Environmental Modelling for Radiation Safety (EMRAS II)

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EFFECTS GROUP, sub-group on Population models and Alternative Methods

(led. by Tatiana Sazykina, Russia)

Task: Development of generic population model for radiological assessment

RADIATION EFFECTS IN A GENERIC POPULATION. CASE: POPULATION IN A LIMITED ENVIROMENT

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In ecology, the most simple generic model for population growth is logistic model.

Logistic model was developed by Belgian mathematician Pierre Verhulst (1838) who suggested that the rate of population increase may be limited, i.e., it may depend on population density.

The dynamics of the population is described by the differential equation:

$$\frac{dN}{dt} = r_0 \times N \times (1 - \frac{N}{K})$$

which has the following solution:

$$N(t) = \frac{N_0 \times K}{N_0 + (K - N_0) \times \exp(-r_0 \times t)}$$

N(t)- size (or density) of population; N_0- initial size;

R_0=b-d; b-birth rate; d-death rate.

parameter K is the upper limit of population growth and it is called carrying capacity. It is usually interpreted as the amount of resources expressed in the number of organisms that can be supported by these resources.

Here we consider a more modern form of the logistic growth model, Which is named "population in a limited environment".

The model is based on consideration that growth of population Biomass is restricted by a limiting resource. The total amount of this Resource in a particular habitat patch is constant: RES=const. According to Liebig's principle, the growth rate is proportional to the amount of resource S currently available for organisms.

So, the Verhulst equation is transformed to a system of equations:

$$\frac{dM}{dt} = -\varepsilon \times M + \beta \times M \times S;$$

$$S + M = RES;$$

M- biomass per unit volume/square of environment;
S-limiting resource available;
RES- total amount of limiting resource (unit of biomass require a unit of resource);
ε -biomass losses due to mortality, metabolism and predation;
β- biomass specific growth rate due to biosynthesis, including reproduction.

Population size/density at stationary state:

$$\mathbf{M}^{\mathbf{stat}} = \mathbf{RES} - \frac{\varepsilon}{\beta} > 0$$ Population size

$$\mathbf{S}^{\mathbf{stat}} = \frac{\varepsilon}{\beta}$$ Residual resource in the environment

The dynamic behavior of the population biomass follows the formula of Logistic growth

$$M(t) = \frac{M^{stat} \times M(0)}{M(0) + (M^{stat} - M(0)) \times exp\{-(\beta \times RES - \varepsilon) \times t\}};$$

Comparing with the Verhulst equation, we see that the term “Carrying capacity K” here is actually $\mathbf{M}^{\mathbf{stat}}$.
or, in other words, we obtain in direct form, how the carrying capacity **K** depends on radiation exposure.

Introducing chronic radiation exposure with the dose rate DR in the Model parameters we obtain

$$\mathbf{M^{stat}(DR) = RES - \left(\frac{\varepsilon(DR)}{\beta(DR)}\right)}$$

$$\mathbf{M_0^{stat} - M^{stat}(DR) = \left(\frac{\varepsilon(DR)}{\beta(DR)} - \frac{\varepsilon_0}{\beta_0}\right);}$$

Since the growth and reproduction decrease with the increasing dose rate, and mortality increases with exposure; the ratio ε/β is increasing function of dose rate (DR).

Dose rate – effect curves

General form

$$y(DR) = y(Lethal) + \frac{y(0) - y(Lethal)}{1 + (DR/EDR50)^q}$$

Reproduction (biomass growth rate)

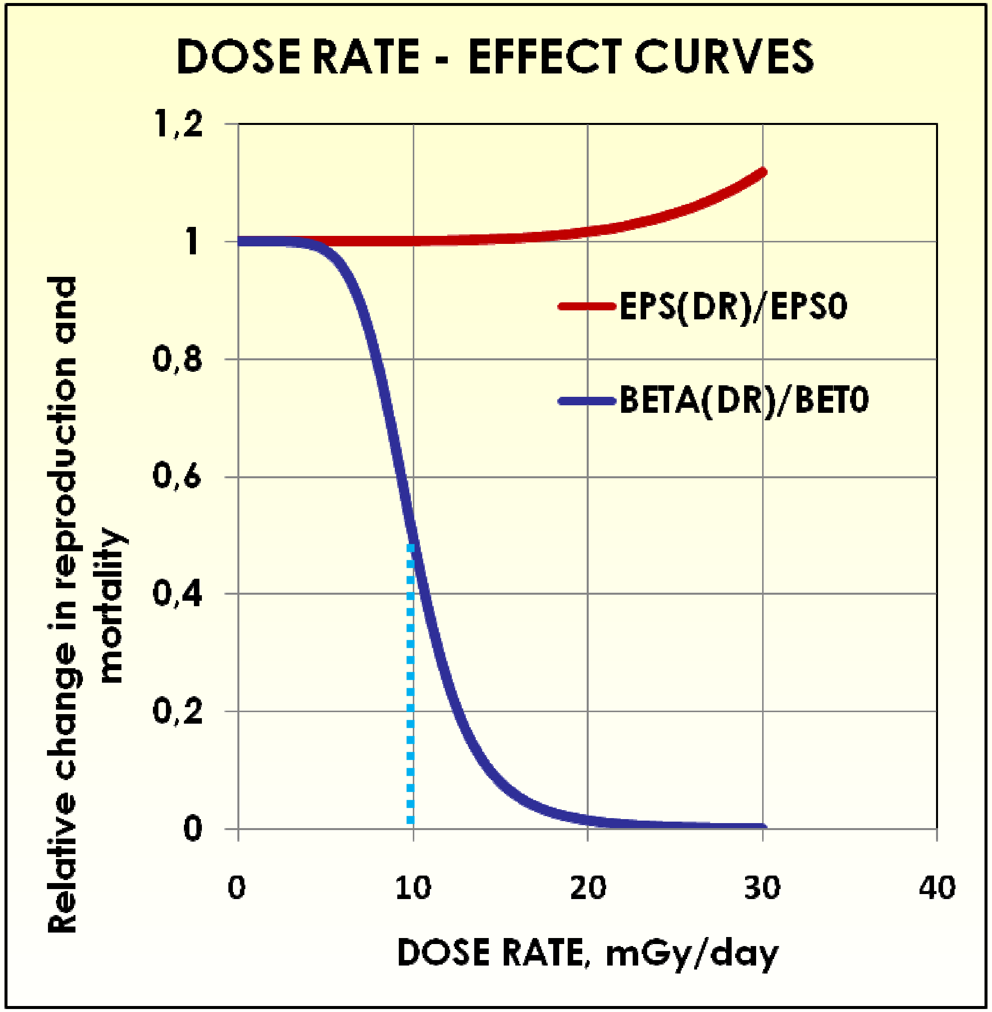
$$\beta(DR) = \frac{\beta(0)}{1 + \left(DR/EDR_{\beta 50}\right)^q} \quad intrinsic\ \ biomass\ growth\ rate$$

Mortality (biomass losses)

$$\varepsilon(DR) = \varepsilon(Lethal) + \frac{\varepsilon(0) - \varepsilon(Lethal)}{1 + (DR/EDR\varepsilon_{50})^q}$$

DRB50=10mGy/d

DRE50=100mGy/d

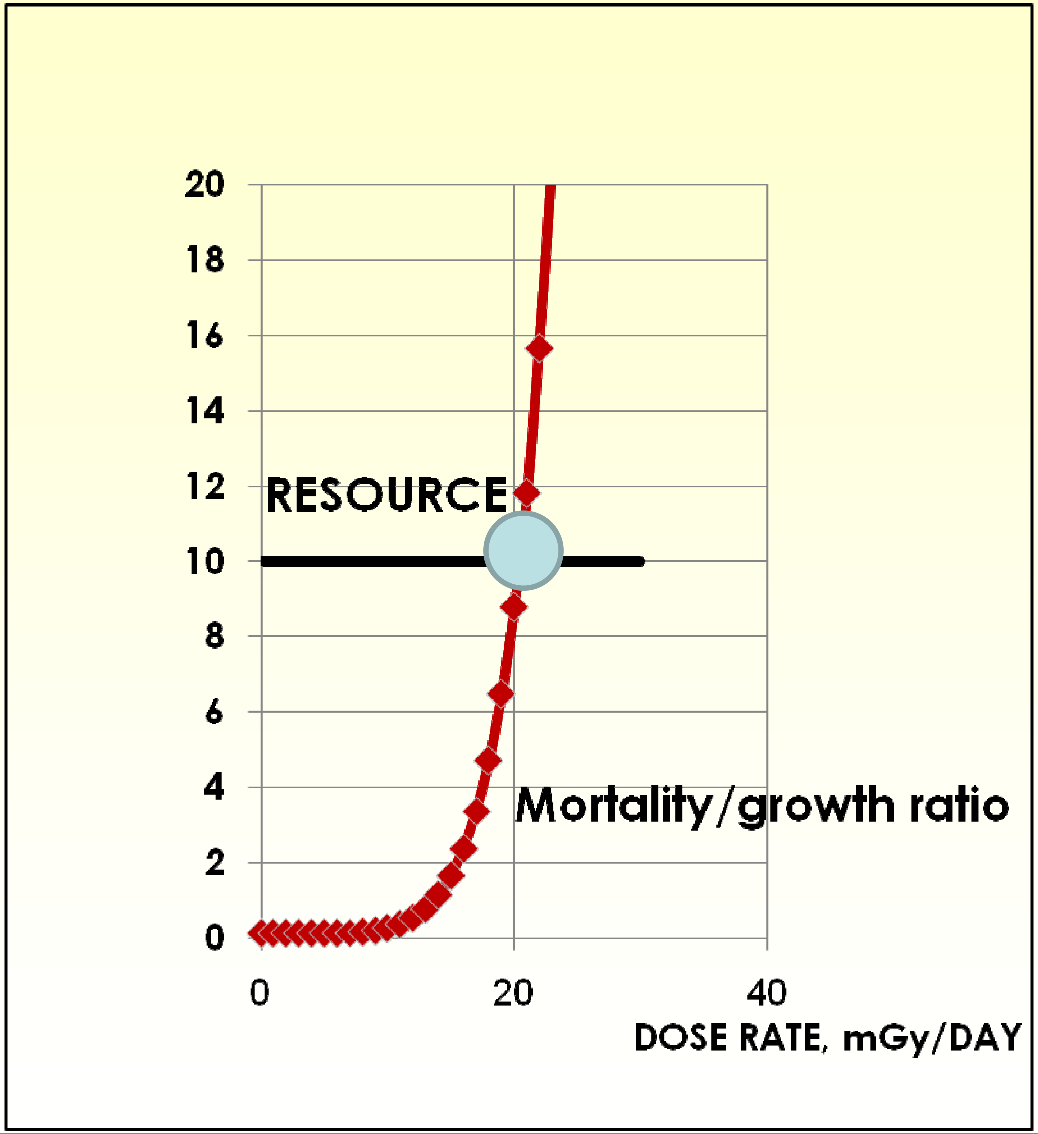


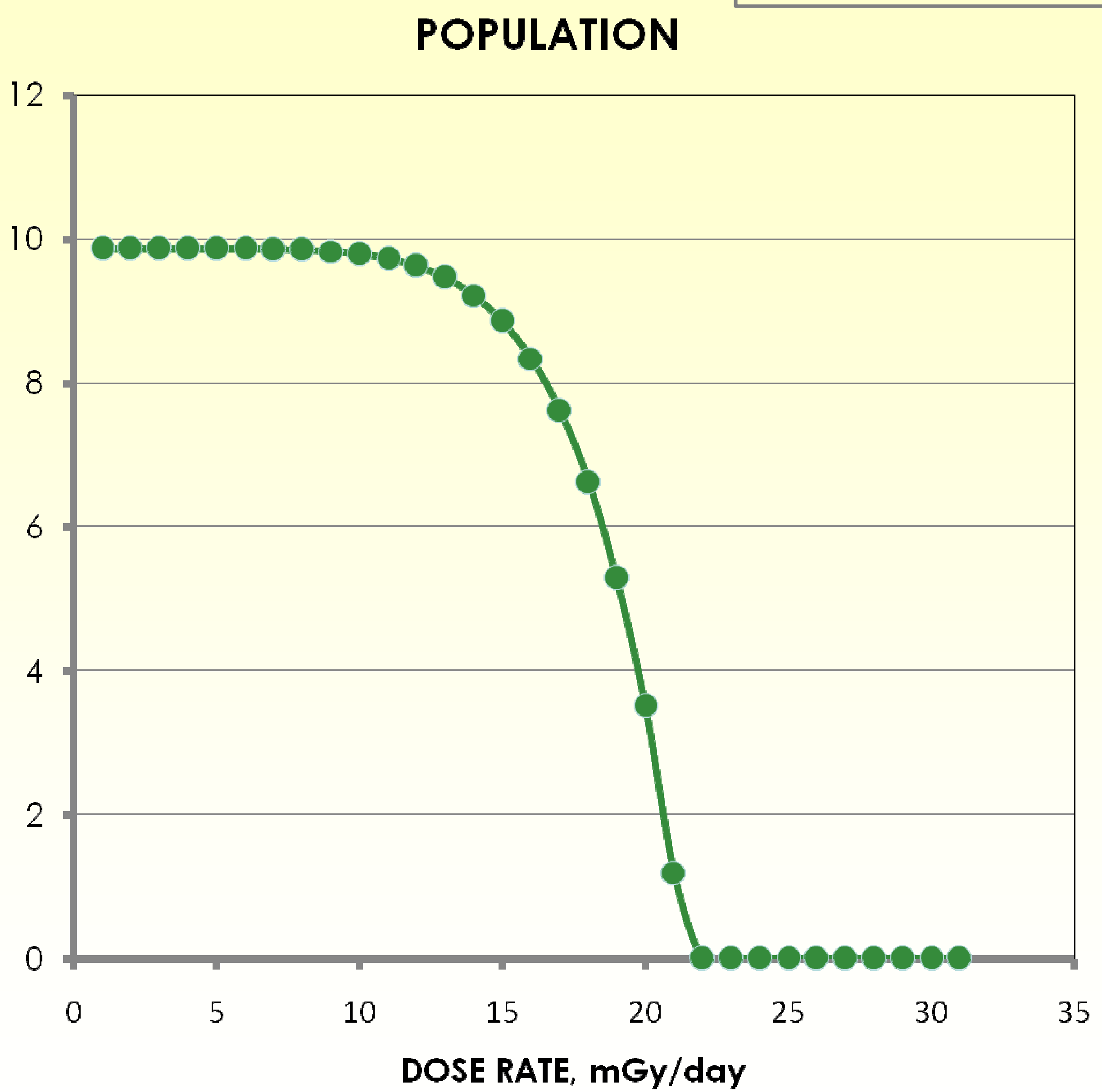
The relative change of population size at dose rate DR comparing with non-irradiated population is described by the formula

$$\frac{\Delta M^{stat}(DR)}{M^{stat}(0)} - \frac{\Delta(\frac{\varepsilon}{\beta}(DR))}{M^{stat}(0)} \cong \frac{\Delta(\frac{\varepsilon}{\beta}(DR))}{RES}$$

If the amount of resource RES is big, even dose rates producing considerable effects on reproduction do not seriously affect the population size (in %).

As soon as the Mortality/growth ratio is increasing to the value RESOURCE, the stationary state of population goes to extinction.




POPULATION
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
DOSE RATE, mGy/day

CONCLUSIONS

The generic model “population in a limiting environment” is able to describe the radiation effects on a population level.

The effects of radiation on the population numbers do not follow directly the effects on individual organisms.

The effect on population is described by a ratio “mortality/reproduction” , also it depends on the total amount of limiting resource available for the given population.

If the amount of resource is large, population is more resistant to radiation, comparing with radiation response of individual organisms.