IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

RADIOPROTECTION OF THE ENVIRONMENT

elementary ecotoxicity data, derived screening benchmarks and applications

Workshop on environmental effects of chronic low level radioactive contamination, February 2013, Lancaster (UK)

GARNIER-LAPLACE J., BEAUGELIN-SEILLER K., ADAM-GUILLERMIN C., DELLA VEDOVA C.

IRSN/PRP-ENV/SERIS, Cadarache, France

Screening benchmarks *vs*. Standards & their applications

General Definition:

- For assessing and managing ecological risk, we need limit(s) quantifying the interface between an acceptable stressor level (*e.g.*, in a given medium, in biota) and an unacceptable level [« acceptable » being related to the protection goal]

Applications

- Ecological Risk Assessment – used as screening values, associated with a tiered RA scheme;
  - Exceeding means « do more » to better characterize the risk (e.g., the screening value in the ERICA integrated approach for radioactive substances)
    - » ***namely PNEDR for radioactive substances vs. PNEC for chemicals***

- Regulation – used as legally binding criteria (standards) to be met to answer the legal requirements;
  - Exceeding means « act » on a legal point of view
    - » ***namely EQS and QS for chemicals - do not exist at present for radioactive subtances eventhough their derivation is intended by ICRP and IAEA (OSPAR)***

Why laboratory data have been used preferably to establish the benchmark?

- A robust way to characterize cause-effects relationships;
- Control of exposure of organisms in lab is easy to implement : the cause of the observed effects (if any) can be identified with certainty and can be quantified according to a gradient of exposure;
- Tests can be replicated;
- Under GLP, there is a certainty to face no significant cofounders;
- Dose (rate) effect relationships (when such a relationship exists) can be built with robustness (*ad hoc* experimental design to allow for a relevant statistical power and regression models);
- This preference was the one 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 (even the unique for a great number of chemicals).

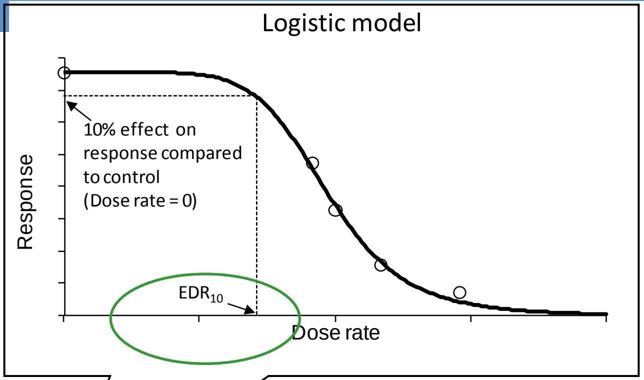
The story of the « 10 µGy/h » in a nutshell

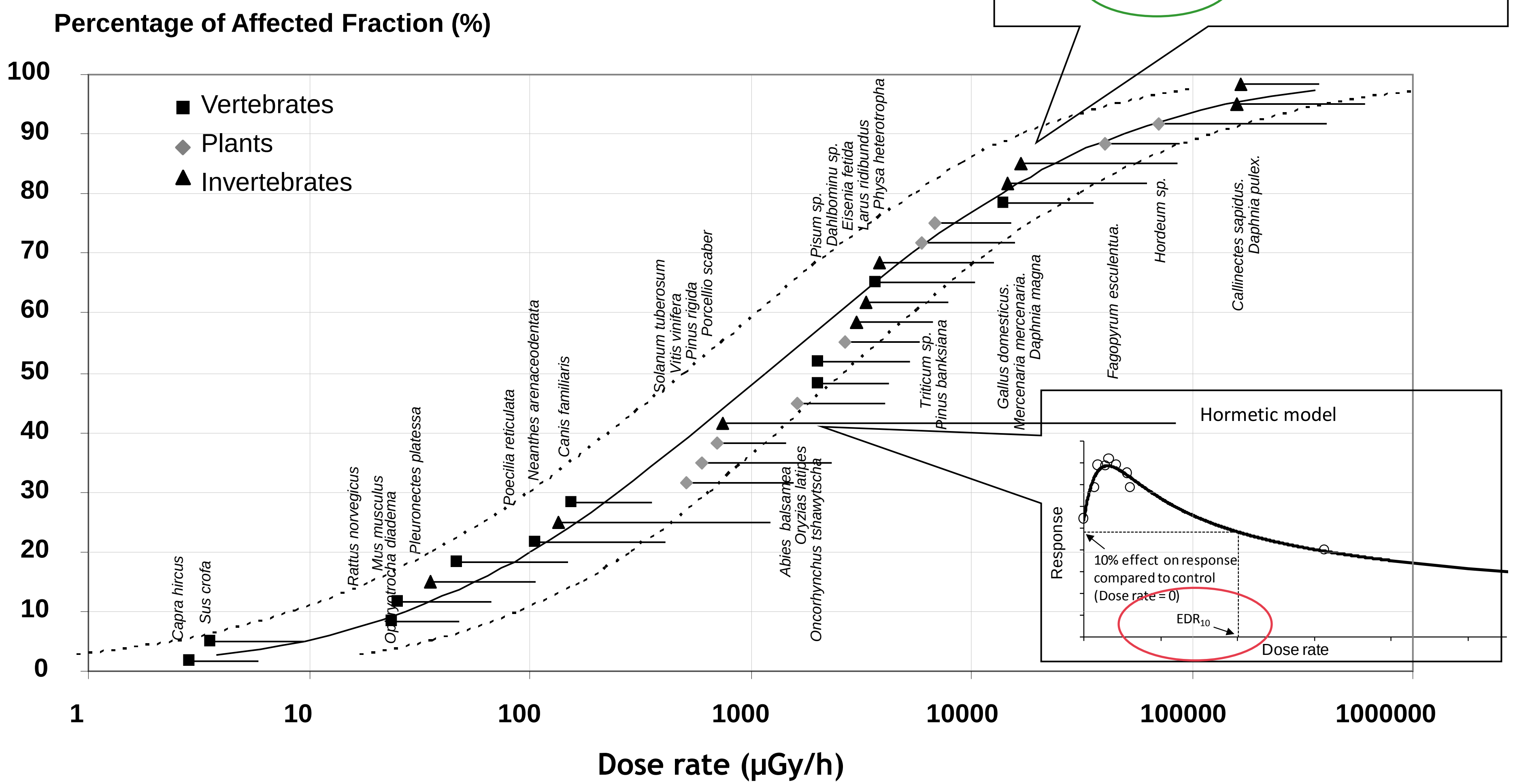
- ERICA, PROTECT and EMRAS II Effect Group have proposed and applied a 5-step methodology for deriving **“the Predicted No-Effect Dose Rate”** (**PNEDR**)
  - 1- extract adequate data sets from FREDERICA,
  - 2- Build dose-response curves for various species and endpoints, estimate the EDR_{10} per (species, endpoint) – *EDR_{10}=Dose Rate giving 10% effect*
  - 3- Implement a *Species Sensitivity Distribution-type* meta-analysis for plotting radiosensitivity variability inter-species (statistical distribution of selected EDR_{10}s - minimum EDR_{10} among ecologically relevant endpoints per species)
  - 4- Estimate the dose rate protecting 95% of the species (*Hazardous Dose Rate for 5% of the species- HDR_5)*
  - 5- Apply a *Safety Factor* to the HDR_5 to obtain the final PNEDR if needed for ERA purpose

- The meta-analysis is based on the use of **the range of variation of radiosensitivity between species** and was done on the basis of comparable critical ecotoxicity values EDR_{10} from chronic exposure to external gamma irradiation under controlled exposure conditions (lab or semi-field i.e. field iradiators)

- We obtained **246 EDR_{10}** for ecologically-relevant endpoint and 30 species; we used the minimum value per species for the SSD

Radiosensitivity variation between species under chronic γ controlled exposure





Why are other sources of knowledge needed?

- Laboratory and semi-field tests constitute a too simplistic way to represent the complex nature as they generally ignore inter-individual and inter-species interactions, variety of routes of exposure and variety of responses from all species;

- Eventhough generally conservative to assess/predict risk, the derived knowledge from this simplified “virtual world” generally fails in supporting the prediction of complex ecological responses;

- The approach now largely promoted in the last EC recommendations for EQS derivation for chemicals (TG n°27: EC, 2011) is to use field data to enrich the information and to set even more robust benchmarks;

- Field data are representative of “real world” but they always document changes that are on-going or have already occurred (exposure levels may have already caused damages);

- Field observed effects may be caused or modified by simultaneously occurring stressors (issue of confounding factors)

How to use existing effect data from radioactive contaminated field?

- We have tried to apply the same methodology to field data corresponding to realistic mixed exposure in radioactive contaminated sites and compared the variation of species sensitivity to chronic exposure to ionizing radiation observed in field *vs.* controlled conditions (lab/field irradiators)

  - 1- selection of adequate data sets
  - 2- dose-response curves and EDR_{10}
  - 3- *Species Sensitivity Distribution*

Selection criteria of field data

- Same rules to **quality assessed** field data sets as those developped for laboratory data sets (see Garnier-Laplace *et al.*, 2010)

- Contaminated field sites experiencing **chronic** exposure

- Need for **analogous controls and gradient of radiation** (at least 2 in addition to the control)

- Need for **proper dosimetry** (or be able to reconstruct with confidence)

- Need for a good interpretation of the **spatial heterogeneity** of exposure experienced by free-ranging wildlife

- Good knowledge of potential **confounding variables** (*e.g.*, seasonal factors)

Selected field data -> FREDERICA + Russian database

- Due to increasing controversy about Chernobyl long-term ecological consequences, we dedicated our first analysis to the **Chernobyl Exclusion Zone**, and the **chronic exposure phase** (*ca.* 15 years after the accident up to now)

- Only **12 references from FREDERICA and from Geraskin's Russian** database meet the criteria, especially for the exposure analysis: Dose rates to species are properly estimated from external γ irradiation and internal contamination (^{137}Cs, ^{90}Sr)

- **28 data sets adequate for DRC acquired for 10 terrestrial species** -> 10 minimum EDR_{10} selected after having checked the ecological relevancy of the observed enpoints (*e.g.*, mutation not taken into account at that stage)

Selected field data -> Moller et al.'s studies on Chernobyl bird populations

- Species richness, abundance and population density for forest birds decrease when radiation level increases

Møller AP, Mousseau TA (2007). Species richness and abundance of forest birds in relation to radiation at Chernobyl. *Biology Letters*, 3 : 483-486

- A statistical relationship between ambiant radiation level and intensity of effects was found: bird abundancy decreased by 60% between sites where radiation varied from 0.1 to 1 mGy/h, and control sites characterized by 0.1 µGy/h.

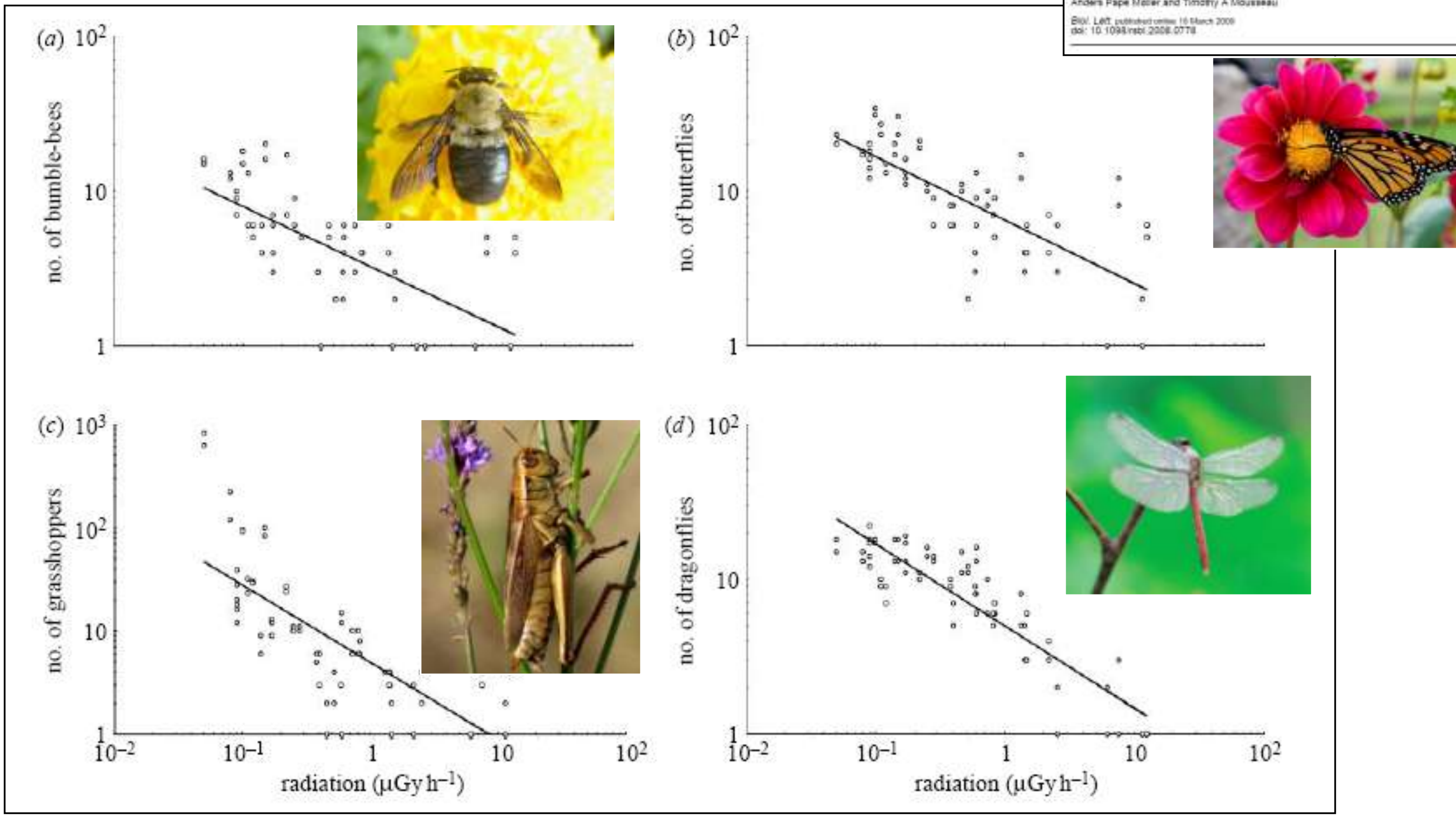
- Under the assumption of a linear dose-response relationship, EDR_{10} would be : *ca.* 20 **µGy/h (*ambiant*) for abundancy**

…and on terrestrial invertebrates


biology letters

Reduced abundance of insects and spiders linked to radiation at Chernobyl 20 years after the accident

Anders Pape Møller and Timothy A Mousseau

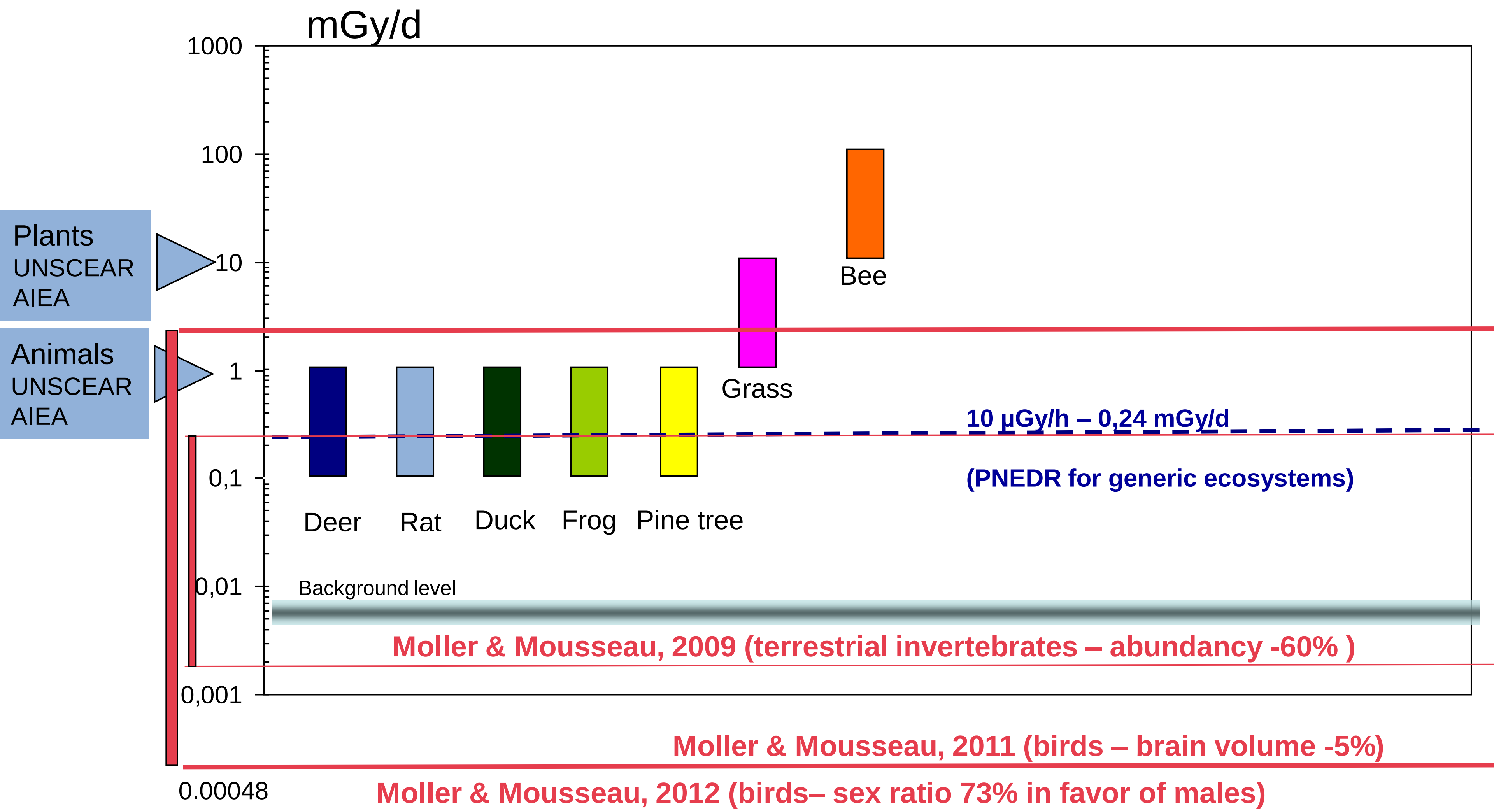


- For Moller & Mousseau (2009): link between the ambiant radiation level and abundancy of several species

- Decreasing x10 from **0.1 μGy/h to 10 μGy/h** (ambiant): under a linear relationship, EDR_{10} is *ca.* **1.1 μGy/h** (ambiant) **for abundancy**

Effects data from Moller et al. put into perspectives

Derived Consideration Reference Levels (ICRP108, 2008) - bands of low probability of effects - and other existing benchmarks



Re-estimation of total dose rates for Moller's data: methods

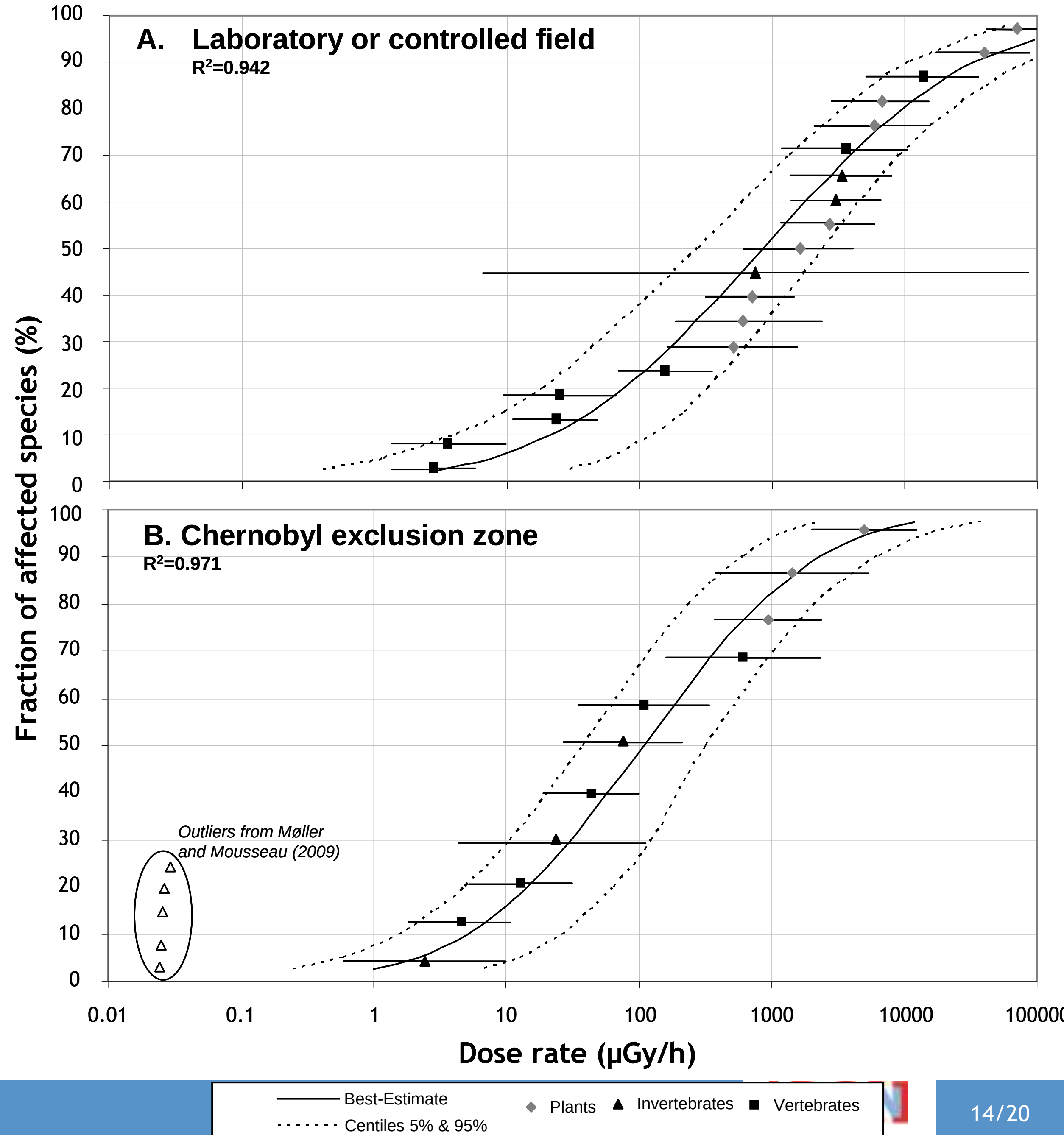
- **External radiation levels** were measured by hand held device.

- This introduced **a bias ignoring internal dose rates**. Under the assumption that the device used was properly calibrated, the corresponding bias varies according to:
  - The **ratio between the two major radionuclides** measured in the Chernobyl zone (Cs-137/Sr-90 varies from 1 to 10 – [*Atlas of Ukrainian radioactive contamination, Kiev, 2008*]
  - The **soil-based aggregated concentration ratios**, specific per radionuclide and species (ERICA Radioecology Database, median values, w.w.)
    - 0.75 & 0.55 for birds and for Cs-137 and Sr-90 respectively;
    - 0.055 & 0.063 for flying insects and for Cs-137 and Sr-90 respectively.

- The way **to estimate the total dose rates** is then as follows:
  - Knowing that only Cs-137 contributes to the external dose rates, the x-axis from Moller & Mousseau (ambiant radiation level) can be used to estimate **the Cs-137 concentrations in soil**
  - Knowing the range of the isotopes ratio in the Zone, **the Sr-90 concentrations in soil** can be calculated
  - Using Cs-137 and Sr-90 concentrations calculated in soils, the **internal then the total dose rates** can be estimated.

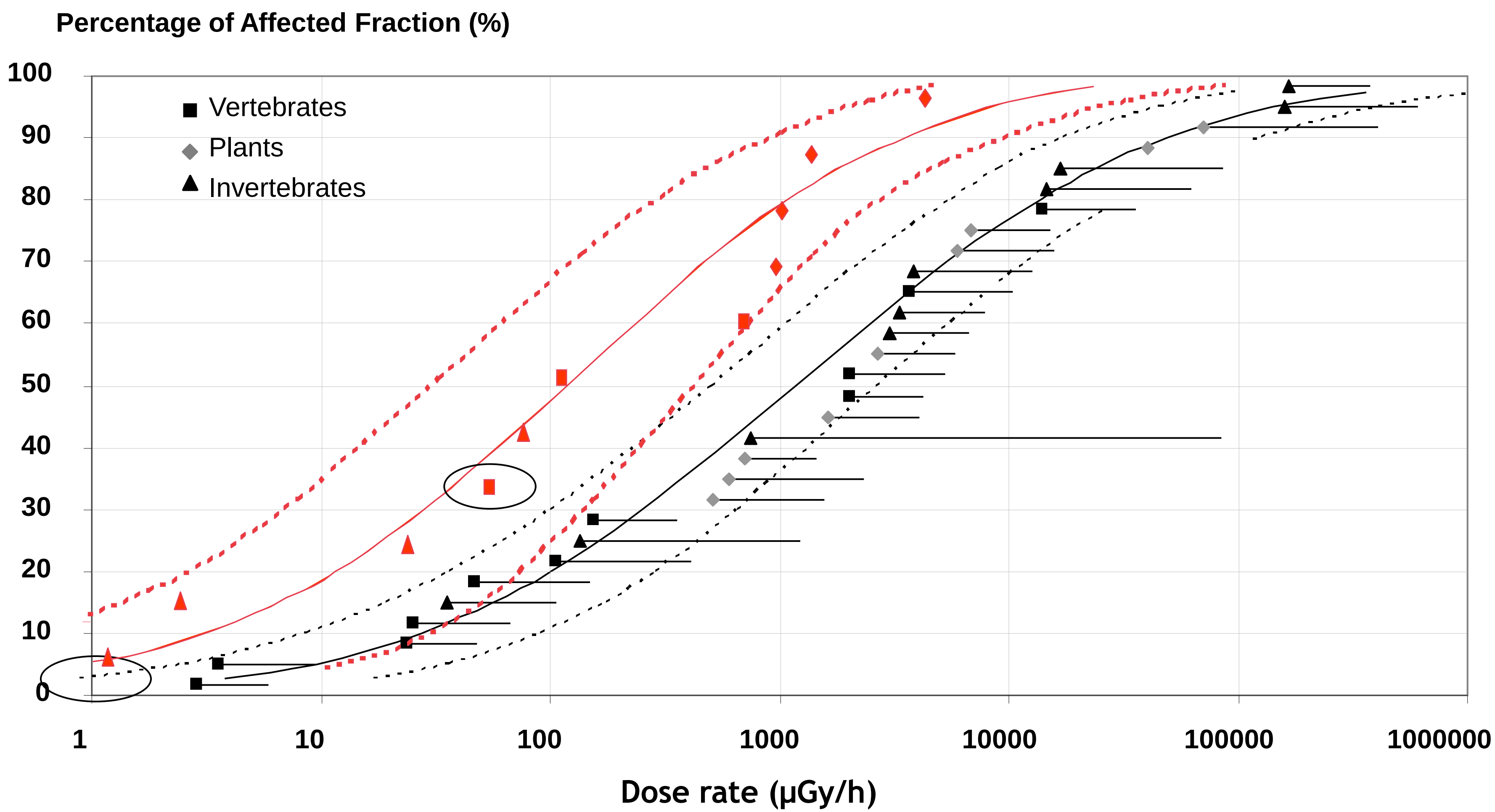
- EDR_{10} for bird abundancy of 20 µGy/h based on external dose rate: re-estimated in the range of **52 to 110 µGy/h //** EDR_{10} for invertebrate abundancy of 1.1µGy/h based on external dose rate: re-estimated in the range of **1.2 to 1.5 µGy/h**

Radiosensitivity variation between species under chronic irradiation



Garnier-Laplace et al., 2012. JER

Radiosensitivity variation between species under controlled chronic γ exposure vs. realistic field exposure (Chernobyl)



- More sensitive in field than in lab with a shift by a factor of 5-10 to the left hand: still bad dose rate estimation for field?, worse consequences through generations?, sampling bias with seasons and life cycles?

- Higher relative sensitivity of invertebrates *vs.* vertebrates in field

Conclusions and perspectives

- In contrast to laboratory and controlled field irradiator studies, dosimetry under realistic exposure situations, such as occurs at contaminated field sites, is much more complex; Surveys of external exposure, using hand held instruments at ground level, as reported in a number of papers on Chernobyl consequences to wildlife, do not always adequately represent the absorbed dose received by free-ranging organisms.

- Re-estimation of the correct dose rate is difficult: **the need for robust field data** is very much needed to understand the effects of environmental & ecological variables

- Both sources of data are complementary and we need a combination of them to achieve a richer and proper understanding.

- At present the existing field data in the CEZ are internally contrasted (e.g., drastic effects reported form Moller et al. with no-effect reported from Baker et al.) and un-consistent with laboratory data. We need a deeper understanding of the mechanisms underlying the variation of radiosensitivity among species and among radiation types; including transgenerational effects.

Predicting responses of real nature is complex… and may be misunderstood….

…by non-human species….

I am a researcher… and here to protect you and your family…!!!!

Thank you for your attention!