SPECIES COMPOSITION OF CLADOCERAN COMMUNITY IN THE HIGHLY EUTROPHIC LAKE KASUMIGAURA

Hanazato, T.

Environmental Biology Division, National Institute for Environmental Studies, Onogawa, Tsukuba, Ibaraki 305, Japan.

ABSTRACT

Changes in species composition of the cladoceran community in the highly eutrophic Lake Kasumigaura were investigated over 14 years (1976 - 1989). The composition was stable in summer, when small-sized cladoceran species, especially Bosmina fatalis, became dominant. Fish predation, high water temperature and the inhibitory effect of blue-green algae on cladoceran feeding seemed to induce this. In addition, a stable food supply for Cladocera by blue-green algae through the detritus food-chain may be partly responsible for the stability in species composition during summer. In contrast, the species composition in spring, fall and winter (non-blooming seasons for blue-green algae) changed from year to year. Daphnia ambigua and D. galeata often established large populations in these seasons after 1984; they appear to reduce greatly the algal biomass by their grazing.

Key words: Cladoceran community, species composition, eutrophic lake, blue-green algae

INTRODUCTION

Lake Kasumigaura is shallow (maximum depth, 7.3 m; mean depth, 4.0 m) and highly eutrophic. Blue-green algae, mostly Microcystis spp., form heavy water blooms in summer and early fall. The zooplankton community was observed for 14 years from 1976 to 1989 (12,14,16,20,30,40,41), and Cladocera were found to dominate the lake.

The present paper reports the seasonal changes in species composition of the cladoceran community in Takahamairi Bay, the most eutrophic basin in Lake Kasumigaura, over the 14 year-period, and discusses factors controlling the species composition and its relation to the algal community.

SEASONAL CHANGES IN SPECIES COMPOSITION OF CLADOCERAN COMMUNITY

Table 1 shows changes in the dominant species of the cladoceran community for the 14 years. Diaphanosoma brachyurum and Bosmina fatalis dominated the community during July - September in every year, indicating that the species composition is stable in summer. In particular, B. fatalis was the most important species in terms of biomass and production; it accounted for the highest percentage of the annual biomass and production of the total cladoceran species (14,16).

In contrast, the species composition during fall - spring differed considerably among the years. No Cladocera were found in late fall, winter and/or spring of 1976 - 1983, 1985 and 1988. The absence of Cladocera in these seasons might have been caused by the predation of a mysid, Neomysis intermedia, because cladocerans are favorable food items for Neomysis (31), and the

Table 1. Monthly changes in the first and second dominant species of the cladoceran community in Takahamairi Bay of Lake Kasumigaura from 1976 to 1989. Species with a density < 1 individual l^{-1} were not considered.

	JAN	FEB	MAR	APR	MAY	JUN	JUY	AUG	SEP	OCT	NOV	DEC
1976	--*	--	--	--	--	--	Di Mo	Di Bo	Bo Mo	Di Bo		
1977						Di Bo	Bo	Bo	Di Bo	Bo Ce		
1978							Di	Di BF	Di BF	BF Ch	BF	
1979							Di	Di	Di BF	Di		
1980						BL Di	Di BL	Di BF	Di BF	Di		
1981						BL Di	BL Mo	Di BF	Di BF	Di BF	BF	BF
1982					Mo	Mo Di	Mo Di	Di BF	Di BF	Di BF	BF BL	
1983						Di	Di	Di BF	Di BF	BF Ch	Ch Ce	Ch BL
1984	BL	--	BL	BL	DA BL	Di BF	Di BF	Di BF	BF Ch	BF Ch	BF Ch	Ch
1985							Mo BF	Di BF	BF Ce	BF Ch	BF Ch	BF Ch
1986	DA BL	DA					Di BF	Di BF	Di BF	BF Ch	BF Ch	BF DG
1987	DG	DG	--	DG		Mo	Di BF	Di BF	Di BF	Di BF	Di BF	
1988							Di	Di Mo	Di BF	BF Ch	BF Ch	DG BL
1989	DG BL	DG BL	DG BL	DG	DG	DG Di	Di BL	Di BF	Di BF	BF Ch	BF Ch	DG BL

Di = *Diaphanosoma brachyurum*; BL = *Bosmina longirostris*; BF = *Bosmina fatalis*; Bo = *Bosmina* (*B. longirostris* or *B. fatalis*); Ch = *Chydorus sphaericus*; Ce = *Ceriodaphnia cornuta*; Mo = *Moina micrura*; DA = *Daphnia ambigua*; DG = *Daphnia galeata*
* Month lacking data

time when cladocerans were absent accorded well with the time when the mysids were abundant in the lake (20).

Daphnia ambigua built up a large population in May 1984. This was the first colonization of a species belonging to the genus *Daphnia* in Lake Kasumigaura. *D. ambigua* appeared again in January - March 1986 at low density (< 10 individuals l^{-1}), but has not been found since then. The appearance of *D. ambigua* after the spring of 1986 was probably suppressed through competition by *D. galeata*, which has often occurred abundantly since the fall of 1986. *D. galeata* excluded *D. ambigua* from experimental ponds and is considered to be competitively superior to the latter (25). The occurrence of *Daphnia* in the lake is probably related to the *N. intermedia* predation, because *Daphnia* appeared when mysids were absent (12,16,20). *N. intermedia* had shown two density peaks a year, in spring and fall, before 1983 (20,37). Subsequently, however, the seasonal pattern of mysid density became irregular and mysids often failed to establish their populations. This might have allowed the appearence of *Daphnia* in the lake.

Zooplankton communities in eutrophic lakes are usually dominated by small-bodied cladocerans, rotifers and copepods (7,8,9,33,34) and this applies to the summer zooplankton community in Lake Kasumigaura. Brooks (3) and Kerfoot (28) ascribed the dominance of small zooplankters to predation by fish, which are abundant in eutrophic lakes and predate large zooplankters selectively. In Lake Kasumigaura, the predation pressure by fish on zooplankton appears to be high (14). High predation pressure may suppress the population growth of large cladocerans and allow the small cladocerans *D. brachyurum* and *B. fatalis* to predominate. This was also inferred from the fact that in outdoor experimental ponds with bottom mud from Lake Kasumigaura, but no fish, the larger *Moina micrura* dominated the smaller *B. fatalis* in summer (17).

Water temperature is high in summer in Lake Kasumigaura, often exceeding 30 °C. The high summer temperature is probably unfavorable for the large cladoceran *Daphnia*, because a temperature above ca. 25°C reduces the feeding efficiency of many *Daphnia* species (4,5) and seems to damage their populations. In the outdoor experimental ponds mentioned above, *Daphnia* spp. always dominated the zooplankton communities in spring, fall and winter, but never in summer, when the water temperature was usually 28 - 30°C (17,22,23,24).

The occurrence of blue-green algal blooms is another important factor inducing the domination of small-sized zooplankters in eutrophic lakes, because the algae inhibit the feeding activity of large cladocerans, but not small cladocerans, rotifers and copepods (6,9,10,39). In Lake Kasumigaura blue-green algae, mostly *Microcystis* spp., bloom in summer and early fall (July - October), and the algal bloom appears to suppress colonization by *Daphnia*, because *Daphnia* did not increase in October of 1985 - 1989, when the water temperature was favorable for daphnids, mysids were rare, but a blue-green algal bloom was present.

DOMINANCE OF *BOSMINA FATALIS* IN SUMMER

Fish predation, high water temperature and an inhibitory effect of blue-green algae on zooplankton feeding are considered important factors controlling the summer zooplankton community structure. However, they cannot explain the dominance of B. fatalis in summer, because another species of Bosmina, B. longirostris, also appeared in the lake. These two species are similar in size, indicating that they have similar tolerance to fish predation and to the inhibitory effect by colonial blue-green algae. Furthermore they show similar adaptation to temperatures (15).

Nevertheless, the prevalent seasons of the two species of Bosmina were different in Lake Kasumigaura; B. longirostris appeared in the spring or early summer and was replaced by B. fatalis in mid-summer (26). In late fall, the former species reappeared when the density of the latter decreased. A similar succession of the two Bosmina species has been observed in another eutrophic lake, Lake Suwa (27).

In the experiments using enclosures at the innermost part of Takahamairi Bay, the succession of the two species of Bosmina was apparently influenced by a Microcystis bloom; the predominant period of B. fatalis accorded well with the blooming period of Microcystis (26,32), suggesting that the Microcystis bloom offered favorable food conditions for B. fatalis. However, live Microcystis cells were unfavorable to B. fatalis, as well as to B. longirostris (18).

Hanazato and Yasuno (18) demonstrated that the competitive superiority between the two species of Bosmina changed according to the food level: B. fatalis outcompeted B. longirostris at a high food level, whereas the latter won at a low food level. Thus, the dominance of B. fatalis in Lake Kasumigaura in summer may be explained by the high food supply for zooplankters. Microcystis is inedible for B. fatalis and other cladocerans (13,18,19,21,29). However, the alga turns into a utilizable food when it is decomposed, and decomposing or decomposed Microcystis has been regarded as an important food in this lake in summer (18,19). The high water temperature occurring in summer must prompt the decomposition of Microcystis, which probably assures a large food supply for zoolankton and may support the dominance of B. fatalis in summer.

In general, phytoplankton populations supply food for zooplankton. However, the algal biomass is reduced by grazing of the increased zooplankton population, if predation pressure on the zooplankton is low. The reduction of algal biomass leads to food depletion for zooplankton and may alter the competitive relationships between them. However, this cannot be applied to the relationship between blue-green algae and Cladocera. The biomass of blue-green algae is not reduced by Cladoceran grazing because the algae are inedible, whereas the algae supply the food for Cladocera after being decomposed. Thus, it is supposed that the bloom of blue-green algae assures Cladocera of a stable food supply. This may be partly responsible for the stability in species composition of the summer cladoceran community in Lake Kasumigaura.

INFLUENCE OF DAPHNIA ON ALGAL BIOMASS

The appearance of D. ambigua and D. galeata is an event that merits special mention, since it is the most drastic change in the species composition of the cladoceran community to have occurred during the 14-year study period. This change in species composition affected the algal abundance.

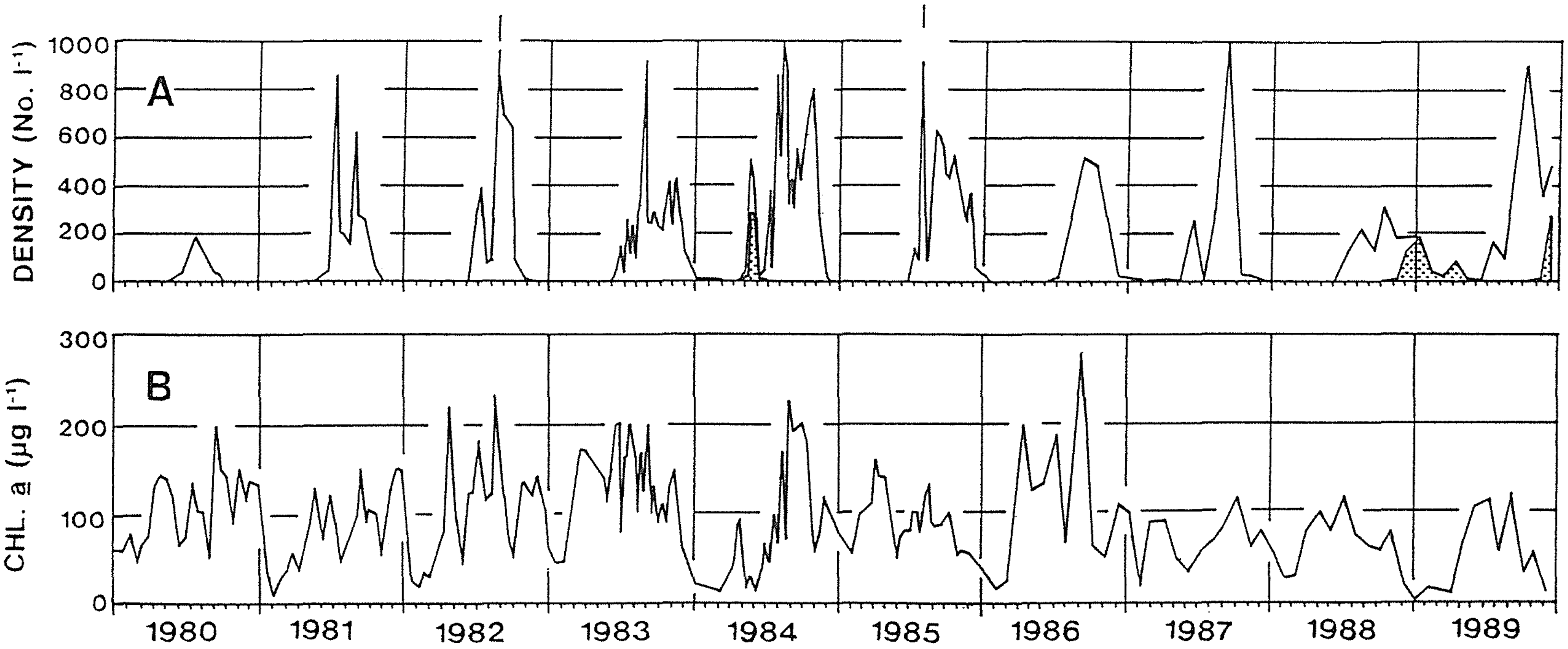

Fig. 1. Seasonal changes in density of total cladoceran species (A) and in chlorophyll a concentration (B) in Takahamairi Bay of Lake Kasumigaura during 1980 - 1989. The shaded area in the panel (A) indicates the density of Daphnia spp. The data of chlorohyll a concentration were cited from Aizaki et al. (1,2), Hanazato and Yasuno (16) and Aizaki (in prep.).

Figure 1 shows the seasonal changes in total cladoceran density and those in chlorophyll a concentration during 1980 - 1989. In most years, the highest cladoceran density was established in summer, and was mainly contributed by B. fatalis. Chlorophyll a concentration was maintained at around 100 µg l^{-1} during spring - fall. The minimum concentration was usually 20 - 30 µg l^{-1}, which occurred in January - March. The dominant phytoplankton species were Synedra rumpens in spring, Microcystis spp. in summer and early fall, Cyclotella sp. and Coscinodiscus lacustris in late fall, and Cryptomonas spp. in winter (36). The figure clearly shows that the chlorophyll a concentration declined greatly when D. ambigua and D. galeata established large populations (in May 1984, January - March 1989, and December 1989). In particular, the concentration became as low as 0.7 µg l^{-1} in January 1989. The decline in chlorophyll a concentration must be a result of reduction of algal biomass due to grazing by Daphnia.

Recently, biomanipulation for lake restoration has been performed in lakes and ponds (11,35,38). One approach is to increase the size and grazing pressure of herbivorous zooplankton by reducing the population of planktivorous fish, which results in a decline of phytoplankotn abundance. The events in Lake Kasumigaura suggest that even in highly eutrophic lakes, the phytoplankton biomass is reduced considerably when herbivorous zooplankton, especially Daphnia, establish large populations. However, this may not be applicable to lakes during the blue-green algal blooming season, because, in Lake Kasumigaura, chlorophyll a concentration was not reduced when cladoceran biomass increased in the blooming season of Microcystis (July - October), probably due to the algae being inedible for cladocerans (12).

REFERENCES

1. Aizaki, M., Fukushima, T., Ebise, S., Hosomi, M., Iwakuma, T., Takamura, N., Hanazato, T., Kasuga, S., Yasuno, M., Otsuki, A., Kawai, T., and Nishikawa, M. (1984) Limnological data in Lake Kasumigaura. Res. Data Natl. Inst. Environ. Stud., 25:1-149.
2. Aizaki, M., Fukushima, T., Ebise, S., Hosomi, M., Iwakuma, T., Hanazato, T., Takamura, N., Nohara, S., Otsuki, A., Kawai, T., Shiraishi, H. and Nojiri, Y. (1988) Limnological data in Lake Kasumigaura. Res. Data Natl. Inst. Environ. Stud., 33:1-66.
3. Brooks, J.L. (1969) Eutrophication and changes in the composition of the zooplankton, In Eutrophication: causes, consequences, correctives, pp.236-255, Publ. Nat. Acad. Sci., Washington, D.C.
4. Burns, C.W. (1969) Relation betwen filtering rate, temperature, and body size in four species of Daphnia. Limnol. Oceanogr., 14:693-700.
5. Burns, C.W. and Rigler, F.H. (1967) Comparison of filtering rates of Daphnia rosea in lake water and in suspensions of yeast. Limnol. Oceanogr., 12:492-502.
6. Fulton, R.S.III. and Paerl, H.W. (1987) Effects of colonial morphology on zooplankton utilization of algal resources during blue-green algal (Microcystis aeruginosa) blooms. Limnol. Oceanogr., 32:634-644.

7. Geller, W. and Muller, H. (1981) The filtration apparatus of Cladocera: Filter mesh-size and their implications on food selectivity. Oecologia, 49:316-321.
8. Gliwicz, Z.M. (1969) Studies on the feeding of pelagic zooplankton in lakes with varing trophy. Ekol. Pol. A., 17:663-708.
9. Gliwicz, Z.M. (1977) Food size selection and seasonal succession of filter feeding zooplankton in an eutrophic lake. Ekol. Pol., 25:179-225.
10. Gliwicz, Z.M. and Siedlar, E. (1980) Food size limitation and algae interfering with food collection in Daphnia. Arch. Hydrobiol., 88:155-177.
11. Gulati, R.D. (1989) Structure and feeding activities of zooplankton community in Lake Zwemlust, in the two years after biomanipulation. Hydrobiol. Bull., 23:35-48.
12. Hanazato, T. (submitted) Changes in species composition of cladoceran community in Lake Kasumigaura during 1986 - 1989: Occurrence of Daphnia galeata and its effect on algal biomass. Jpn. J. Limnol.
13. Hanazato, T. and Yasuno, M. (1984) Growth, reproduction and assimilation of Moina macrocopa fed on Microcystis and/or Chlorella. Jpn. J. Ecol., 34:195-202.
14. Hanazato, T. and Yasuno, M. (1985) Population dynamics and production of cladoceran zooplankton in the highly eutrophic Lake Kasumigaura. Hydrobiologia, 124:13-22.
15. Hanazato, T. and Yasuno, M. (1985) Effects of temperature in the laboratory studies on growth, egg development and first parturition of five species of Cladocera. Jpn. J. Limnol., 46:185-191.
16. Hanazato, T. and Yasuno, M. (1987) Characteristics of biomass and production of cladoceran zooplankton in Lake Kasumigaura. Jpn. J. Limnol., 48:S45-S57.
17. Hanazato, T. and Yasuno, M. (1987) Effects of a carbamate insecticide, carbaryl, on the summer phyto- and zooplankton communities in ponds. Environ. Pollut., 48:145-159.
18. Hanazato, T. and Yasuno, M. (1987) Experimental studies on competition between Bosmina longirostris and Bosmina fatalis. Hydrobiologia, 154:189-199.
19. Hanazato, T. and Yasuno, M. (1987) Evaluation of Microcystis as food for zooplankton in a eutrophic lake. Hydrobiologia, 144:251-259.
20. Hanazato, T. and Yasuno, M. (1988) Impact of predation of Neomysis intermedia on a zooplankton community in Lake Kasumigaura. Verh. Internat. Ver. Limnol., 23:2092-2098.
21. Hanazato, T. and Yasuno, M. (1988) Assimilation of Diaphanosoma brachyurum and Moina macrocopa on Microcystis. Jpn. J. Limnol., 49:37-41.
22. Hanazato, T. and Yasuno, M. (1989) Effects of carbaryl on the spring zooplankton communities in ponds. Environ. Pollut., 56:1-10.
23. Hanazato, T. and Yasuno, M. (1989) Influence of over-wintering Daphnia on spring zooplankton communities: An experimental study. Ecol. Res., 4:323-338.
24. Hanazato, T. and Yasuno, M. (1990) Influence of time of application of an insecticide on recovery patterns of a zooplankton community in experimental ponds. Arch. Environ. Contam. Toxicol., 19:77-83.

25. Hanazato, T. and Yasuno, M. (in press) Insights into competition in zooplankton communities derived from studies using experimental ponds. Verh. Internat. Ver. Limnol., 24:
26. Hanazato, T., Yasuno, M., Iwakuma, T. and Takamura, N. (1984) Seasonal changes in the occurrence of Bosmina longirostris and Bosmina fatalis in relation to Microcystis bloom in Lake Kasumigaura. Jpn. J. Limnol., 45:153-157.
27. Hanazato, T., Hayashi, H., Ichikawa, T. and Watanabe, Y. (1989) Dynamics of zooplankton community in enclosures of different types in a shallow eutrophic lake. Jpn. J. Limnol., 50:25-37.
28. Kerfoot, W.C. (1974) Net accumulation rates and the history of cladoceran communities. Ecology, 55:51-61.
29. Lampert, W. (1982) Further studies on the inhibitory effect of the toxic blue-green Microcystis aeruginosa on the filtering rate of zooplankton. Arch. Hydrobiol., 95:207-220.
30. Morishita, M. and Yasuno, M. (1979) Seasonal change and horizontal distribution of zooplankton at Takahamairi Bay in Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud., 6:155-170. (in Japanese with an English abstract).
31. Murtaugh, P.A. (1981) Selective predation by Neomysis mercedis in Lake Washington. Limnol. Oceanogr., 26:445-453.
32. Natl. Inst. Environ. Stud., (1984) Enclosure experiments for restoration of highly eutrophic shallow Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud., 52, 101p. (in Japanese with English abstracts).
33. Orcutt, J.D. and Pace, M.L. (1984) Seasonal dynamics of rotifer and crustacean zooplankton populations in a eutrophic, monomictic lake with a note on rotifer sampling techniques. Hydrobiologia, 119:73-80.
34. Richman, S. and Dodson, S.I. (1983) The effect of food quality on feeding and respiration by Daphnia and Diaptomus. Limnol. Oceanogr., 28:948-956.
35. Shapiro, J. and Wright, D.I. (1984) Lake restration by biomanipulation: Round Lake, Minnesota, the first two years. Freshwat. Biol., 14:371-383.
36. Takamura, N., Iwakuma, T. and Yasuno, M. (1984) The biomass and production of phytoplankton in Lake Kasumigaura during 1981-1983. Res. Rep. Natl. Inst. Environ. Stud., 51:11-56. (in Japanese with an English abstract).
37. Toda, H., Takahashi, M. and Ichikawa, S. (1982) Abundance and life history of Neomysis intermedia Czerniawsky in Lake Kasumigaura. Hydrobiologia, 93:31-39.
38. Vanni, M.J., Luecke, C., Kitchell, J.F., Magnuson, J.J., Rentmeester, Y. and Temte, J. (in press) Food web effects on phytoplankton in Lake Mendota, Wisconsin, USA: Effects of massive fish mortality. Hydrobiologia.
39. Webster, K.E. and Peters, R.H. (1978) Some size-dependent inhibitions of larger cladoceran filters in filamentous suspensions. Limnol. Oceanogr., 23:1238-1245.
40. Yasuno, M., Morishita, M. and Sugaya, Y. (1977) Benthos and zooplankton at Takahamairi Bay in Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud., 1:94-107. (in Japanese).
41. Yasuno, M., Morishita, M. and Hanazato, T. (1981) Standing crop of zooplankton at Takahamairi Bay in Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud., 22:149-158. (in Japanese with an English abstract).