Impacts of radiation exposure on the experimental microbial ecosystem: a particle–based model simulation approach

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1. Introduction

Well-designed experimental model ecosystem could be a simple reference of the actual environment and complex ecological systems. For ecological toxicity tests of radiation and other environmental toxicants, we investigated an aquatic microbial ecosystem (closed microcosm) in the test tube with initial substrates, autotroph flagellate algae (Euglena, G.), heterotroph ciliate protozoa (Tetrahymena T.) and saprotroph bacteria (E.coli) [1]. These species organizes by itself to construct the ecological system, that keeps the sustainable population dynamics for more than 2 years after inoculation only by adding light diurnally and controlling temperature at 25 degree Celsius.

Objective of the study is to develop the particle-based computer simulation by reviewing interactions among microbes and environment, and analyze the ecological toxicities of radiation on the microcosm by replicating experimental results in the computer simulation.

2. Materials and methods

Fig.1 shows the outline of the interspecies interactions in the microcosm [1, 2, 3, 4,], and Fig.2 illustrates its major material cycles (carbon and Nitrogen) [5].

Fuma et al. conducted some ecological toxicity tests by adding toxic heavy metals [6, 7, 8, 9] and gamma radiation [10], and discussed the acute impacts on the populations.

Based on these experimental facts, computer simulation program is developed with N-logo system for computer modeling, distributed by Professor Wilensky through http://ccl.northwestern.edu/netlogo/models/.

Particle-based simulation is a method to generate a particle to represent an individual of each microorganism, and to simulate the demographic stochasticity and dynamics of the population as a total set of particles. Environment is divided into two dimensional square patches (divided by 100 x
100 lattice), and environmental stochasticity and structural profiles of the habitats are simulated.

Fig. 3 shows the illustration of the particle-based simulation to copy the microcosm in the computer. Tetrahymena is a predator of E. coli, and their relationship might be predicted by the Lotka-Volterra’s predator-prey population dynamics model.

As well as mathematical approach in ecology, the particle-based computer simulation is adopted to obtain an in-depth understanding of synergistic mechanism of sustainable ecosystem. As shown in Fig. 4, physiological parameters of each individual protozoa are regarded as an array, that follows the allometry and dynamic energy mass budget to show the life cycle with growth, cell proliferation, eating, assimilation, excretion, somatic maintenance, respiration and death as a dynamic mass budget model. Fig. 5 summarized the optimal foraging model by Iwasa et al. [11], and the negative binominal model is programmed as the grazing strategy of each particle of Tetrahymena.

Euglena and E. coli utilize the same organic substrate in the habitat, they may also follow the well-known Lotka-Volterra’s classical interspecies resource competition model.

Fig. 2. Major Material cycles in microcosm [5]


FIG. 3. Concept from Microcosm to Simulation

FIG. 4. Scheme of dynamic mass budget

FIG. 5. Scheme of optimal foraging [11]

FIG. 6. Computer simulation outputs. Left: at 24 hrs iteration, right: at 240 hrs iteration

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More details of the particle-based simulation are shown in Doi, et al. [12, 13].

Using the computational model ecosystem, synergistic impacts of acute gamma radiation exposures on their population dynamics and mass budgets were estimated. To simulate the impacts of acute exposure of gamma radiation, lethal dose (LD50) are adopted to 330 – 170 Gy for Euglena gracilis, 4000 Gy for Tetrahymena thermophila, and 50 Gy for E. coli-DH5-alpha [10, 14].

3. Results and discussion

Figs. 6 shows results of computer simulation, which follow the experimental population dynamics as shown in Fig.7 at 50 Gy (left) and 100 Gy (right) of acute exposures, respectively. If the knowledge of interaction in the microcosm, as shown in Fig.1 were missing, acute impact of 500 Gy of gamma radiation were projected to kill more than half of Euglena, all of E.coli, and only a few of Tetrahymena, because of its high LD50 value of 4000 Gy. Actually, experimental data showed the 500 Gy of gamma exposure, killed off E.coli immediately, and later, this extinction of E.coli resulted in the significant reduction and following extinction of

![Comparison of experimental data (filled circle) [10] and simulation (open circle). Left: at 24 hrs iteration, right: at 240 hrs iteration](image-url)
Taking LD50 of Tetrahymena into account, extinction of Tetrahymena at 500 Gy exposure must be considered as the secondary effect of the extinction of E.coli, by starvation.

In addition, taking the effect of well-being of Tetrahymena, i.e. 10-30% reduction of metabolism by 500 Gy gamma exposure [15], computer simulation suggested the prolonged survival rate without food as compared in Fig. 8.

Empirical and theoretical impact analyses of much lesser dose of radiation exposure are now ongoing to find the effects on the species in the microcosm by detecting impacts on well-being, acute lethality, reproductive success and score able cytogenetic damages of microbes in the microcosm. Computer simulation is a useful tool to predict the impacts of low dose rate and chronic exposure of radiation, which should prove the robustness of the ecological system. Chronic exposure simulation will be appeared soon.

4. Remarks

Using the computational model ecosystem, synergistic impacts of acute gamma radiation exposures on their population dynamics and mass budgets were estimated. It is also suggested that the impact on metabolism rate of Tetrahymena may caused its prolonged survival rate by starvation.

Acute lethality is an index of acute impact, but is recoverable as a dose-effect relationship. Impacts on intrinsic factors (growth rate, etc.) may cause some potential consequences for the fitness (future sustainability) of species and ecological system. Chronic exposure simulation is expected, of which results will come soon.
References