3.11 Ecological effects of ionizing radiation on population and ecosystem : A computational model ecosystem study

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INTRODUCTION

Protection of the environment from the effects of radiation is a contemporary topic to deal with increasing public concern to safeguard the well-beings of future generations. Sustainable development is a key concept of Rio Declaration at UNCED in 1992, which requires the protection of the environment from the effects of radiation as well as radiation protection for human health.

Ecosystem is a self-sustaining system of complexity, and their responses to the impacts are synergistic and subjected to the demographic stochasticity of the species, environmental stochasticity and randomness (catastrophes, etc.). Environmental fate and effects of radiation has ranged from observable DNA damage of the cell to the fare on tissues, individual(s), population (s), community and ecosystems. One of the key issues to judge the benchmark exposures of radiation for environmental protection is : What is the ecological relevance of laboratory toxicity data, and how to conduct a laboratory-to-field extrapolation ? Aim of this study is to develop some mathematical and computational ecosystem models to deepen understanding of extrapolation from the results of laboratory ecotoxicity tests to the effects of ecosystem level in the actual field.

MATERIAL AND METHODS

The quantitative, systematic individual-based model, SIM-COSM was developed to simulate impacts of radiation exposure and other toxicants on an aquatic microbial ecosystem (microcosm) [Kawabata et al. 1995, Fuma et al. 2000]. The microcosm consists of heterotroph ciliate protozoa, *Tetrahymena thermophila B* as a consumer, autotroph flagellate algae, *Euglena gracilis Z* as a producer and saprotroph bacteria, *Escherichia coli DH5* as a decomposer The culture medium is 10 ml of water with inorganic salt and initial organic nutrients, and held in the airtight test tube. It is cultured statically with fluorescent lamps under 2500 lx and 12 hrs light-dark cycle at 25 ℃ (**Figure 1**).

The symbiosis among microbes is self-organized by realizing material cycle and sustained for more than 2 years after inoculation. The system can not afford to lose anyone of the microbes to maintain its sustainability (**Figure 2**) . Experimental ecotoxicological tests for **(a)** gamma radiation [Fuma et al. 1998a, 1998b], **(b)** Manganese ions [Fuma et al. 2000] and **(c)** Gadolinium [Fuma et al. 2001] are summarised (**Figure 3**).

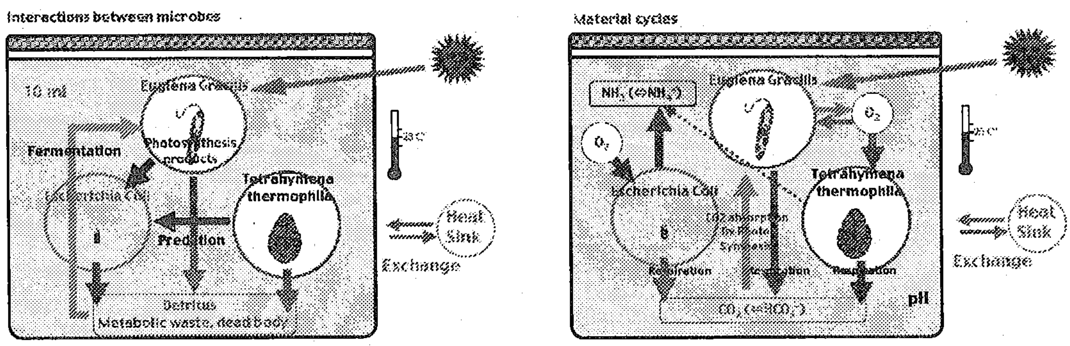
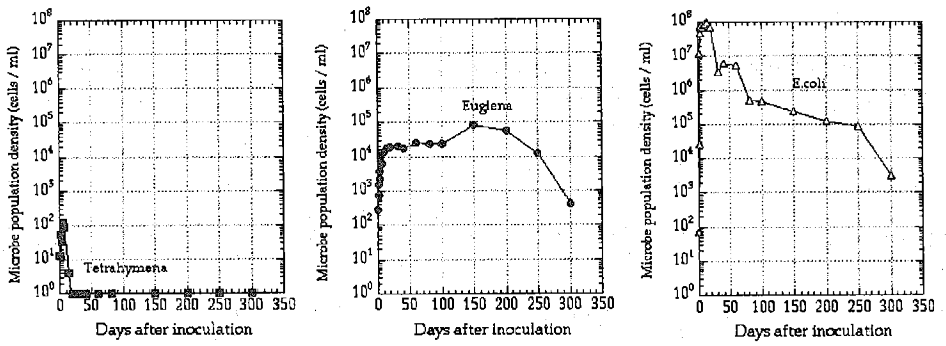
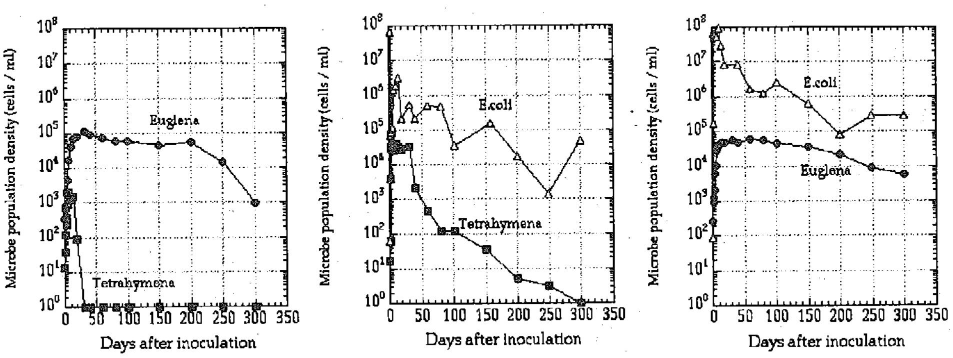


Figure 1 Interactions between species in the microcosm (Left) and Interrelationships among constituent elements in the microcosm

(a) Single species cultures [Fuma et al. 1998a]



(b) Two species cultures [Fuma et al. 1998a]



(c) Three species cultures [Fuma et al. 1998a]

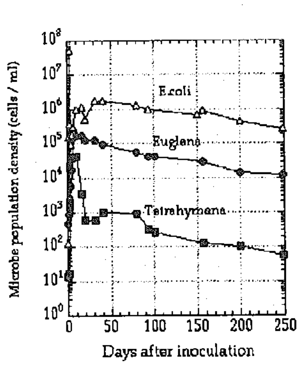
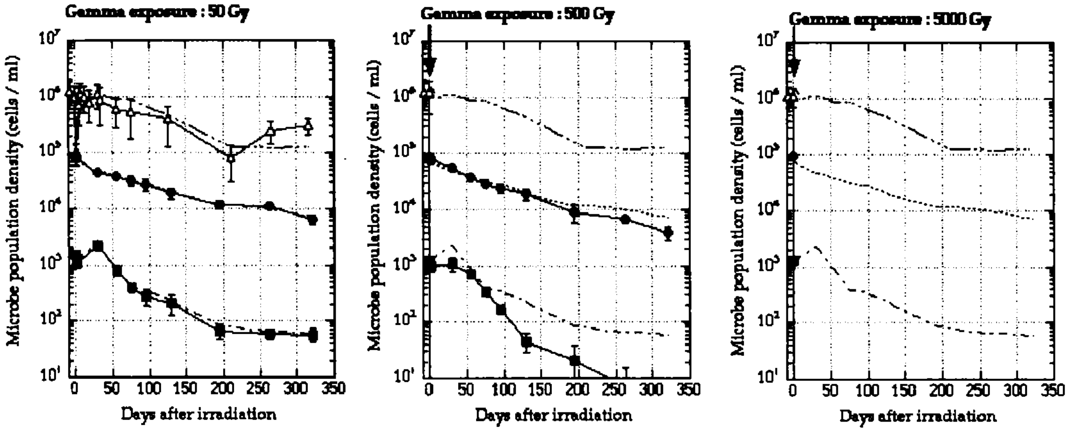
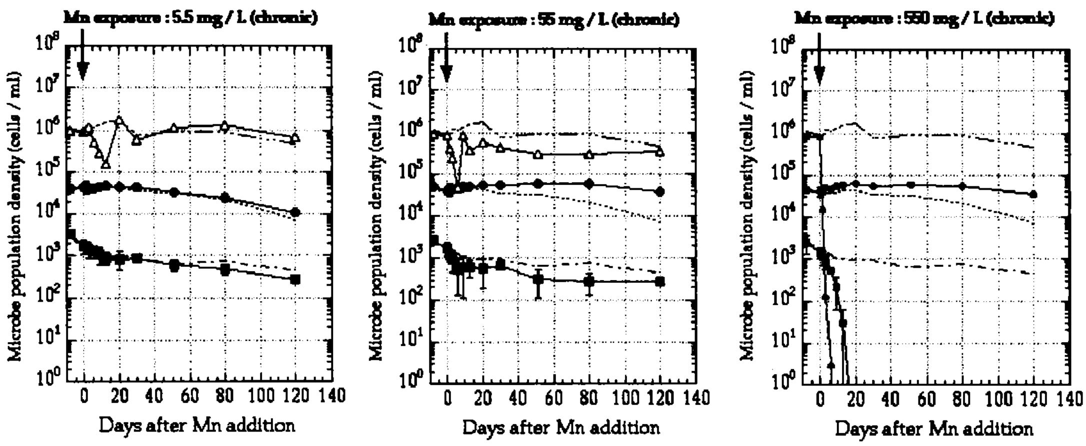


Figure 2 Population dynamics of **(a)** single-species, **(b)** two-species and **(c)** three species cultures

(a) gamma radiation exposure[Fuma et al. 1998a, 1998b]



(b) Manganese ions [Fuma et al. 2000]



(c) Gadolinium exposure [Fuma et al. 2001]

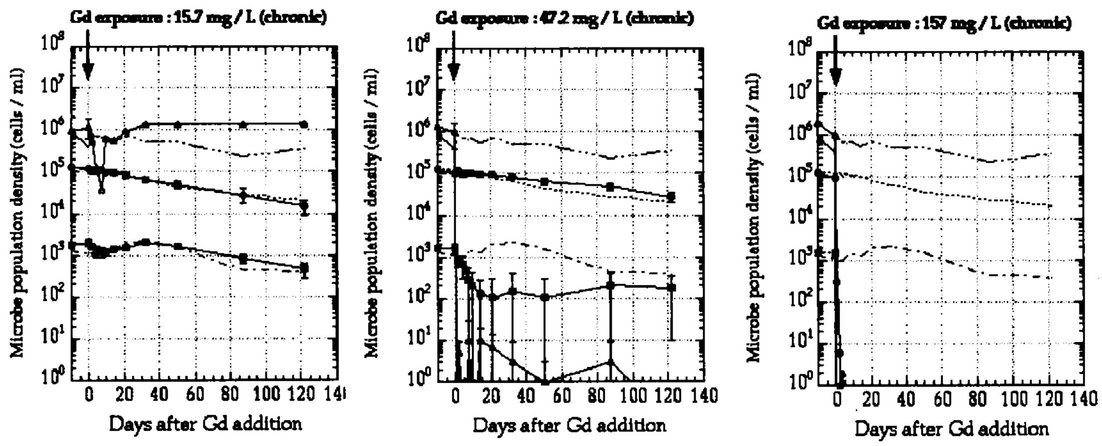


Figure 3 Population dynamics of three-species in the Microcosm by the exposures of **(a)** gamma radiation [Fuma et al. 1998a, 1998b], **(b)** Manganese ions [Fuma et al. 2000] and **(c)** Gadolinium [Fuma et al. 2001]

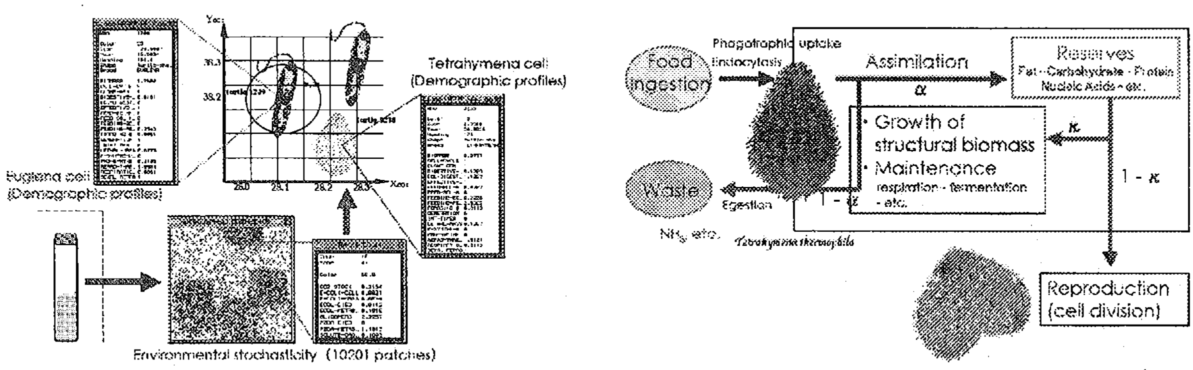


Figure 4 Basic concept of the particle-based computer simulation model (SIM-COSM) [Doi et al. 2000]converted from microcosm [Kawabata et al. 1995; Fuma et al. 1998a, 1998b, 2000, 2001; Matsui et al. 2000; Shikano and Kawabata 2000] **(Left)** and Schemes of dynamic energy budget model in biochemical systems [Kooijman 2000] **(Right)**

While, SIM-COSM is developed as a project of StarlogoT, an object-based parallel modelling languages developed by Center for Connected Learning and computer-based Modelling, North western University (http://ccl.northwestern.edu).

1) The SIM-COSM has lattice of 10201 patches as spatial environments, each one of the patches has environmental attributes (pH, O_2, CO_2 (HCO_3^-), NH_3 (NH_4^+), dissolved organics, etc.).
2) Each individual protozoa (*Tetrahymena* and *Euglena*) has its own physiological , structural and behavioural attributes (heading direction, current patch address, velocity, structural biomass, reserve mass, age, cell cycle phase, maintenance rate, breathing rate, assimilation rate, etc.)
3) *Tetrahymena* behaves by following optimum foraging strategy to quest for *E.coli* and eat them (predator-prey relationship) [Iwasa 1981]
4) *Euglena* utilizes CO_2 in the patches and synthesize organic substrates in day time (photosynthesis).
5) *E.coli* utilises dead protoplasm and metabolic wastes in the patches and break them into inorganic substrates (CO_2 etc.) for the use of photosynthesis by *Euglena*. (microbial loop)
6) *Tetrahymena*, *Euglena* and *E.coli* respirate O2 and release CO2, utilise organic materials and excrete metabolic materials into the patches.
7) *Tetrahymena*, *Euglena* and *E.coli* reproduce by cell division (cell cycle, structural biomass), and die by starvation (reserves mass).
8) Environment and species are assumed to be verticality homogeneous. Gravity is not taken into consideration in the SIM-COSM.

RESULTS AND DISCUSSION

Population dynamics of microbes in Microcosm and its computer simulations by SIM-COSM are

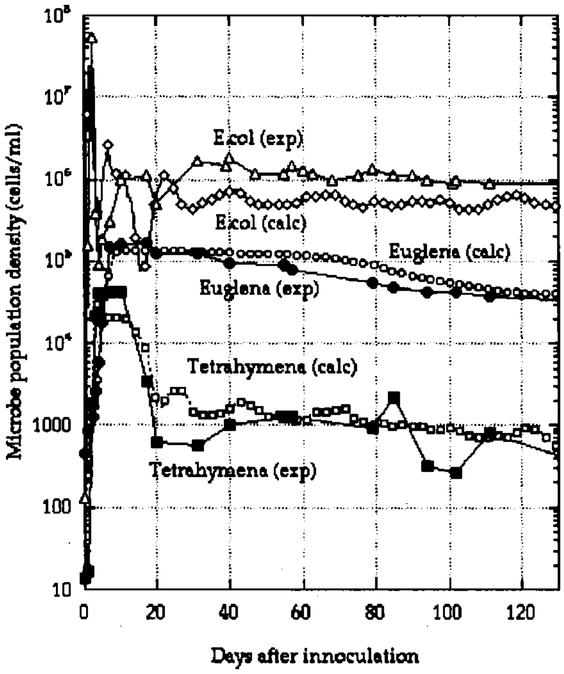


Figure 5 Population dynamics of Microcosm and its computer simulations by SIM-COSM

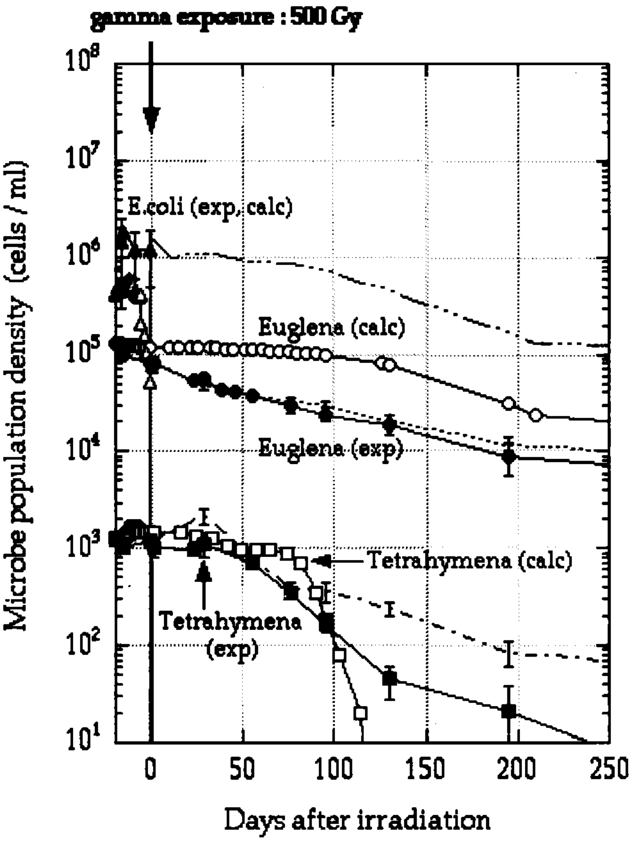


Figure 6 Population dynamics of Microcosm and SIM-COSM after 500 Gy of γ -radiation

shown together in **Figure 5**.

To simulate the impacts of acute exposure of gamma radiation, acute lethal dose (LD50) are adopted to 330 – 170 Gy for Euglena gracilis, ,4000 Gy for Tetrahymena thermophila, and 50 Gy for E. coli-DH5 α, which is a highly radiosensitive strain on the basis of experimental data in the references. For Tetrahymena, metabolism rate is regarded to reduce to 10-30% by 500 Gy exposure.

Population dynamics in Microcosm and SIM-COSM exposed to 500 Gy of gamma-radiation at 50 days after inoculation are shown together in **Figure 6**. Taking LD50 of Tetrahymena into account, extinction of Tetrahymena might be regarded as the secondary effect of the extinction of E.coli, that is a prey of Tetrahymena.

CONCLUSIVE REMARKS

To take the effects on the interactions between species and environment into account, one option herein proposed is to put the ecotoxicity tests as experimental micro ecosystem study and a theoretical model ecosystem analysis. With these tests, the stressors which are more harmful to the ecosystems should be replaced with less harmful ones on the basis of unified measure. Management of environmental toxicants and radiation should be discussed consistently from the unified view point of environmental protection.

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