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Moderate Impact by an Insecticide Increases Species Richness in a Zooplankton Community : Results Obtained in Experimental Ponds

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Abstract

The insecticide carbaryl at nominal concentrations of 0 (control), 10 (low dose) and 100 $\mu g\ l^{-1}$ (high dose) was applied repeatedly to experimental ponds containing predacious larvae of the midge *Chaoborus* and to ponds without the predator, and the effect of the chemical on species richness of the zooplankton community was analyzed. Cladocerans dominated the ponds without *Chaoborus*, but were kept at very low densities in the ponds with *Chaoborus* due to predation. In the Cladocera-dominant ponds, the treatment with high-dose carbaryl reduced the species diversity of the cladoceran community to just one : only the small cladoceran *Bosmina fatalis* survived. Rotifers established large populations in the ponds with *Chaoborus* because they were released from competition with the superior competitor cladocerans, which were suppressed by the *Chaoborus* predation. In these ponds, the species richness of the rotifer community became higher in the high-dose ponds than in the control and low-dose ponds during and after the period of insecticide application. The chemical treatment seemed to suppress, but not eliminate, the dominant rotifer species, allowing the species inferior in competition but more tolerant to the insecticide to coexist with the competitively superior species. The moderate impact of carbaryl might have increased the species richness. These results suggest that the impact of human influence such as insecticide contamination does not always reduce biodiversity in organic communities.

1 Introduction

The significance of conservation of high biodiversity on Earth has been recognized in recent years. It is believed that human activity is the major factor reducing biodiversity in various organic communities. This may also be the case for freshwater zooplankton communities. For example, lake acidification, which has been accelerated by human activity, has reduced the species richness of zooplankton communities in

Scandinavian and North American countries[1-3].

In contrast, HANAZATO[4] has demonstrated using experimental ponds that insecticide contamination in fact increases the species richness of the zooplankton community. He applied the insecticide carbaryl once to the ponds and observed increased species richness during the process of recovery of the community from the effects of the chemical. Carbaryl has a high degradation rate: 90% of the chemical applied to ponds disappears within 1.18 days at 20°C[5]. Thus, in HANAZATO's experiment, the insecticide had a direct impact on the community for only a very short time.

HANAZATO[6] had earlier applied carbaryl to ponds repeatedly in order to analyze the longer term impact of the chemical on the zooplankton community in the same ponds with or without the predacious larva of the midge *Chaoborus flavicans*. In that experiment, I analyzed the complex effects of carbaryl and *Chaoborus* on zooplankton community structure, but not on species richness. In the present study, I re-analyzed the results of my earlier 1991 experiment in relation to the species richness of the zooplankton community, and assessed the insecticide's effect on it.

2 Methods

The experimental design has been described in detail by HANAZATO[6], and therefore it is summarized only briefly here.

Twelve outdoor concrete ponds, each measuring 1.5 m x 2 m and 0.7 m deep, were used. At the start of the experiment, each pond received 1.5 metric ton (0.5 m depth)

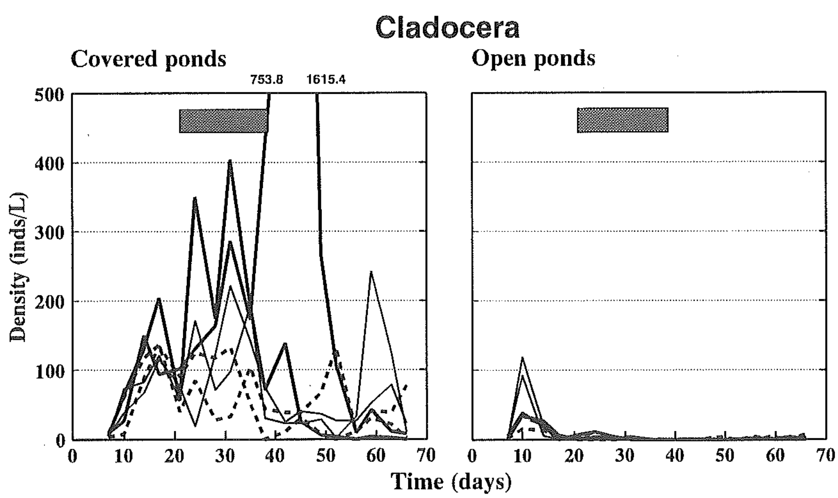

Fig. 1. Changes in total cladoceran density in the covered and open ponds. Thin lines: control ponds, broken lines: low-dose ponds, thick lines: high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

of ground water and 5 kg of bottom mud from eutrophic Lake Kasumigaura.

Six of the ponds were covered with nets (mesh size 1.5 mm) to prevent invasion by *Chaoborus*, and the other six were kept open to allow oviposition by *Chaoborus* adult females, and were also seeded with *Chaoborus* egg masses. Thus, the covered ponds were free from *Chaoborus*, whereas the open ponds had abundant *Chaoborus* populations.

Both the covered and open ponds received repeated application (10 times) of the

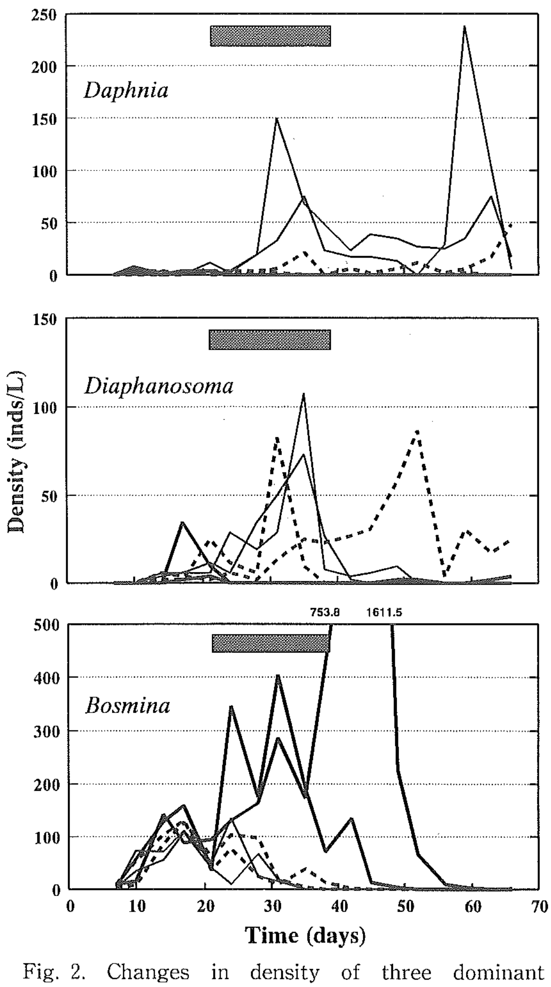

Fig. 2. Changes in density of three dominant cladoceran species, *Daphnia galeata*, *Diaphanosoma brachyurum* and *Bosmina fatalis*, in the covered ponds. Thin lines : control ponds, broken lines: low-dose ponds, thick lines: high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

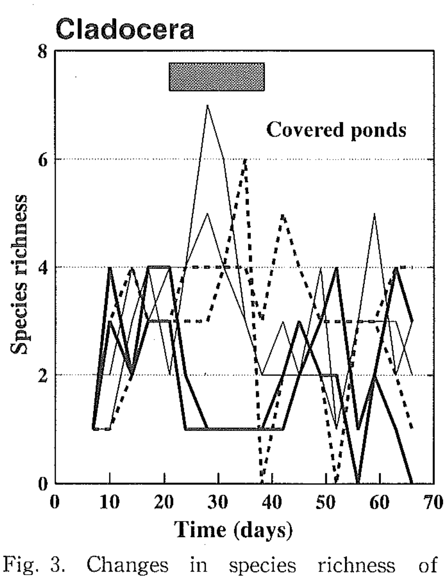

Fig. 3. Changes in species richness of cladoceran community in the covered ponds. Thin lines: control ponds, broken lines: low-dese ponds, thick lines : high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

insecticide carbaryl at three different nominal concentrations, 0 $\mu g\ l^{-1}$ (control ponds), 10 $\mu g\ l^{-1}$ (low-dose ponds) and 100 $\mu g\ l^{-1}$ (high-dose ponds). Two of the covered or open ponds served for each insecticide treatment, and thus the number of replications for each treatment was two. The chemical application was conducted ten times at two day intervals from day 21 to day 39. The experimental period was 67 days in spring (May- July), when the water temperature ranged mostly between 20 and 26°C.

Zooplankton in the ponds was collected semi-weekly using a water sampler and a net with a 40-μm sized mesh. The species richness of the zooplankton community was determined as the number of species which appeared at $\geqq 1$ individual l^{-1}.

3 Results

The covered ponds were dominated by cladocerans, whose total density was

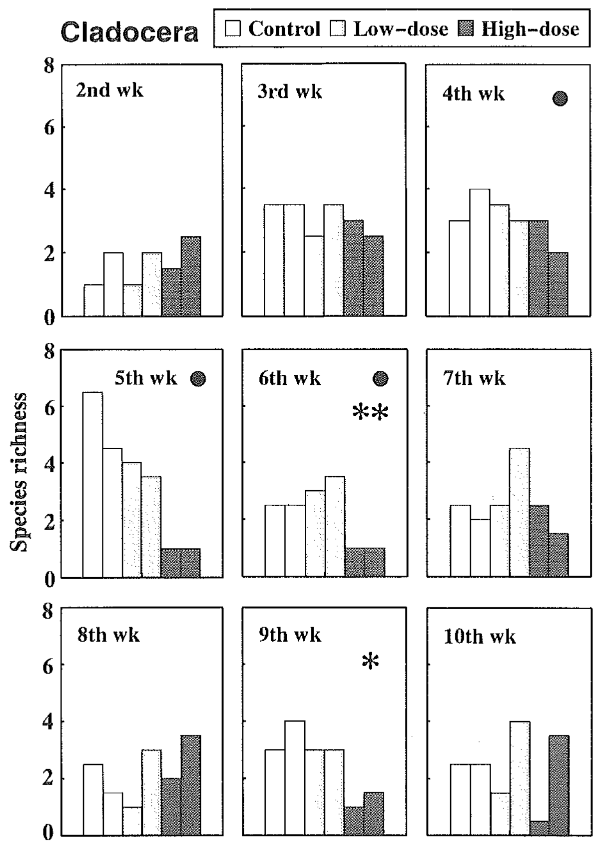

Fig. 4. Weekly mean value of species richness of cladoceran community in covered ponds. The insecticide application was conducted in the weeks shown by solid circles. Asterisks indicate that there are statistically significant differences between the ponds (*p<0.05, **p<0.01; nested ANOVA).

around 100 individuals l^{-1} in the control and low-dose ponds, but much higher in the high-dose ponds (Fig. 1). The dominant species differed among the ponds. *Daphnia galeata* appeared most abundantly in the control ponds, and *Diaphanosoma brachyurum* was very common in the control and low-dose ponds (Fig. 2). In the high-dose ponds, however, these species were nearly eliminated, and instead *Bosmina fatalis* increased exclusively and attained a high density.

In the open ponds, the cladoceran densities remained very low (Fig. 1), due to intensive predation by *Chaoborus* larvae[6].

Species richness of the cladoceran community was analyzed in the covered ponds where the cladocerans were abundant. It fluctuated greatly between 0 and 7 in all the ponds, but the values mostly settled within the range of 2 - 4 in the control and low-dose ponds (Fig. 3). In the high-dose ponds, the value fell to only 1 from day 24 to day 42, when only *B. fatalis* appeared. This was apparently the result of insecticide application, which killed all the other cladoceran species.

The species richness in the covered ponds was significantly lower in those that received a high dose of carbaryl than in the other ponds for some weeks during and after the treatment period (Fig. 4).

Rotifers were much less abundant in the covered ponds, but established large

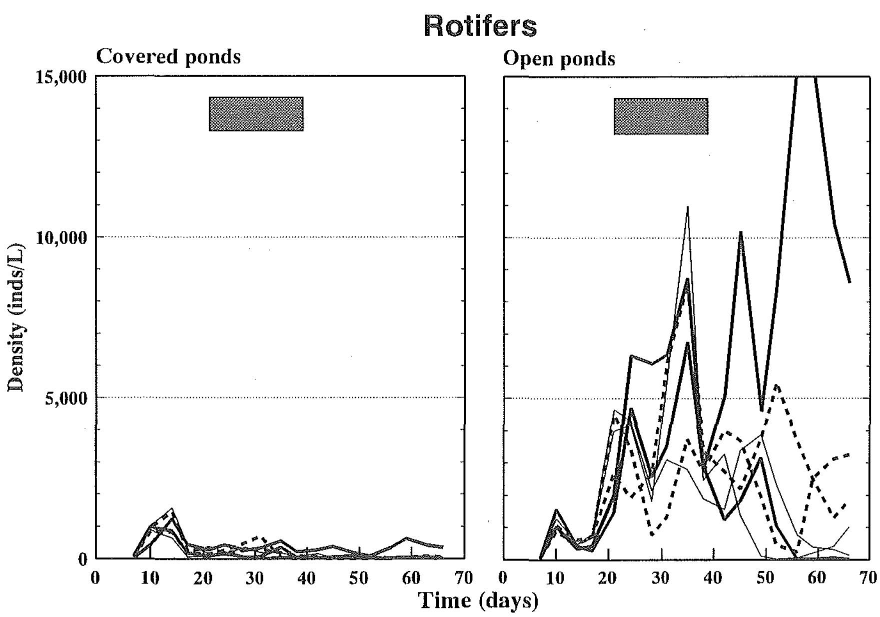

Fig. 5. Changes in total rotifer density in the covered and open ponds. Thin lines: control ponds, broken lines: low-dose ponds, thick lines: high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

populations in the open ponds (Fig. 5). The low abundance of rotifers in the former ponds was the result of competition with the superior cladoceran competitors[6]. In the open ponds, rotifers were released from the competition, because cladocerans were almost totally eliminated by *Chaoborus* predation.

In the open ponds, the succession of the dominant rotifer species was similar in the control and low-dose ponds (Fig. 6): *Brachionus calyciflorus* increased first and was replaced by *Brachionus angularis* and *Keratella valga*. Then, *Hexarthra mira* and *Polyarthra trigla* dominated, and maintained their dominance in the later half of the experiment. In the high-dose ponds, *K. valga* largely increased its density during and after the period of insecticide application. *B. calyciflorus* created a large population after day 40 in a high-dose pond. *P. trigla* and *H. mira* remained at relatively low

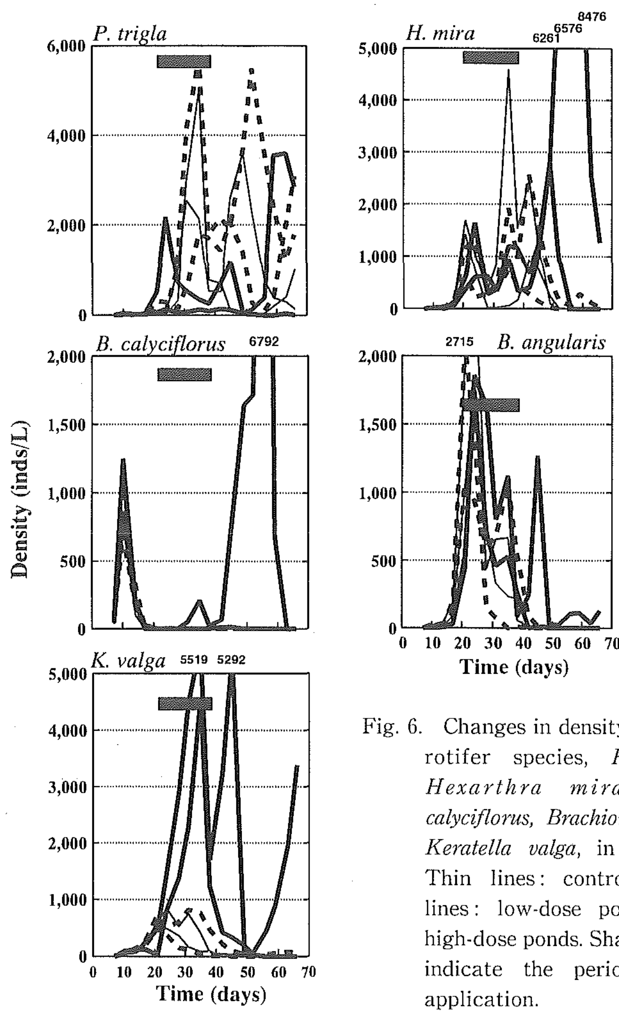

Fig. 6. Changes in density of five dominant rotifer species, *Polyarthra trigla*, *Hexarthra mira*, *Brachionus calyciflorus*, *Brachionus angularis* and *Keratella valga*, in the open ponds. Thin lines: control ponds, broken lines: low-dose ponds, thick lines: high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

densities during the treatment, but their dominance had increased by the end of the experiment. Thus, *K. valga* and *B. calyciflorus* showed increased dominance while *P. trigla* and *H. mira* showed decreased dominance in the high-dose ponds.

The species richness of the rotifer community was analyzed in the open ponds (Fig. 7). The species richness reached a maximum of 12-15 on or around day 15. It then decreased steadily until the end of the experiment in the control and low-dose ponds. In the high-dose ponds, however, the decline of species richness was suppressed, and the value remained at 7-11 until the end of the experiment in one pond and until day 52 in the other. The species richness was apparently higher in the high-dose ponds than in the others during the period of insecticide application and thereafter (Fig. 8). A significant difference in species richness between these ponds was evident in the 8th week. Thus, it may be concluded that the high-dose treatment increased the diversity of the rotifer community.

4 Discussion

The dominant cladoceran species differed among the ponds (Fig. 2), possibly indicating the differences in tolerance to carbaryl among the species ; *D. galeata* is the most sensitive to the chemical while *B. fatalis* is the most tolerant.

The difference in carbaryl tolerance among rotifer species was also shown in the high-dose ponds. The population growth of *Polyarthra* and *Hexarthra* seemed to be suppressed during the period of chemical treatment (Fig. 6). On the other hand, *B. angularis* appeared to be unaffected by the treatment, and *K. valga* in fact increased during and after the treatment period. These results suggest that *Polyarthra* and *Hexarthra* are less tolerant to carbaryl than *B. angularis* and *K. valga*.

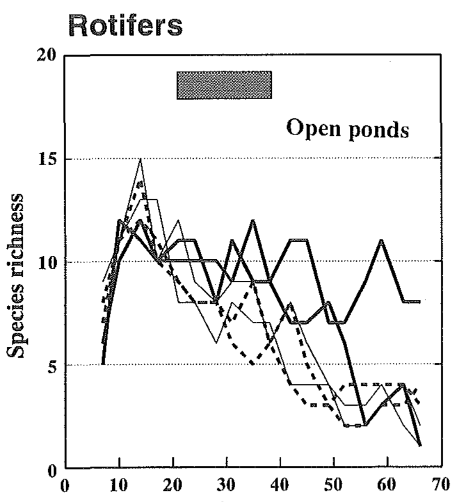

Fig. 7. Changes in species richness of rotifer community in the open ponds. Thin lines: control ponds, broken lines : low-dose ponds, thick lines : high-dose ponds. Shaded bars in panels indicate the period of insecticide application.

The resutls indicate that cladocerans (excepting *Bosmina*) are more sensitive to carbaryl than rotifers. *Chaoborus* larvae are much tolerant to the insecticide. They seemed not to be affected by carbaryl even in the high-dose ponds in the present experiment[6], and in the ponds treated with carbaryl at 500 $\mu g\ l^{-1}$ [7].

The repeated application of 100 μg carbaryl l^{-1} (high-dose treatment) reduced the species richness of the cladoceran community to one. This might have been because the impact of the treatment was strong enough to eliminate nearly all of the cladoceran species, allowing only the tolerant *Bosmina* to survive.

In contrast, the same chemical treatment increased the species richness of the rotifer community. The chemical suppressed the *Polyarthra* and *Hexarthra* populations,

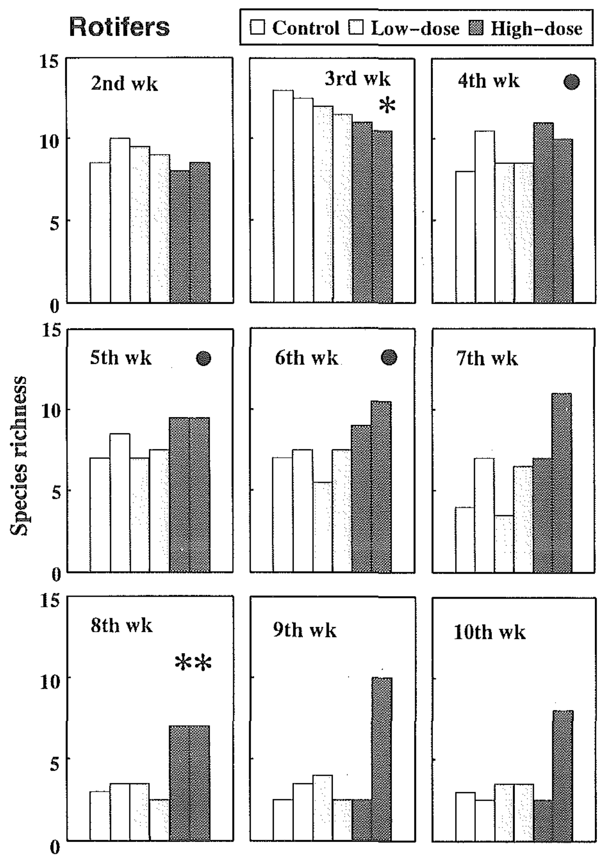

Fig. 8. Weekly mean value of species richness of rotifer community in open ponds. The insecticide application was conducted in the weeks shown by solid circles. Asterisks indicate that there are statistically significant differences between the ponds (*p<0.05, **p<0.01 ; nested ANOVA).

but did not eliminate them. The decrease of these species might have released *Keratella* and *Brachionus* from competition with them, and probably allowed these latter species to increase as a result. Thus, the impact of carbaryl seemed to allow these species inferior in competition but more tolerant to the chemical to coexist with competitively superior species, which, however, were less tolerant to the chemical. This might explain the increase in species richness in the ponds during and after the chemical treatment. The impact of the high-dose treatment (100 μg carbaryl l^{-1}) on the rotifer community might not be too strong or too weak. Thus, the moderate impact of carbaryl may sometimes increase the species richness of zooplankton communities.

The factors affecting species richness of lake zooplankton have been analyzed by DODSON[8-9], who have demonstrated that species richness of the crustacean zooplankton in European and North American lakes is significantly correlated with lake size, primary productivity and the number of lakes within 20 km. Larger lakes may have greater environmental heterogeneity for zooplankton than smaller ones, thus explaining the positive correlation of species richness with lake size. Increased primary productivity may change the quality and quantity of the food supply to zooplankton. Thus, the presence of a correlation between species richness and primary productivity suggests that food conditions are an important factor affecting species diversity. The number of lakes within 20 km may determine the rate of immigration of new species into the lake. In addition to these factors, the present study has shown that perturbation by certain kinds of stress is also an important factor maintaining high species richness in zooplankton communities.

Insecticide contamination is a typical environmental problem caused by humans, whose activities are reducing the biodiversity on Earth. However, the present study suggests that human impact does not always reduce biodiversity, and may even increase it.

Acknowledgments

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