes** in Dryophytes japonicus.
- P5-14 (L Camoin, INSERM, France): "Protein expression patterns and activities of two metabolic enzymes (CS and LDH) highlight a disturbance in the metabolic pathways of tree frogs living in the Chernobyl Exclusion Zone" explores **metabolic alterations linked to radiation exposure in amphibians**.





# Conclusion and Call to Action

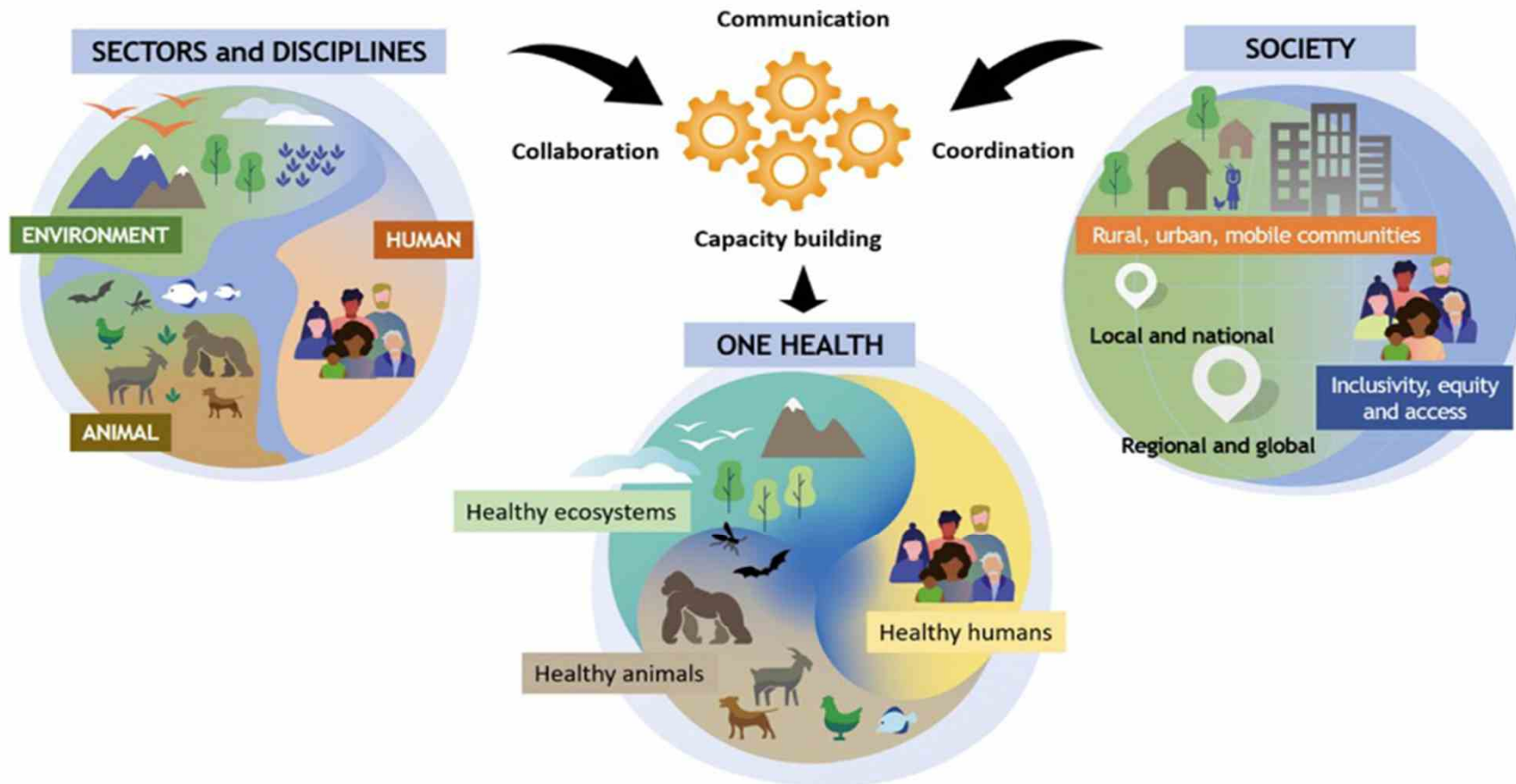
## Strategic Research Agenda European Radioecology Alliance

### ➔ Developing an integrated approach for risk assessment and evaluation from environmental exposure to ionising radiation

1. **To Predict Human and Wildlife Exposure in a Robust Way by Quantifying Key Transfer Processes:** Process-based transfer and exposure models (physical, chemical and biological interactions, kinetics)
2. **To Determine Ecological Consequences under Realistic Exposure Conditions:** Effects at higher levels of organization (population dynamics, trophic interactions, indirect effects at the community level, ecosystem functioning)
3. **To Improve Human and Environmental Protection by Integrating Radioecology:** Integrate human and environmental protection frameworks & Multi-criteria perspective for an optimised decision-making



# One health concept



See Sarah Donaher's talk O5-01 about ICRP TG125 on Thursday

Working together for the health of humans, animals, plants, and the environment. One Health Joint Plan of Action. (FAO, UNEP, WHO, and WOA 2022).

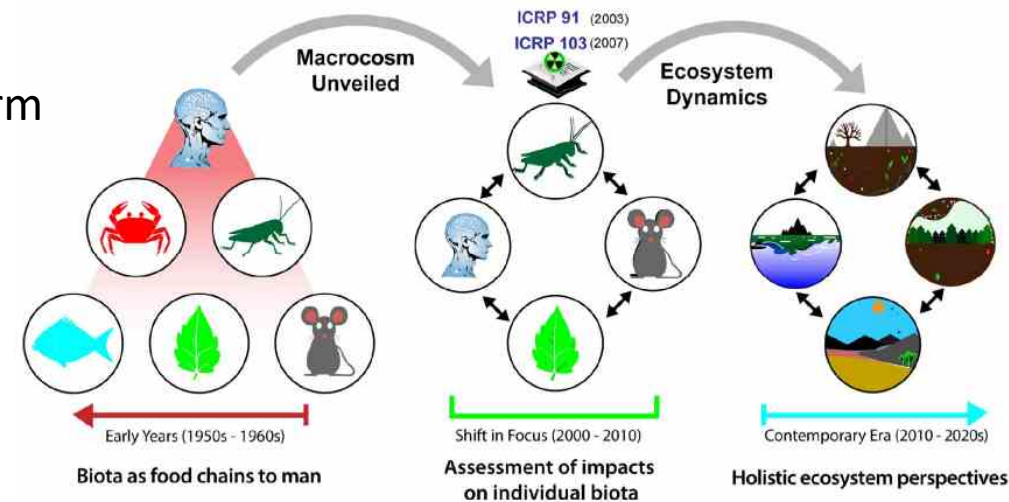
<https://doi.org/10.4060/cc2289en>

## Future direction

- **Integrating Ecosystem Science:** Enhancing radioecology by incorporating ecosystem-level endpoints to provide a holistic understanding of radiological impacts.
- **Beyond Individual Metrics:** Transitioning from organism-based assessments to ecosystem-wide analyses to capture complex interactions and long-term effects.
- **Research Needs:** Identifying causal links between radiological exposure and ecosystem functions, supported by robust statistical models and interdisciplinary approaches.
- **Policy Implications:** Strengthening regulatory frameworks through ecosystem approaches, aligning environmental protection with biodiversity conservation, climate change mitigation, and the Sustainable Development Goals (SDGs).

## Chronological journey of radioecology

Matarèse et al. (2024) *Radiation Research* 202(2)



**Thank you for your  
attention**

