Population modelling

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Workshop – EMRAS II WG-6
Vienna 26 January 2010

Principles to develop a 'contaminant migration-population effects' model

The models should account for:

(a) the dynamics and the dispersal of the biota populations;

(b) the migration of the contaminants through the abiotic environmental components, the transfer from these to living organisms and, finally, the following dispersion of contaminant in the environment due to the biota movements;

(c) the influence on the population dynamics of the detrimental effects caused by the environmental contamination.

Reductionistic approach

The population equation:

$$\frac{\partial n(\mathbf{x},t,a)}{\partial t}+\frac{\partial n(\mathbf{x},t,a)}{\partial a}=\mathrm{L_X}\,n(\mathbf{x},t,a)-\mathrm{L_{Mp}}\,n(\mathbf{x},t,a)+\delta(a)\,\mathrm{L_{Np}}(\mathbf{x},t)$$

The contaminant migration equation:

$$\frac{\partial \mathbf{Q}(\mathbf{x},t,a)n(\mathbf{x},t,a)}{\partial t}+\frac{\partial \mathbf{Q}(\mathbf{x},t,a)n(\mathbf{x},t,a)}{\partial a}=n(\mathbf{x},t,a)\,\mathrm{L_B}\,\mathbf{Q}(\mathbf{x},t,a)+$$

$$+\ \text{movement term}\ -\ \text{mortality term}\ +$$

$$+\ \text{natality term}\ +\ n(\mathbf{x},t,a)\mathbf{M}(\mathbf{x},t,a)$$

Equations for assessing the birth and the death rates as functions of the environmental stress (f.i., contamination and/or of the internal contamination of organisms, dose rates, etc.)

System and process aggregation

The effects of ionising radiations on biological systems can occur at different levels of organisation:

- ✓cells,
- ✓organs,
- ✓ individuals,
- ✓populations
- ✓communities

Aggregated components

The model comprises two basic groups of aggregated components:

- ✓resource producers (autotrophic organisms, prevailingly green plants)
- ✓ consumer (heterotrophic organisms, chiefly animals, preys and predators)

Aggregated processes

The complex processes of ecological nature controlling the dynamics of the species population can be summarised in three main categories:

- ✓biomass development
- ✓saturation effects
- ✓competition among species

The biomass model equations

N_1= Producer density (kg m^{-2})
N_{1s}= Producer density at the steady state
N_2= Consumer density (kg m^{-2})
N_{1s}= Producer density at the steady state

$$\frac{dN_1}{dt} = k_1 N_1 - k_2 N_1^2 - k_3 N_1 N_2$$

$$\frac{dN_2}{dt} = -k_4 N_2 + k_5 N_1 N_2 - k_6 N_2^2 - \alpha \mu N_2 + \beta \mu^* N_{2s}$$

$$\gamma k_3 = k_5$$

$$\mu^* = \mu \frac{N_1}{N_{1s}}$$

The biomass model parameters

Values of the parameters and input variables used for the examples of the model applications

Input variable	Derived variable	Variable description	Value	Dimension
P		Potential aboveground net primary production minus producer biomass death rates	0.9	kg $m^{-2}year^{-1}$
N_{1smax}		Producer density at steady state when consumption by consumers is 0	5	kg m^{-2}
N_{1s}		Resource biomass density	3.65	kg m^{-2}
N_{2s}		Consumer biomass density	0.0035	kg m^{-2}
T_s		Consumer decay time	0.05	year
γ		Utilisation factor of producer biomass by consumers	0.35	dimensionless
λ_L		Time decay rate of consumer biomass when competition and reproduction rate are 0	0.693	$year^{-1}$
	k_1	Growth rate of resource components	0.18	$year^{-1}$
	k_2	Limiting coefficient of resource biomass	0.036	kg^{-1} m^2year^{-1}
	k_3	Coefficient of consumption of resources by consumers	13.9	kg^{-1} m^2year^{-1}
	k_4	Time decay rate of consumer biomass	13.9	$year^{-1}$
	k_5	Utilisation coefficient of resources by consumers	4.86	kg^{-1} m^2year^{-1}
	k_6	Limiting coefficient of consumer biomass	1108	kg^{-1} m^2year^{-1}
	ε	Fraction of resource consumption for consumer maintenance	0.742	dimensionless

The radiological model equations

linear dose-response relationship without threshold

$$k_1^* = k_1 - a_1 D$$

$$k_4^* = k_4 + a_4 D$$

Examples of applications

Scenario

Zones:

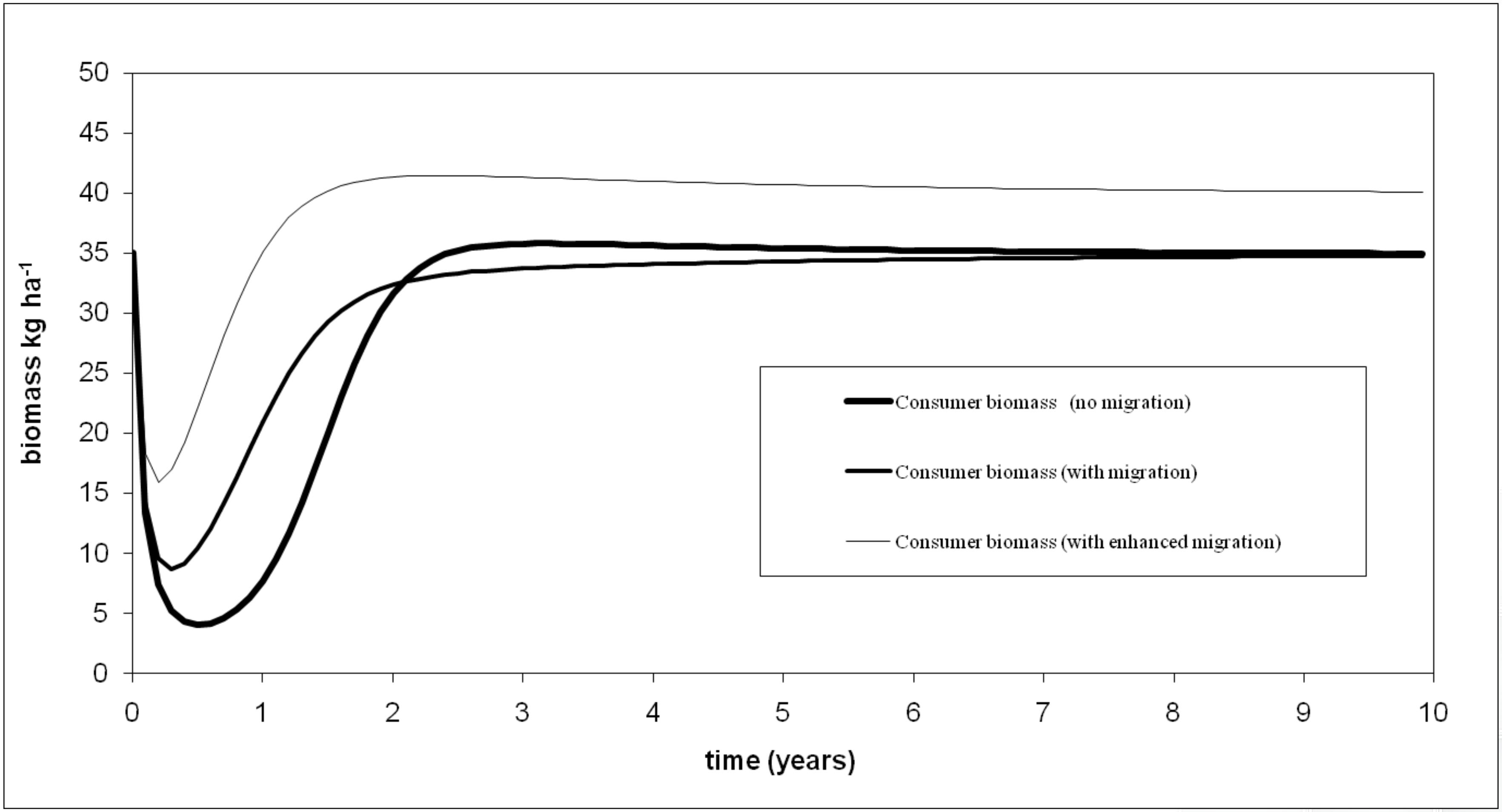
- ✓ EZ – Exclusion Zone
- ✓ BRZ- Biota Reservoir Zone

Dose rate in the EZ

$$D(t) = 0.1 * \exp(-0.693 * t / 0.25) + 1.25x10^{-4} * \exp(-0.693 * t / 30)$$

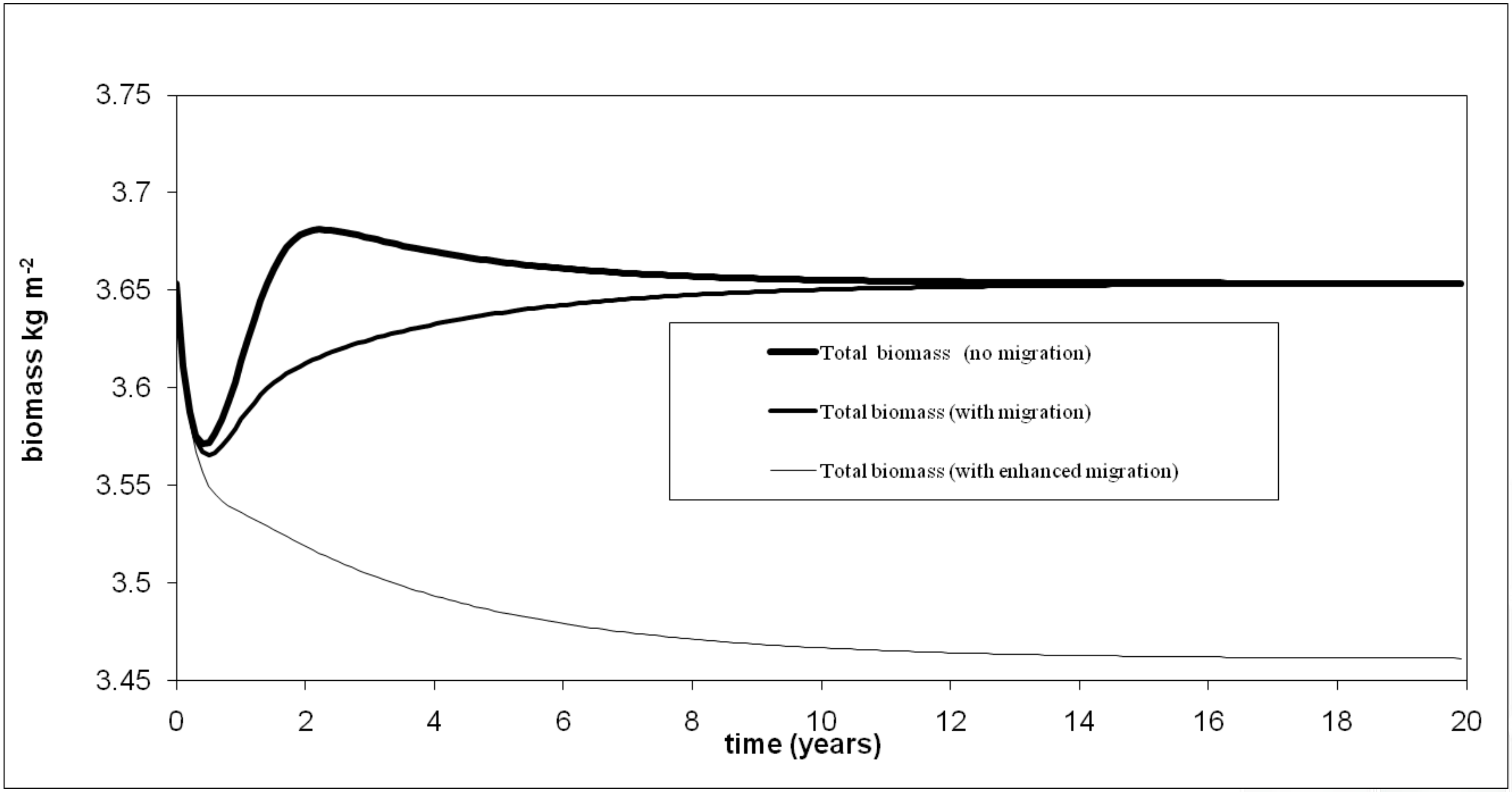
Examples of applications

Combined effects of radiation dose, animal migration and human evacuation. The consumer biomass in the EZ at steady state increases in the case of enhanced animal migration stimulated by the human evacuation.



Examples of applications

Time behaviour of the total biomass in the EZ due to the combined effects of radiation dose, animal migration and human evacuation. Although the biomass of predators increases due to the enhanced migration from the surrounding BR zone, the consumption of resources by consumers increases causing a decrease of the total biomass density at the steady



Examples of sensitivity analysis

Time behaviour of the consumer density (normalised at Time=0) for different values of k_6= 57, 1108, 8592 $kg^{-1}m^2y^{-1}$. Simulations obtained hypothesising a dose rate constant on time (0.01 Gy day^{-1}). When the competition is low (k_6= 57 $kg^{-1}m^2y^{-1}$) the same dose rate causes a significant perturbation of the system in comparison with the effects occurring in the case of high competition (k_6=8592 $kg^{-1}m^2y^{-1}$).