Ecology of *Oocystis* spp. in Lake Biwa: Abundance, Colony Composition, Viability, and Food Relations with *Eodiaptomus japonicus* and *Daphnia longispina**

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Abstract *Oocystis* spp. in the water of Lake Biwa and in the guts of *Eodiaptomus japonicus* and *Daphnia longispina* were examined by microscopy for abundance, colony composition and viability from June 1984 to January 1985. *Oocystis* spp. were abundant both in the lake water and in the gut in September and from November to December. The late copepodites of *E. japonicus* and all size classes of *D. longispina* contained large numbers of *Oocystis* spp. cells in the gut. In the lake water, the proportion of small colonies was high and viability was low when *Oocystis* spp. were declining. Viable cells were found in the gut, but the proportion of small colonies was higher and viability was lower in the gut than in the lake water.

Introduction

Oocystis is a common freshwater phytoplankter, and often found intact in the guts of zooplankters (Porter, 1975; Infante, 1978; Infante & Edmondson, 1985). Freshwater phytoplankters are divided into the following three groups according to their responses to the grazing of zooplankters (Porter, 1977): small and digestible species, large species, and the small species which is capable of viable gut passage. *Oocystis* belongs to the third group.

By microscopy, the large phytoplankters in Lake Biwa were studied for population dynamics and food relations with zooplankters (Kawabata, 1987a). Direct observation with a microscope shows the colony composition and viability as well as abundance of each phytoplankter species. And gut analysis shows the result of feeding processes occurred *in situ*, and is a suitable method in studying natural food relations between phytoplankters and zooplankters. In the present study, the seasonal changes in the abundance, colony composition and viability of *Oocystis* spp., and their food relations with two dominant herbivorous zooplankters, *Eodiaptomus japonicus* and *Daphnia longispina*, were investigated by microscopy.

Oocystis spp. in this study included small species, *O. borgei, O. parva, O. lacustris* and *O. submarina*. The width of most colonies was less than 20μm. I excluded a large species, *O. solitaria* or *O. eremosphaeria*, whose cells were larger than 15 μm in width.

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Materials and Methods

Samples were collected at a fixed station (72 m deep, Station O in Kawabata, 1987b) in the north basin of Lake Biwa at 5–7 depths at intervals of 2.5–5 m from the surface to 20 m depth (to larger depths from November) at approximately weekly intervals from June 1984 to January 1985. *Oocystis* spp. were collected with a Van Dorn sampler (capacity, 3 l), fixed with Lugol solution, concentrated by natural sedimentation, and examined with a phase-contrast microscope. *E. japonicus* and *D. longispina* were collected with a Schindler-Patalas trap (capacity, 40 l), concentrated by filtration through a plankton net, anesthetized with ice cubes, fixed with formalin, cleared with sodium hypochlorite solution, and examined with a differential interference microscope. On each sampling date, 10 or more individuals were analyzed for each developmental stage of *E. japonicus* or each size class of *D. longispina*. Details of collection and examination were described by Kawabata (1987a, b).

When the abundance of *Oocystis* spp. in the water column exceeded 2×10^5 cells cm^{-2}, quartile depths were calculated. These divided the abundance into four equal parts. *Oocystis* spp. colonies were divided into three classes by cell number: 1, small; 2–4, middle; 5 and over, large. After combining data from all depths, the frequency distribution of colony classes (n > 50) and the proportion of viable cells, termed viability, in each class (n > 50) were calculated.

Results

In the lake water, *Oocystis* spp. were abundant in September and from November to December (Fig. 1A). They were confined to the layers shallower than 20 m until mid-November, and dispersed into deeper layers by vertical water mixing from late November (Fig. 1B). *Oocystis* spp. were distributed in the same layers as *E. japonicus* and *D. longispina* (Kawabata 1987b, in preparation).
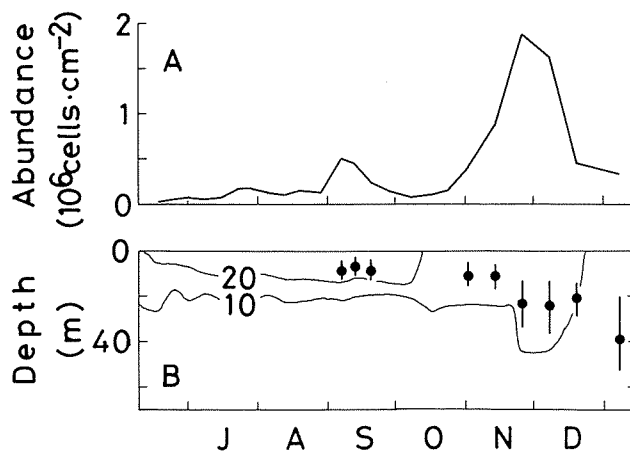

Fig. 1. Seasonal changes in abundance (A) and vertical distribution (B) of *Oocystis* spp. B: second quartile depth (plots) with interval from the first to third quartile depth (bars) and isotherms in °C (lines).

The cell numbers of *Oocystis* spp. in the guts of *E. japonicus* and *D. longispina* were high in September and from November to December (Figs. 2 and 3). Therefore, *E. japonicus* and *D. longispina* ingested more cells when *Oocystis* spp. were more abundant (Fig. 1A). The cell numbers in the gut of *E. japonicus* were high from copepodite stage III (CIII), and CIV and the later stages showed similar values (Fig. 2). *D. longispina* contained many cells in the gut even in the smallest size class, and did not show large difference among classes (Fig. 3).

In the lake water, the proportion of small colonies was low in early September and early November, and high in late September and December (Fig. 4A). Therefore, middle and large colonies were dominant when *Oocystis* spp. were increasing, and small colonies when they were declining (Fig. 1A). In the guts of *E. japonicus* and *D. longispina*, the proportion of small colonies was higher and that of large colonies was lower than in the lake water (Fig. 4). The proportion of small colonies in the gut changed seasonally in the same way as in the lake water.

In the lake water, viability was low in late September and December in every colony class (Fig. 5). Therefore, *Oocystis* spp. became less viable when they were declining (Fig. 1A). In the guts of *E. japonicus* and *D. longispina*, viability was lower than in the lake water in every colony class (Fig. 5). The seasonal changes in viability
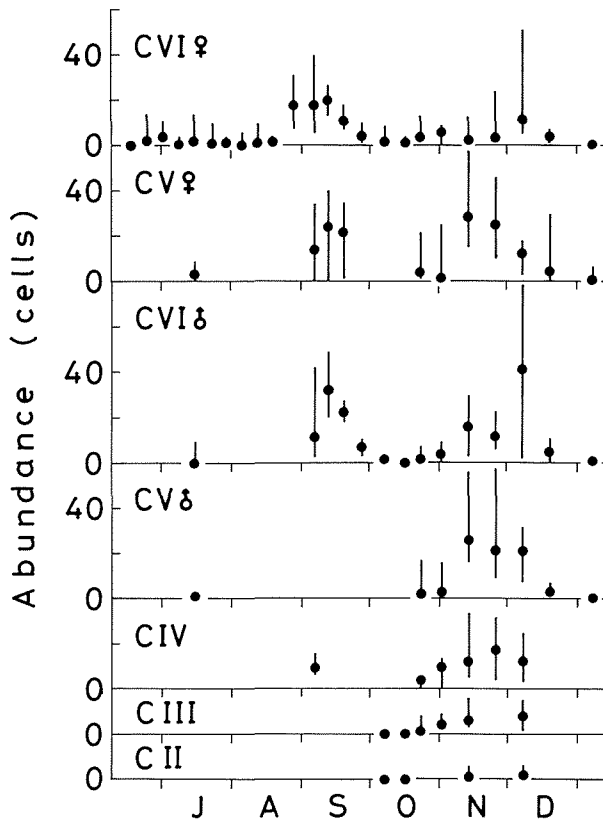

Fig. 2. Seasonal changes in cell numbers of *Oocystis* spp. in the guts of *Eodiaptomus japonicus* copepodites. A circle with a bar represents the median with the 95% confidence interval.
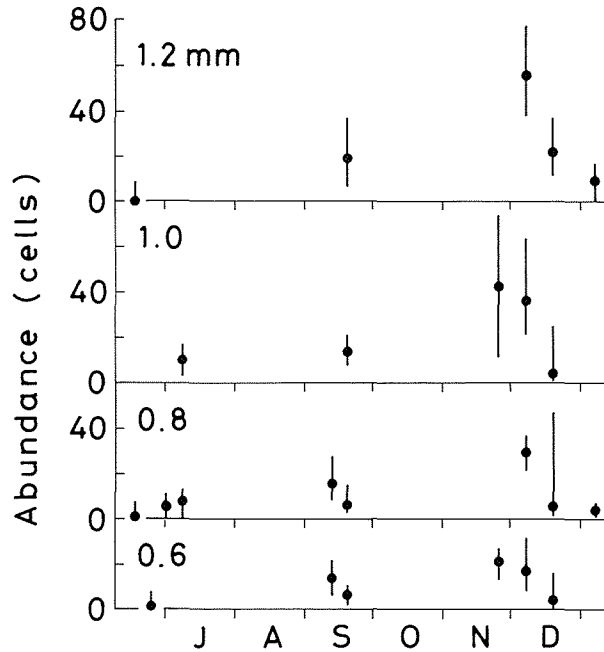
Fig. 3. Seasonal changes in cell numbers of *Oocystis* spp. in the guts of *Daphnia longispina* size classes. Representation is as in Fig. 2.

in the gut were similar to those in the lake water. Both in the lake water and in the gut, viability was lowest in small colonies, which suggests that senescent multicellular colonies were broken to empty single cells.

Discussion

When *Oocystis* spp. were declining, the proportion of small colonies was high and viability was low in the lake water (Figs. 1A, 4A and 5). Ramberg (1980) also found the dominance of single cells in the declining population of *Oocystis parva*. The decline process of *Oocystis* spp. was probably that collapsing colonies exceeded growing colonies, and that dying cells exceeded dividing cells.

The viable cells of *Oocystis* spp. were found in the guts of *E. japonicus* and *D. longispina* (Fig. 5) and therefore, some cells probably passed through the gut intact. During viable gut passage, *Oocystis* spp. may have taken up nutrients as shown for *Sphaerocystis schroeteri* (Porter, 1976). In the gut, however, the proportion of small colonies was higher and viability was lower than in the lake water (Figs. 4 and 5). Colony composition and viability in the gut were not fixed, and seem to have been affected by those in the lake water. This suggests that *E. japonicus* and *D. longispina* ingested *Oocystis* spp. unselectively for colony size and viability. Empty single cells were probably abundant in the gut because *E. japonicus* and *D. longispina* broke and killed viable colonies during ingestion and digestion. When *Oocystis* spp. were ingested, some cells were killed and others may have taken advantage of viable gut
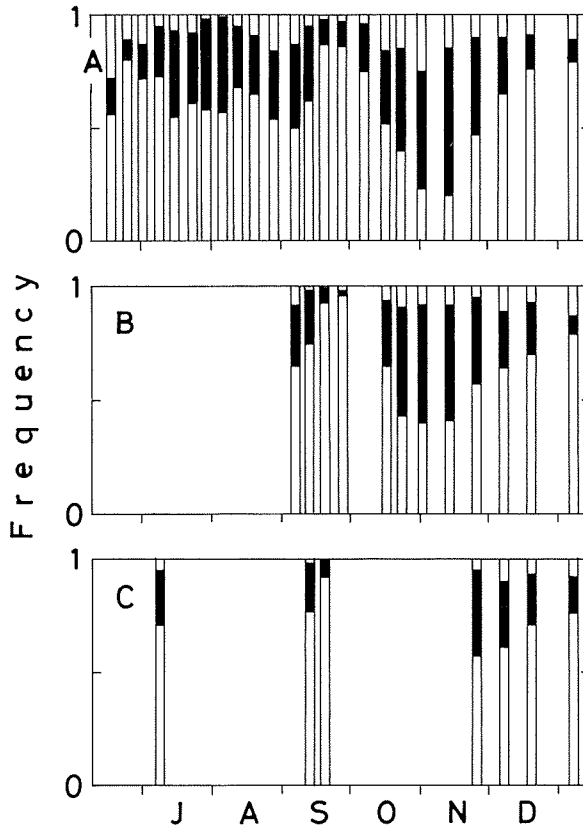
Fig. 4. Seasonal changes in frequency distribution of small (lower open columns), middle (solid columns) and large (upper open columns) colonies of *Oocystis* spp. in the lake water (A) and in the guts of *Eodiaptomus japonicus* (B) and *Daphnia longispina* (C).

passage. Therefore, the relations with *E. japonicus* and *D. longispina* were ambiguous for *Oocystis* spp.

Infante (1981) reported that *Notodiaptomus venezolanus* contains a large number of *Oocystis lacustris* cells in the gut from CI, and that all copepodite stages show similar values. In the present study, the cell numbers of *Oocystis* spp. in the gut of *E. japonicus* were equally high in CIV and the later stages (Fig. 2). For the large diatoms, *Melosira solida* and *Fragilaria crotonensis*, *E. japonicus* contained many cells in the gut only in adult females (Kawabata, 1987a). *E. japonicus* adult females probably acquired the ability to ingest large diatoms while retaining the feeding habit of the earlier stages for small particles. It seems that the adult females can feed in both active and passive modes (Vanderploeg & Paffenhöfer, 1985).

In *D. longispina*, the larger size classes showed the higher cell numbers in the gut for the large phytoplankters, *M. solida* and *Closterium aciculare* (Kawabata, 1987a), but not for *Oocystis* spp. (Fig. 3). The feeding habit of *D. longispina* probably changed ontogenetically only for large phytoplankters.
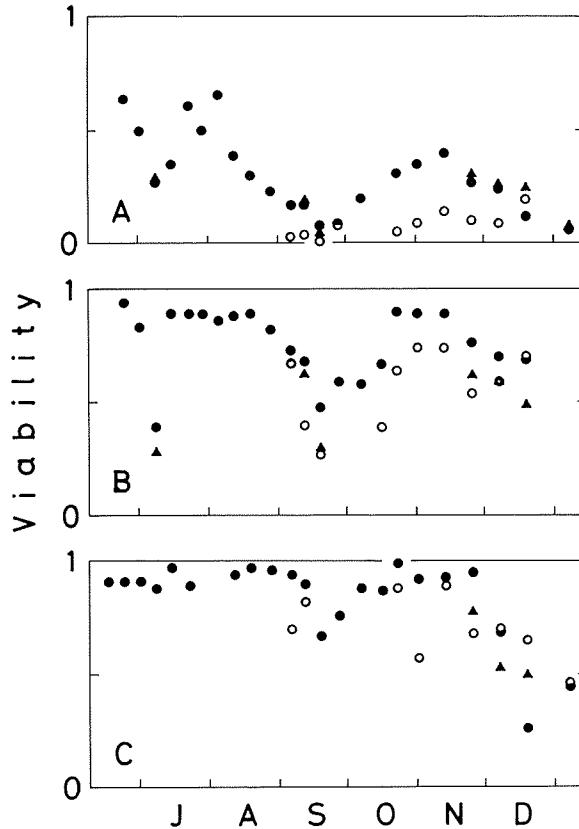
Fig. 5. Seasonal changes in viability of small (A), middle (B) and large (C) colonies of *Oocystis* spp. in the lake water (solid circles) and in the guts of *Eodiaptomus japonicus* (open circles) and *Daphnia longispina* (solid triangles).

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