Establishing relationships between environmental exposures to radionuclides and their consequences for wildlife

inferences and weight of evidence

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Basic lines of methods to demonstrate the protection of the environment

- Ecological Risk is an estimation of the probability (or incidence) and magnitude (or severity) of the adverse effects likely to occur in an ecosystem or its sub-organisational levels, together with identification of uncertainties.
- For performing any ecological risk assessment, it is needed to link exposure to radioactive substances to dose (rate) and dose (rate) to effects.

Exposure analysis
(pathways, transfers, dosimetry)

Predicted Exposure Concentration *(Bq/L or Bq/kg) to be converted into*

Predicted Exposure Dose Rate PEDR
(Gy/time)

Effect analysis
(dose rate - effect relationships)

« Safe » levels or effects benchmarks :
e.g., Predicted No-Effect Dose Rate
PNEDR
(Gy/time)

Risk
RQ = Exposure/PNEDR

- Robustness of any ERA highly depends both on dose (rate) estimates and on wildlife effect benchmarks adopted.
- ICRP 108 recommends to perform the demonstration through a set of Reference Animals and Plants (RAPs).
- Extrapolation rules are needed for both exposure analysis and effects analysis.

Effects benchmarks for wildlife: where are we now?

- ERICA, PROTECT and EMRAS II Effect Group have prepared data and proposed a methodology for deriving ñthe Predicted No-Effect Dose Rateò(PNEDR of 10 µGy/h - *0.24mGy/d*): dose rates below this value are unlikely to have any population effects ï to screen away such exposure situations

  Garnier-Laplace *et al.,* ES&T 2006; Larsson, JER 2008; Andersson *et al.,* JER 2009

- UNSCEAR has published recommendations - e.g., 100 µGy/h ï *2.4 mGy/d* to the most exposed individuals would have unlikely effects on most terrestrial communities

  UNSCEAR, 2008

- ICRP has proposed Derived Consideration Reference Levels for RAPs ï bands of low probability of effects (i.e. where there is likely to be some chance of deleterious effects on individual RAP) as Points of Reference.

  ICRP 108, 2008

- All benchmarks are based on analysis of various dose (rate)- response relationships for a variety of species from plants, invertebrates and vertebrates wildlife groups and of biological endpoints covering mortality, morbidity, reproduction and mutation.

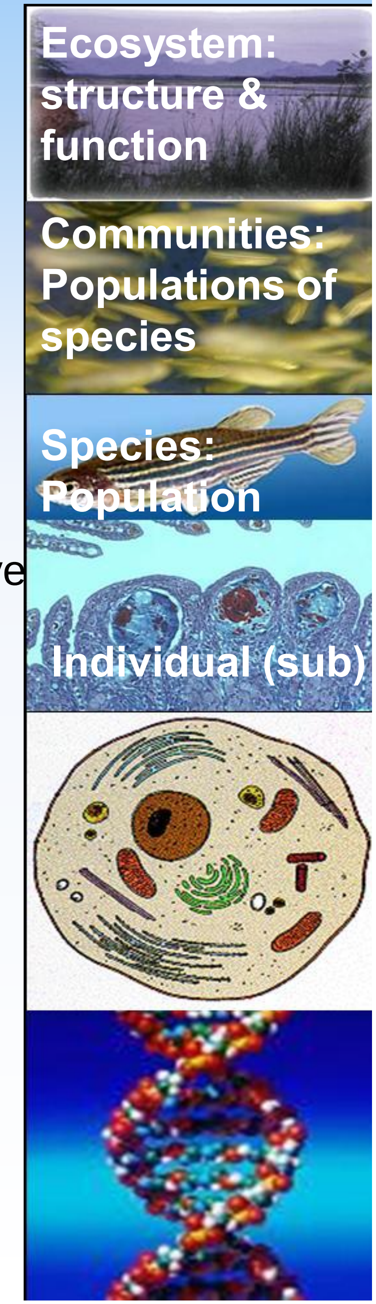
  Garnier-Laplace *et al.,* JER 2010

- Several methods have been used for this analysis of dose(rate)-response relationships
  - per species representative of a family of species (ICRP approach),
  - per sets of species representative of the biodiversity existing among a larger assemblage, a wildlife group or an ecosystem (UNSCEAR, ERICA-PROTECT),
  - All based on extrapolations.

The various extrapolations and associated uncertainties

Responses (nature, intensity) to radiation exposure vary:

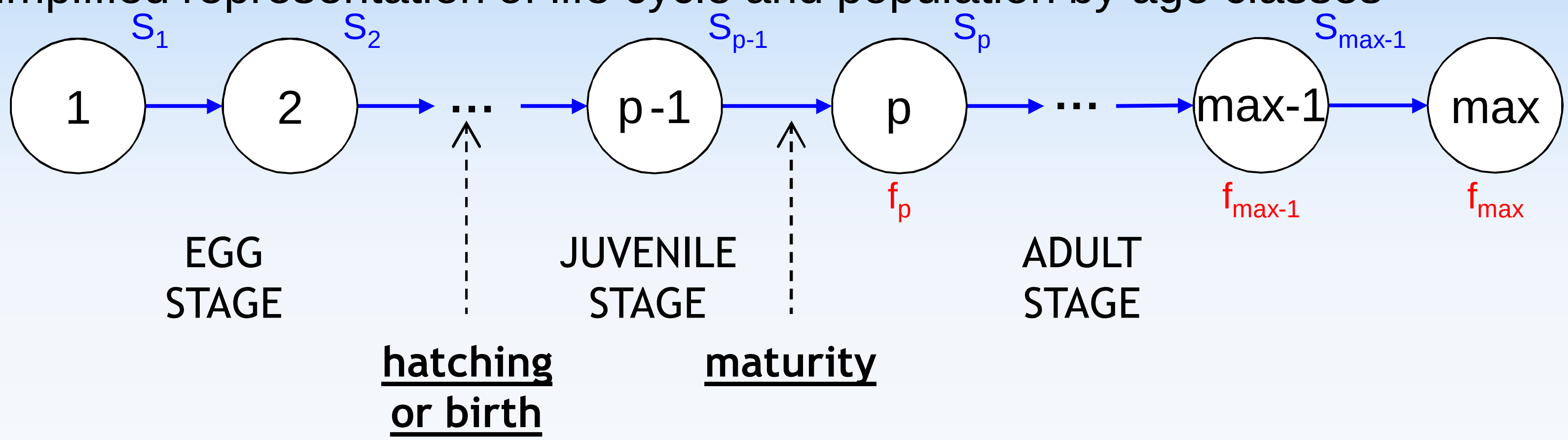
- From one type of radiation to another (up to ca. x50)
- From acute to chronic exposure (ca. 1-2 orders of magnitude); from one single generation to mutiple generations
- Among cell types and tissues
- Among biological endpoints (reproduction recognized as the most sensitive endpoint)
- Among life stages (embryos, larvae, juveniles most sensitive)
- **Among levels of biological organisation**
- **Among species (up to 6 orders of magnitude)**
- **From lab to field**



From individual level to population level

- Principle : For a given species, combining individual dose-response curves to infer the population level by using Leslie matrices

- Simplified representation of life cycle and population by age classes



➔ **3 life stages defined: egg, juvenile and adult**

- Parameters for the Leslie matrices

➔ **Number of age classes**

➔ **Survival rates**

➔ **Fecundity rates (adults)**

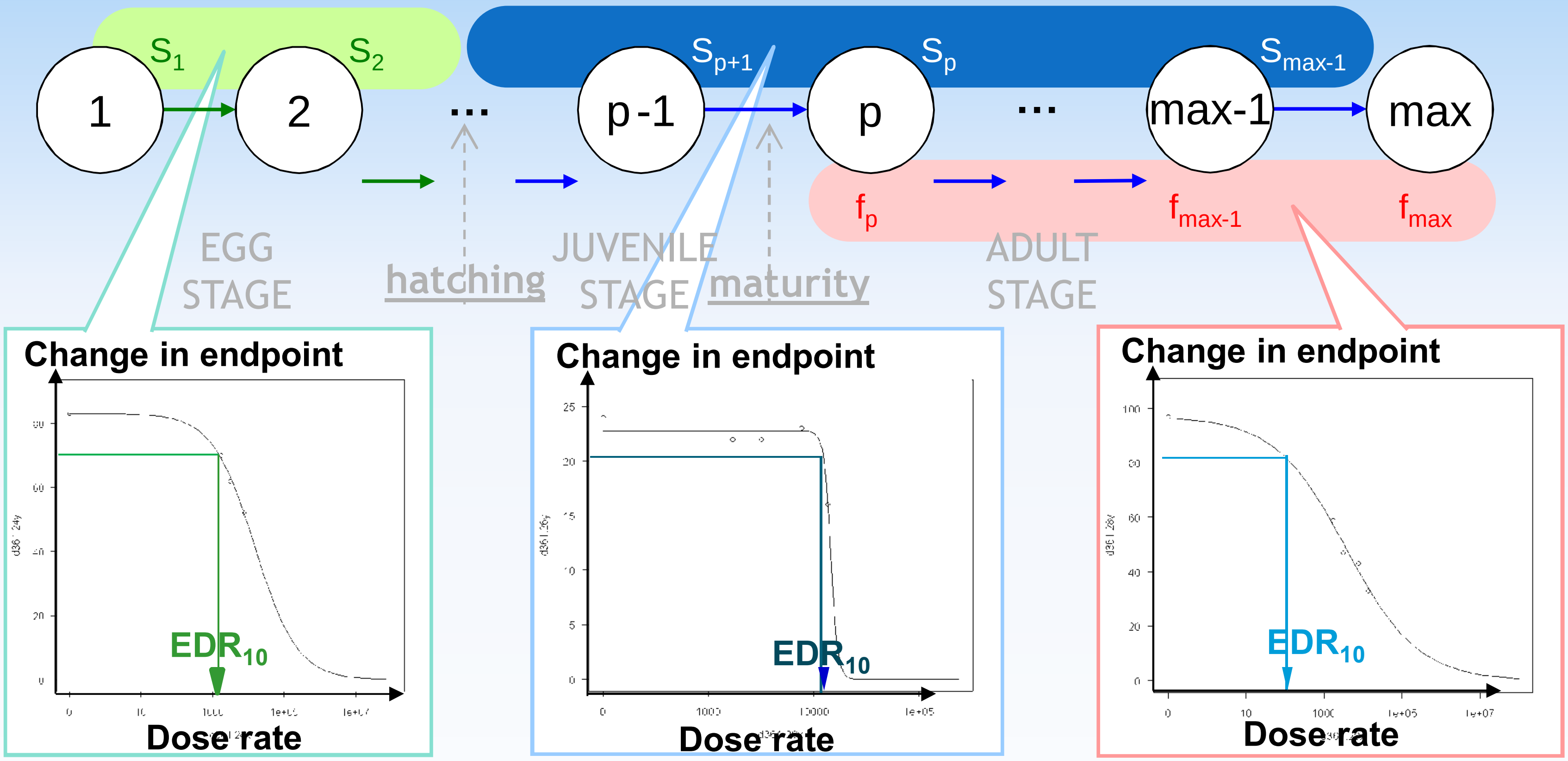
(all life stages) (applies to number of age classes and survival rates)

$$N(t+\Delta)=\begin{bmatrix} 0 & 0 & é & f_p & f_{p+1} & é & f_{max-1} & f_{max} \\ S_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S_p & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{p+1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & S_{max-1} & S_{max} \end{bmatrix} \times N(t)$$

Transition matrix

From individual level to population level

Selection and application of radiation effects to the population
(*e.g.*, chronic external gamma irradiation)



<u>Effect on hatching</u>

Applied as a reduction
in survival rates
in egg stage

<u>Effect on survival</u>

Applied as a reduction
in survival rates
in juvenile and adult stages

<u>Effect on fecundity</u>

Applied as a reduction
in fecundity rates

From individual level to population level

➔ **Combine observed effects among several individual (fitness-related) endpoints**

➔ **Model population growth rate λ and individual reproductive rate R_0 (**number of offspring per individual over a lifetime) **at any dose rate**

➔ **Predict dose rates causing population extinction (λ≤1)**

➔ ***Molecular, cellular and histological damages were not integrated…***

➔ **For a species, allow a comparison between radiosensitivity at the individual level and radiosensitivity at the population level**

From individual level to population level

- Population-level effects depend both on:
  - how key biological functions are affected by radiotoxicity at the organism level and
  - how population dynamics respond to such effects.

- The same level of effect could have different consequences for the population depending on the impaired individual endpoint and on life history strategies.

- The most influential individual endpoint for population dynamics is not necessarily the most radiosensitive.

- A modeling exercise on various species demonstrated three types of situations where the most radiosensitive individual endpoint is :

  (1) an overestimation of the population radiosensitivity**.**

  Or (2) a good proxy of the population radiosensitivity.

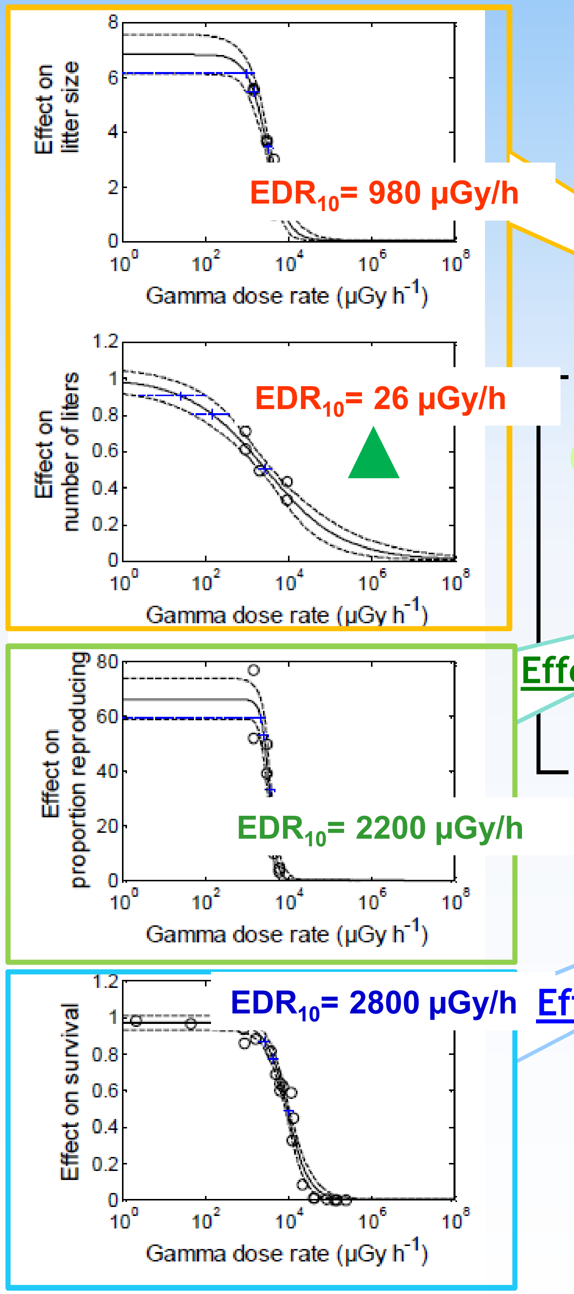
  Or (3) an underestimation of the population radiosensitivity.

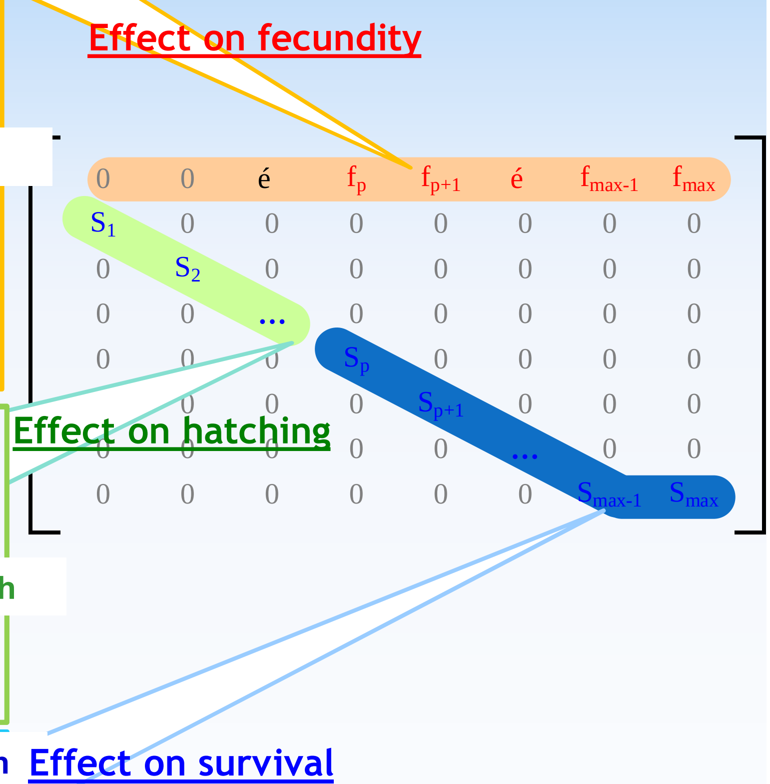
Alonzo *et al.,* JER 2008; Massarin *et al.,* ES&T 2010; Lance et al., STOTEN 2012; STAR D5.2 2012

Ex1: The most radiosensitive individual endpoint is an overestimation of the population radiosensitivity

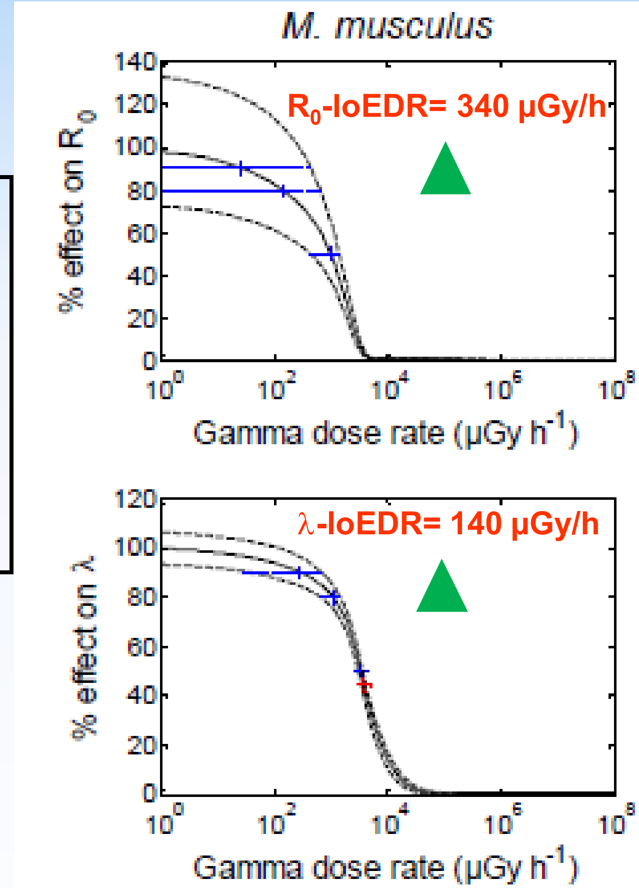
A terrestrial mammal *Mus musculus*

Unisexual
Gestation time 0.6 months
Lifespan 28 months
5.4 litters/y of 7 young





Combined consequences for individual R_0 and population ə



STAR D5.2 2012

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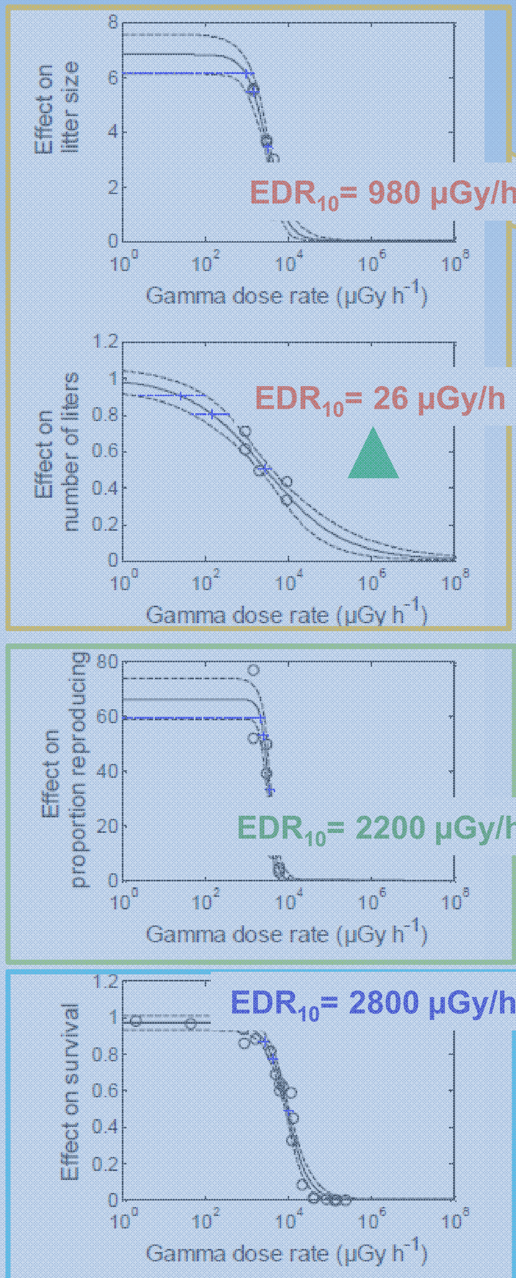


Dose rates giving the lowest significant changes in R_0 and λ are higher than the lowest individual EDR10 by a factor *ca.* 13 and 5 respectively.

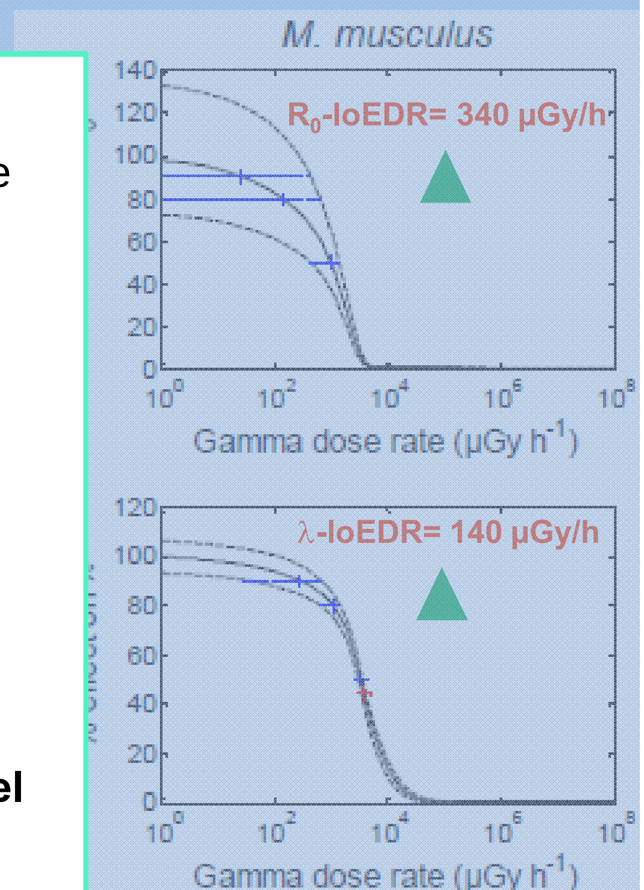
Population is protected when individuals are protected

- **ICRP DRCL Reference rat**

0.1-1 mGy/d or 4-40 µGy/h
is appropriate for individual level

1-10 mGy/d or 40-400 µGy/h
is appropriate for population level

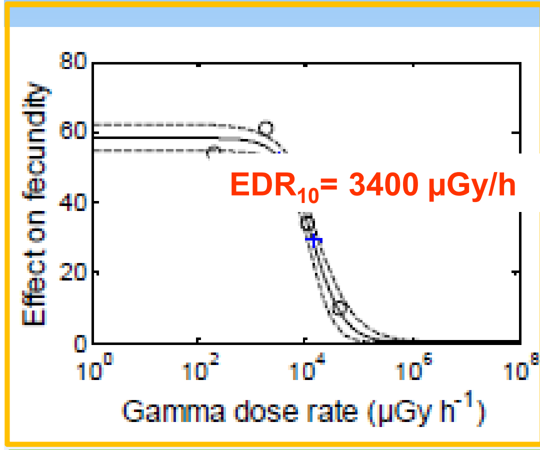
Combined consequences for individual R_0 and population λ

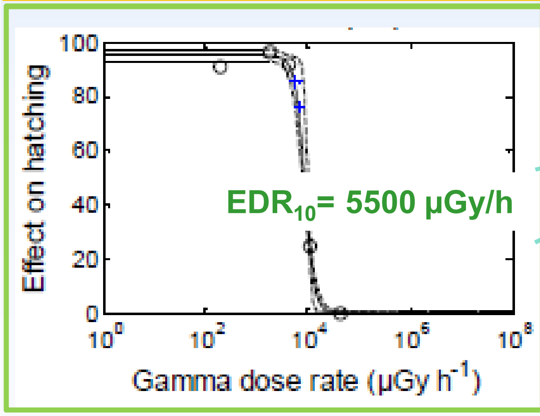


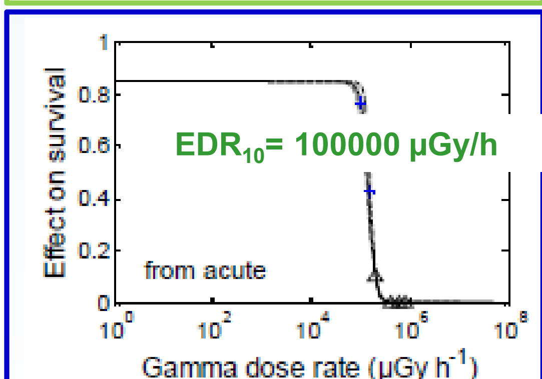
Ex2: The most radiosensitive individual endpoint is an underestimation of the population radiosensitivity

A terrestrial invertebrate *Eisenia fetida*

- Hermaphroditic
- Continuous breeder with 2-5 cocoons/worm/week
- Hatching 1 month
- Maturity 3 months
- Lifespan 20 months



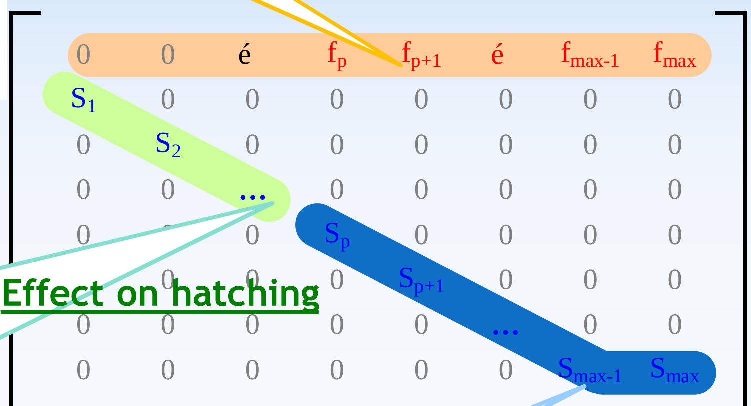




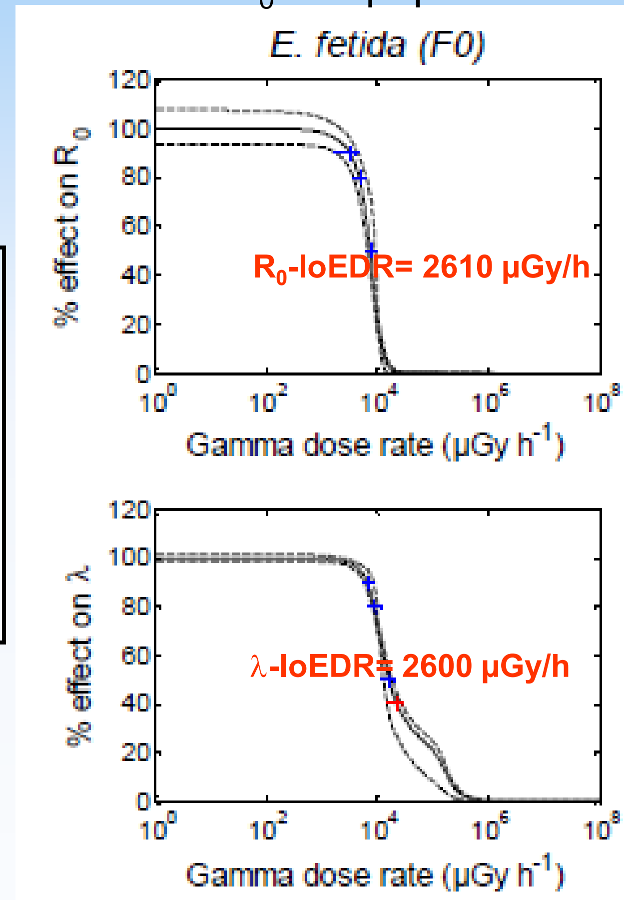
Effect on fecundity

Effect on hatching

Effect on survival



Combined consequences for individual R_0 and population λ



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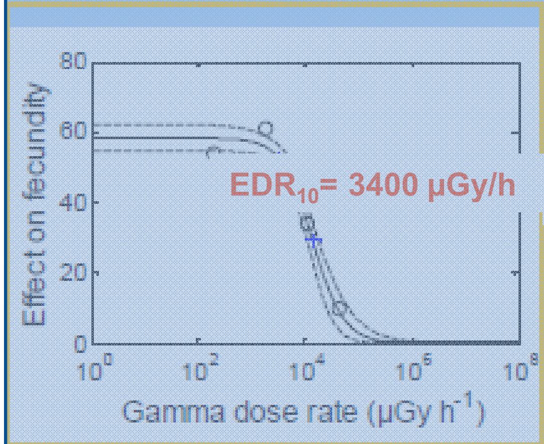
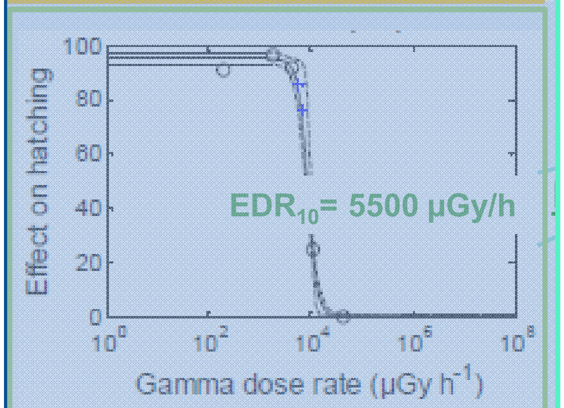
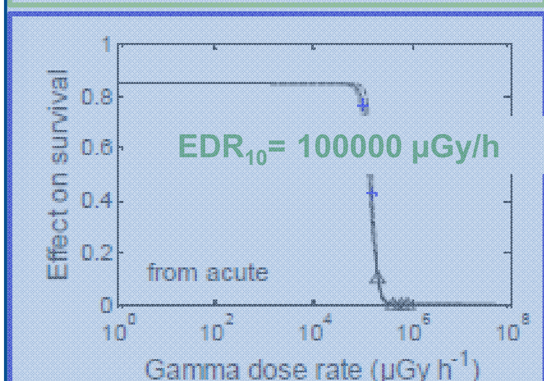
Ex2: The most radiosensitive individual endpoint is an underestimation of the population radiosensitivity







A terrestrial invertebrate
Eisenia fetida

Hermaphroditic
Continuous breeder with 2-5 cocoons/worm/week
Hatching 1 month

- Dose rates giving the lowest significant changes in R_0 and λ are lower than the lowest individual EDR10 by a factor *ca.* 1.3

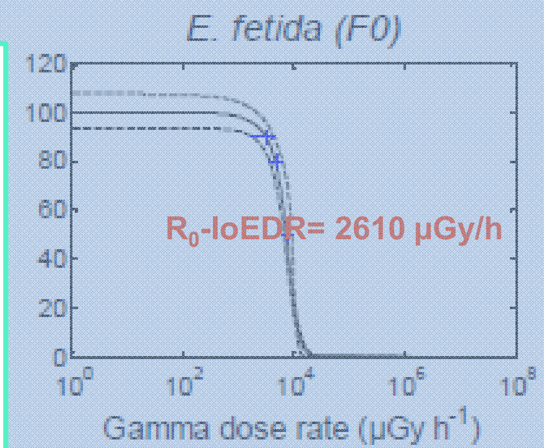
- **Population is not protected when individuals are protected**

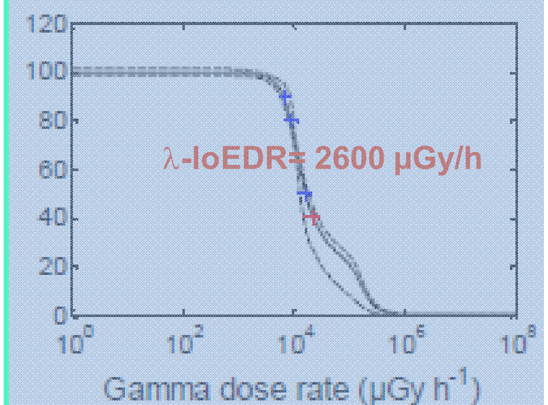
- **ICRP DCRL Reference Earthworm**

10-100 mGy/d or 400 -4000 µGy/h

is appropriate for individual and population levels

Combined consequences for individual R_0 and population λ

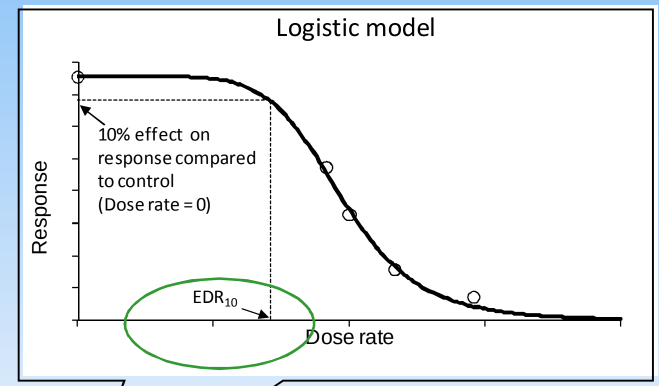


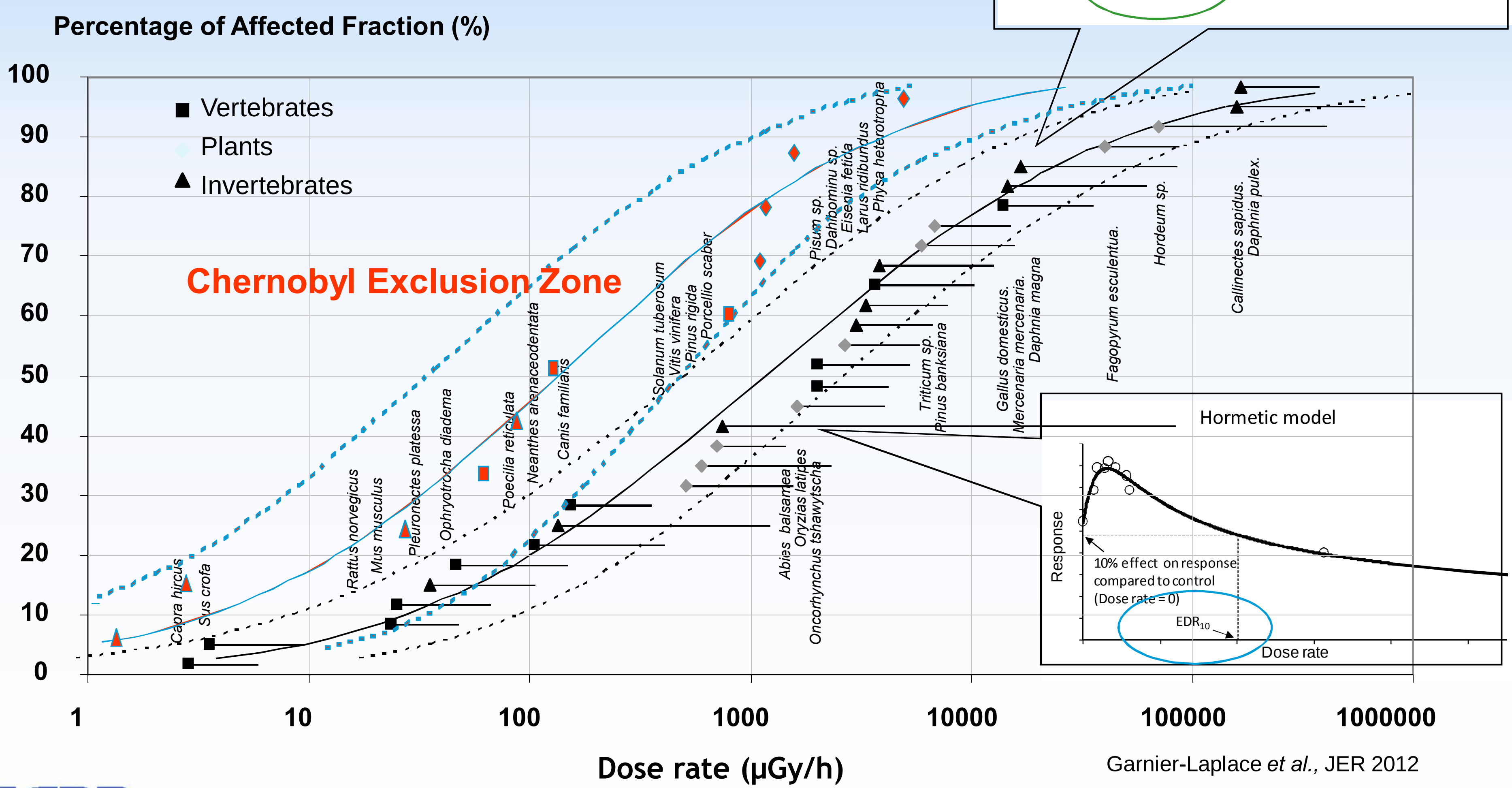


Inter-species extrapolations and lab to field extrapolation issues

- Laboratory data have been preferably used since laboratory conditions offer a robust way to characterize cause-effects relationships
- This was adopted for the EC-funded ERICA-PROTECT suite to derive screening benchmarks consistently with the approach applied for chemicals where laboratory tests have been the main basis of benchmarks until now.
- However, laboratory and semi-field tests constitute a too simplistic way to represent the complex nature: they generally ignore inter-individual and inter-species interactions, variety of routes of exposure and variety of responses from all species.
- Field data are representative of ñreal worldò but they always document on-going or past changes;
- Field observed effects may be caused or modified by simultaneously occurring stressors (issue of confounding factors).

Radiosensitivity variation between species under chronic γ controlled exposure





Garnier-Laplace *et al.*, JER 2012

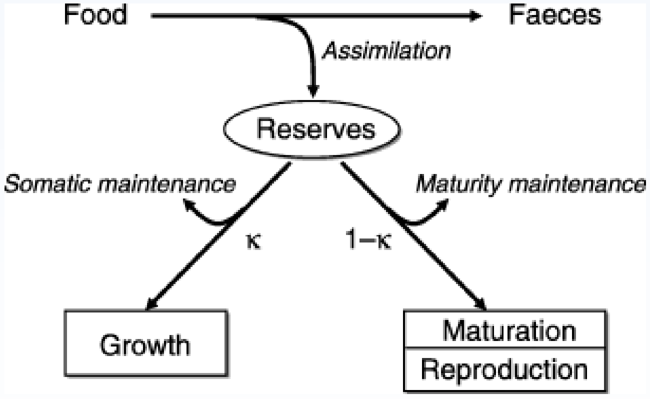
Conclusion, Perspectives

- Predicting radiological consequences at the population level in wildlife species requires knowledge on:
  - exposure conditions,
  - life history characteristics of the organism exposed,
  - integration over time of a time-dependent absorbed dose,
  - and combination of dose-response relationships on impaired individual endpoints.
  - Multigenerational effects need to be studied.

- Research on primary mechanisms of interactions between ionising radiation and living organisms (from biomolecules up to populations) is still needed.

- Advanced biology-based models such as DEBtox will be used to analyse radiation effects as dynamic processes in organisms
  - DEB describes how individuals acquire and use energy based on simple rules for metabolism.
  - DEBTox is a biology-based model describing how toxicants accumulate over time in exposed organisms and alter energy acquisition and allocation to growth and reproduction.

Effects on energy budget



Consequences for survival, growth and reproduction

Thank you for your attention!

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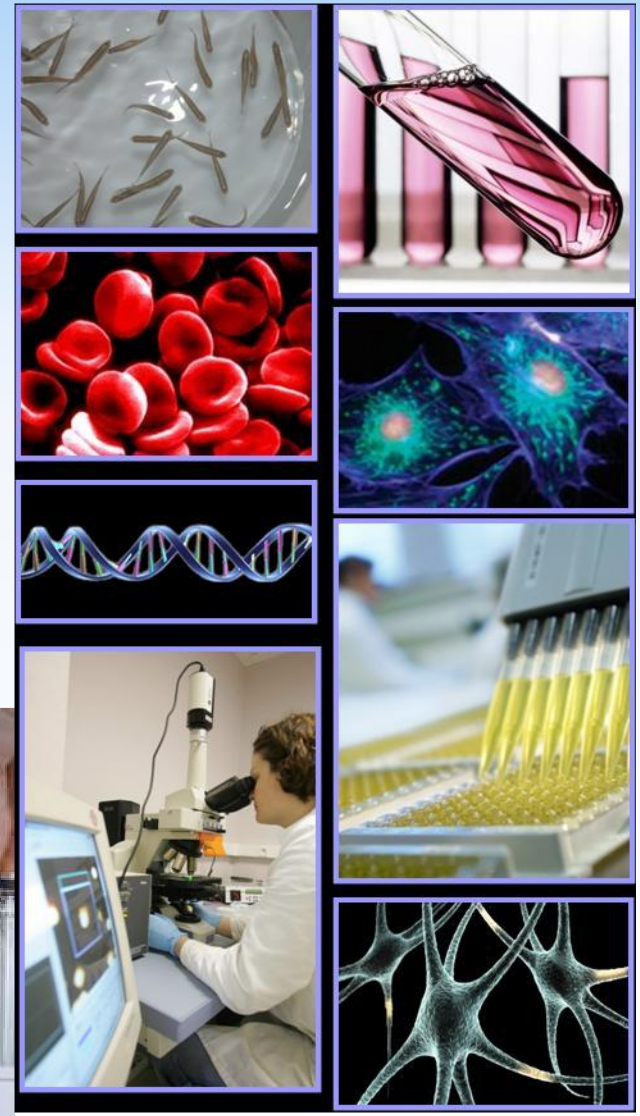
STAR
STRATEGY FOR ALLIED RADIOECOLOGY

COMET

http://www.radioecology-exchange.org



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