Ecosystem Analysis of the Seto Inland Sea: Bioaccumulation Model on a Basis of an Energy Balance Model

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Abstract—Chemical contaminants are accumulated as they pass from lower trophic level animals to higher ones, resulting in higher concentrations in higher trophic level animals. Human consumption of higher trophic level animals therefore may be a serious risk to human health. Therefore, we constructed a bioaccumulation model based on an energy balance model at the individual organism level. Then, we combined it with a population-based model with population demographics such as survival and reproduction. From the model we conclude that a larger allocation of surplus energy to body mass lead to larger maximum body mass, an infinite growth pattern, higher survival rate and lower population growth, and higher concentrations of chemical contaminants. However, a higher temperature condition induces completely inverse results.

Keywords: energy balance, bioaccumulation, individual-based model

INTRODUCTION

In ecosystems, organisms can show higher concentrations of chemical contaminants than that of their diets and surrounding environment. This is referred to as bioaccumulation including both phenomenon. The chemical contaminants are accumulated as they pass from lower trophic level animals to higher ones, resulting in higher concentrations in higher trophic level animals. Human consumption of these highly bioaccumulated organisms with chemical contaminants may result in being exposed to toxic chemicals, which can cause a serious risk to human health.

To quantify the bioconcentration process, many researchers reported the application of mass balance models (Madenjian et al., 1995; Mackey and Fraser, 2000). These mass balance models of organisms may be important for predicting the extent of bioaccumulation under temporal changes in chemical contaminants over a course of their growth, due to diet changes and changing environments.

In the present study, we constructed an individual-based model for predicting chemical contaminants under changing environments. Furthermore, we included
population-level demographics such as survival to the present model for considering density effects on the bioaccumulation process (Fig. 1).

MATERIALS AND METHODS

An individual-based model based on an individual level bioenergetics model (Omori et al., 2009), which is shown below, is combined with population level demographics of survivorship and reproduction. From this, recruitment rate to the population can be estimated.

For survival processes, we adopted $e^{-dx}$ for random death rate, $e^{-(x-xm)/\sigma}$ for longevity, and $e^{-f/STOR}$ for loss from energy balance stress. Here, $d$ is the random death rate and $x$ is age. Moreover, $xm$ is mean longevity, and $\sigma$ is its standard deviation. $STOR$ of the third iteration is a storage level of an individual with a constant $f$.

In modeling dynamics of chemical contaminants, we considered the bioconcentration process, i.e., accumulation through the relative solubility of chemicals to lipid against water, for respiration and biomagnification, i.e., accumulation through diets containing chemical contaminants, for consumption, egestion and reproduction. The model was constructed according to the flow chart presented in Figs. 1 and 2.
RESULTS AND DISCUSSIONS

The different allocation of surplus energy to growth or reproduction lead to different maximum body size of individuals, which resulted in different concentrations of the chemical contaminant. Higher allocation rates of surplus energy to growth relative to reproduction resulted in a lower population growth rate (Fig. 3).

Inevitably, higher allocation rate to growth resulted in higher growth rates, but this also resulted in shorter longevity, as shown in the vertical arrows along
Fig. 4. Calculated concentration of chemical contaminants with different allocation rates to growth.

Fig. 5. Relationship between allocation to growth rate, the concentration of chemical contaminants, survival rate, and body size under different temperature conditions. The left and right side figures denote results at 20 and 21°C, respectively.
the x-axis. Therefore, the final body size is markedly reduced and the concentration of chemical contaminants becomes low (Fig. 4).

A significant reduction in survival rate induced a higher concentration of chemical contaminants and larger body mass through lower density, but low temperature conditions resulted in smaller body sizes and lower concentrations of chemical contaminants (Fig. 5). Therefore, higher temperatures and other poor environmental conditions, which induce a lower survival rate, can lead to a higher risk of bioaccumulation.

In conclusion, results from our study show; A larger allocation of surplus energy to body mass leads to the following: a) larger maximum body mass; b) infinite growth pattern; c) higher survival rate and lower population growth; and d) higher concentration of chemical contaminants. Moreover, we also show that high temperature conditions induced the following: a) smaller maximum body mass; b) finite growth pattern; c) lower survival rate and higher population growth; and d) lower concentrations of chemical contaminants.

REFERENCES


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