Bot. Bull. Acad. Sin. (1998) **39:** 137–145

Dinoflagellate associations in Feitsui Reservoir, Taiwan

Jiunn-Tzong Wu[1,2,3] and Jin-Wen Chou[1]

[1]*Institute of Botany, Academia Sinica, Nankang, Taipei 11529, Taiwan, Republic of China*

[2]*Department of Botany, National Taiwan University, Taipei 10764, Taiwan, Republic of China*

(Received October 16, 1996; Accepted February 5, 1998)

Abstract. In Feitsui Reservoir, dinoflagellate association was composed of three species: *Ceratium furcoides* (Levander) Langhans, *Peridinium bipes* Stein, and *P. umbonatum* Stein var. *umbonatum*. The environmental factors affecting their occurrence were studied at eight sites in the reservoir between January 1990 and December 1994. The peak occurrence of dinoflagellates, at water temperatures between 24 and 26°C, was related to the high watershed runoff due to monsoon rainfall in autumn. The abundance of dinoflagellates was positively correlated with the concentrations of phosphorus, total organic carbon, bacterial number, and chemical as well as biochemical oxygen demand in the water. The decrease in dinoflagellate abundance since 1991 has been followed by the prevalence of nannoplankton such as cyanobacteria and green algae. This coincided well with the continuous increase in N-nutrients in waters, which favors the growth of nannoplankton. It is assumed that N-nutrients play a more important role than P-nutrients in regulating the succession of dinoflagellates in this reservoir.

Keywords: *Ceratium*; Dinoflagellate association; Ecology; Feitsui Reservoir; Limnology; *Peridinium*; Phytoplankton.

Abbreviations: **BOD_5,** biochemical oxygen demand measured for five days; **COD,** chemical oxygen demand; **N,** nitrogen; **P,** phosphorus; **TIN,** total inorganic nitrogen; **TOC,** total organic carbon; **TP,** total phosphorus.

Introduction

Dinoflagellates are microalgae that often develop heavy blooms in the marine environments as well as in freshwater lakes or water reservoirs. Common bloom-forming genera in freshwaters are e.g. *Ceratium, Peridinium,* and *Peridiniopsis*. A number of studies have been performed on the environmental factors regulating the development of such blooms (Pollingher and Serruya, 1976; Pollingher, 1988; Lindström, 1992; Olrik, 1992).

Feitsui Reservoir, a reservoir constructed mainly for the purpose of supplying domestic water to the Taipei metropolitan area, is located in Taipei County, Taiwan. The occurrence of dinoflagellates in this reservoir was quite common and has received public attention owing to the exudates and odors produced by them, which remarkably influence the quality of the water supply. The control of phytoplankton is becoming more and more important due to the increasing pollution of water resources. The present study is done to elucidate the factors which trigger the development of the dinoflagellates in the reservoir and to characterize their abundance.

Background of Feitsui Reservoir

Feitsui Reservoir (N24°54', E121°34') was constructed in 1986, mainly for the purpose of supplying domestic water. It is located in a vale of mountains (altitude between 450 and 1,170 m) near Taipei, with an elevation of ca. 170 m at the dam site. It covers an area of 10.24 km^2 with effective storage of 4.06×10^8 m^3 water. The majority of the watershed of this reservoir is covered by secondary subtropical forests. The massive land use for tea plants on mountain slopes or terraces near the riverine region over S8 of Figure 2 and a village populated by ca. 2,500 people at northeastern to S8 seem to be the main sources of pollution for this reservoir.

Feitsui Reservoir has a maximum depth up to 110 m. During the time of this study, between 1990 and 1994, its depth was kept at 98.0 × 7.8 m. The insolation fluctuated during the year, reaching its maximum in July and minimum in January (Figure 3). The highest and lowest surface water temperatures in this reservoir were 33.5 and 14.4°C, in August and February, respectively. The average was 22.0 ± 4.8°C. The temperature in hypolimnion was nearly constant at 16.2 ± 0.3°C throughout the study. The reservoir thus has a monomictic type of thermal circulation.

Materials and Methods

Phytoplankton samples were collected monthly from eight sites (shown in Figure 2). After immediately fixing by Lugol iodine solution, the phytoplankton samples were prepared in the laboratory for quantitative counting and identification under light- and electron microscopes.

[3]Corresponding author. Fax: 886-2-27827954.

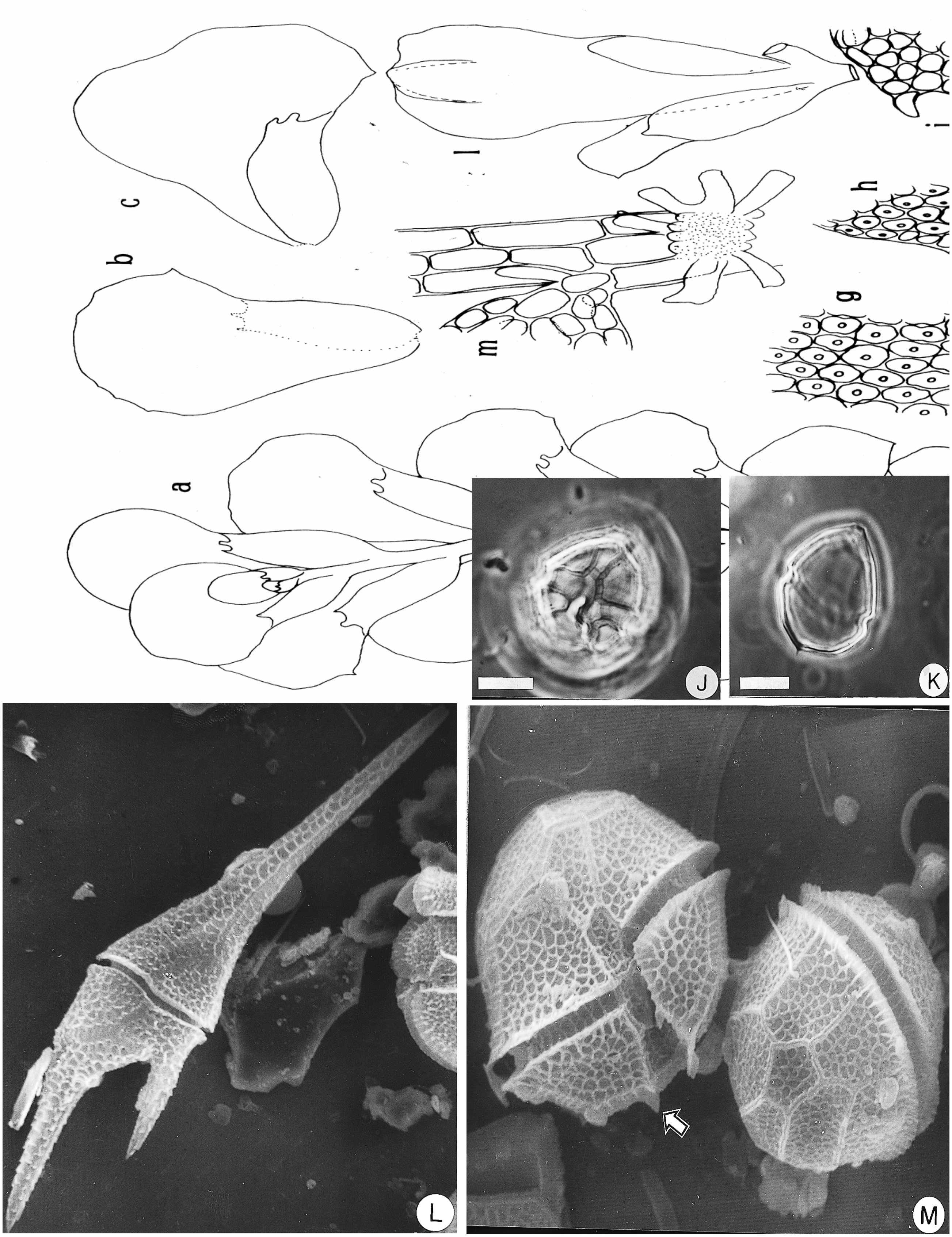

Figure 1. Morphology of *Peridinium umbonatum* var. *umbonatum* (A–D and J–K: A & J, ventral view; B & K, dorsal view; C, epivalve; D, hypovalve;), *P. bipes* (E–H and M: E, ventral view; F, dorsal view; G, epivalve; H, hypovalve; M, ventral and dosal views under SEM with characteristic triangular flanges indicated by arrow) and *Ceratium furcoides* (I and L, dorsal view) in Feitsui Reservoir. Bar = 10 µm.

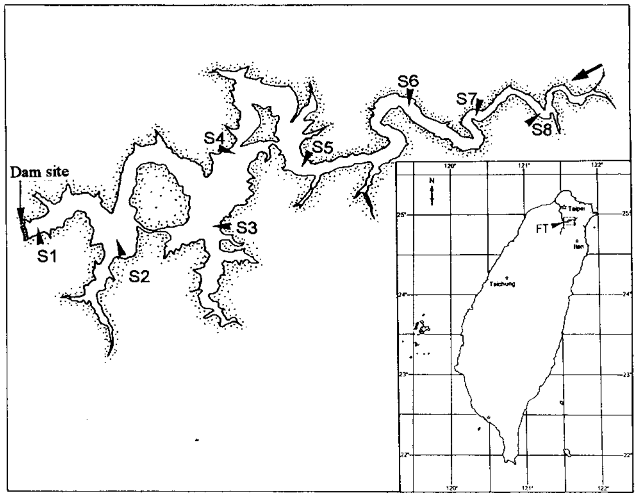

Figure 2. Map of Taiwan, showing the location of Feitsui Reservoir (FT) and the locality of sampling sites (S1–S8). S1 and S8 are close to dam site and riverine region, respectively. The main inflow of water is indicated by ←.

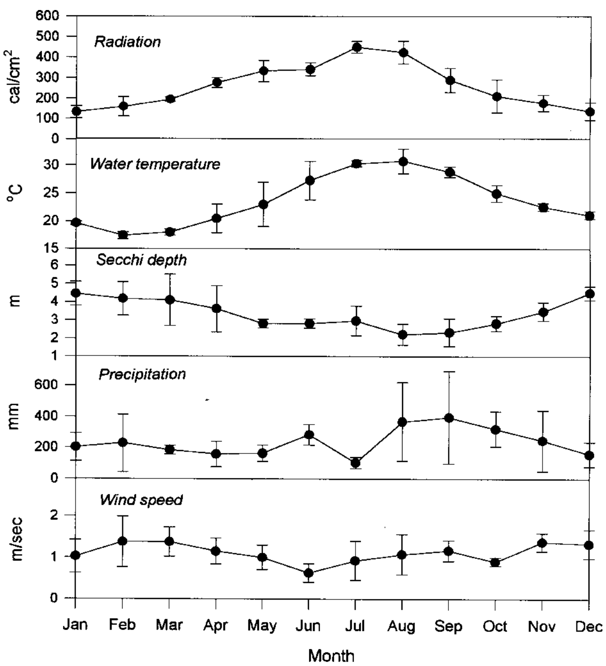

Figure 3. Fluctuation in the monthly averages of radiation, water temperature, transparency (Secchi depth), precipitate, and wind speed in Feitsui Reservoir during the time of this study.

For observations under light microscope, samples were concentrated by centrifugation and immersed in glycerol before being mounted on a slide. For quantitative estimation of algal density, the membrane method was employed (Sournia, 1978). Algal cells were stained with Coomasie Blue solution (1 g Coomasie Brilliant Blue, 50 ml 95% (v/v) ethanol and 100 ml 85% (w/v) phosphoric acid) before being filtered through a nitrate cellulose membrane (pore size 0.45 μm) under reduced pressure. The counting of cell number under light microscope was conducted after the membranes had become transparent by adding immersion oil. For observation under electron microscope, algal samples were refixed in 2.5% glutaraldehyde and 1% osmium tetraoxide. Subsequently, they were dehydrated through a graded series of alcohols, dried under vacuum in a critical point apparatus (Balzers Union, Liechtenstein), coated with gold, and observed under a SEM (Zeiss DSM-950, Oberkochen, Germany) as noted previously (Wu, 1987).

The analysis of the water quality of the samples was conducted according to standard methods (APHA et al., 1992). The concentration of chlorophyll *a* in the water was determined by membrane methods adopted from Rai (1980). The equations given by Carlson (1977) were adopted for the evaluation of the trophic state of the reservoir, using Secchi depth, concentrations of total phosphorus and chlorophyll *a* in the water for the calculation.

Results

Species of Dinoflagellate Associations

In Feitsui Reservoir, three species of dinoflagellates appeared during the period of this study. They were identified as *Ceratium furcoides* (Levander) Langhans, *Peridinium bipes* Stein, and *P. umbonatum* Stein var. *umbonatum* (= *P. inconspicuum* Lemmermann) according to Huber-Pestalozzi (1968) and Popovský and Pfiester (1990) (see Figure 1). These species also occur in great numbers of other water reservoirs in Taiwan.

The abundance of these species in the Feitsui Reservoir is quite different. *Peridinium bipes* is the most abundant species with a maximum density of 763 cells/ml recorded in December 1992 at sampling site S8. *Peridinium umbonatum* var. *umbonatum,* the smallest dinoflagellate in the same reservoir, rarely appears. A maximum density of only 170 cells/ml was recorded for this species in June 1994 at S1. *Ceratium furcoides* did not appear in large numbers either. A maximum density of only 75 cells/ml was recorded in October 1991 at S8.

Succession of Dominant Phytoplankton in the Reservoir

Dinoflagellates had been one of the dominant algae in phytoplankton assemblages of Feitsui reservoir, especially between the late summer and early winter of 1990. After 1991, nannoplanktonic cyanobacteria such as *Aphanocapsa delicatissima* and *Microcystis aeruginosa* dominated, particularly during the late spring and summer (Figure 5). Chlorophytes appeared as subdominant algae during the early spring and late summer. Cryptomonoids, such as *Cryptomonas erosa* and *Chroomonas caudata,* coincided with the occurrence of dinoflagellates.

Dinoflagellates were in the minority of phytoplankton assemblages, calculated in terms of cell numbers. However, they may be important due to their large cell volume. In November of 1990, for instance, dinoflagellates occupied a biomass of 19.6% in terms of phytoplankton cell numbers, but up to 95.7% in terms of cell volume.

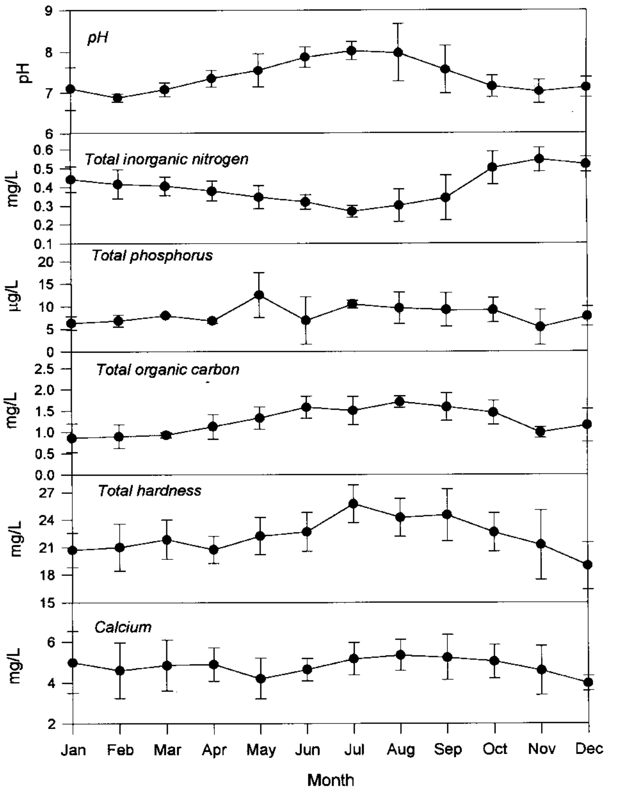

Figure 4. Fluctuation in the monthly averages of pH, concentrations of total inorganic nitrogen, total phosphorus, total organic carbon, calcium and total hardness in surface water of Feitsui Reservoir during the time of this study.

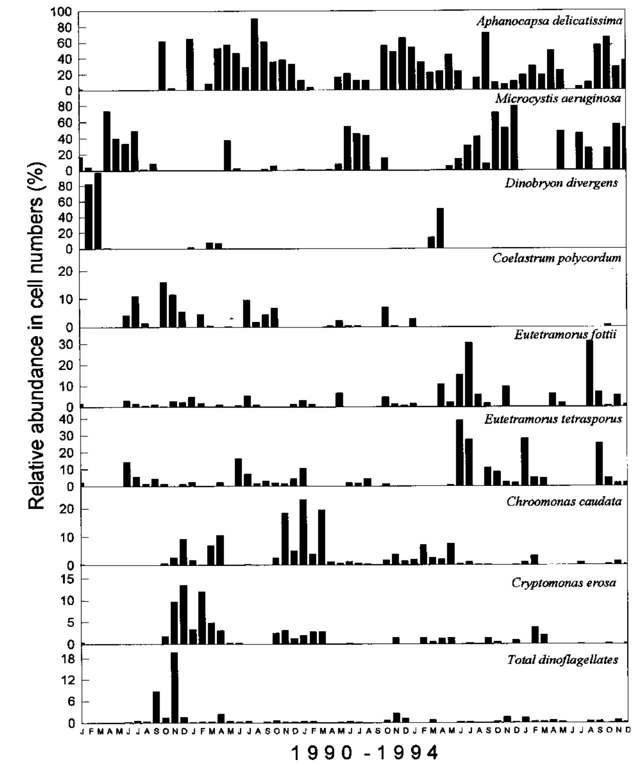

Figure 5. Succession of dominant phytoplankton species at sampling site S1 of Feitsui Reservoir during 1990–1994.

Distribution of Dinoflagellates in the Reservoir

The dinoflagellates were not evenly distributed at the sampling sites. The density of *Peridinium* cells, including *P. bipes* and *P. umbonatum* var. *umbonatum*, was higher near the stream inlet, i.e. S8 (Figure 6). It declined from S8 to S1, demonstrating a gradient in the horizontal distribution. A similar distribution pattern was also observed for *C. furcoides,* except that in certain months the cell density at S1 was slightly higher than that at S2 (cf. Figure 7).

The majority of dinoflagellates were distributed near the surface layer. The analysis done in December 1992 showed that over 95% of *P. bipes* as well as *C. furcoides* were concentrated between 3–15 m in depth. At that time, isothermic conditions occurred at a depth of 5–40 m, while water transparency (i.e. Secchi depth) of 5.2 m with a eu-

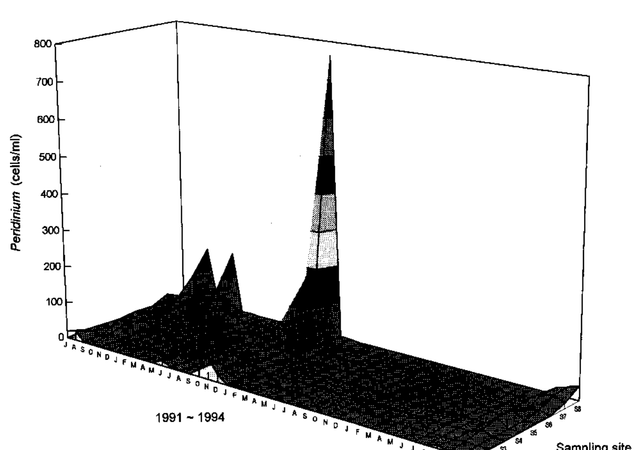

Figure 6. Temporal occurrence and spatial distribution of *Peridinium bipes* at different sampling sites of the Feitsui Reservoir during July 1991–December 1994.

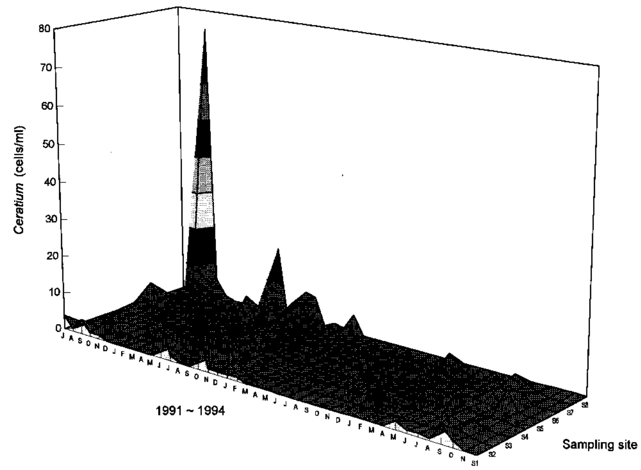

Figure 7. Temporal occurrence and spatial distribution of *Ceratium furcoides* at different sampling sites of the Feitsui Reservoir during July 1991–December 1994.

photic zone down to ca. 15 m was measured. Apparently, the vertical distribution of dinoflagellates coincided with light transparency rather than temperature.

Dinoflagellate Occurrence in Relation to Weather Conditions

The water transparency was lower in summer and autumn due to the outgrowth of phytoplankton, high runoff from the watershed, and monsoon rainfall (August – November). The wind speed was generally low, though it fluctuated to some degree in different seasons. The easterly winds dominated throughout the year. Occasionally, the wind direction was westsouthwest, especially during April–July. The distribution of dinoflagellates in this reservoir was thus not closely related to wind direction.

The occurrence of dinoflagellates exhibited a seasonal dependency. The peak of dinoflagellate density was found between late autumn and early winter for *C. furcoides* as well as *P. bipes,* and in early summer for *P. umbonatum* var. *umbonatum* (Figure 8). The highest density occurred at water temperatures between 24 and 26°C, when it was analyzed by regression (Figure 9). The increase in dinoflagellate abundance in autumn was related to the water level (Figure 10) . The algal peaks coincided well with the time of rapid elevation in water level, which was apparently a result of high runoff from the watershed due to monsoon rainfall.

Dinoflagellate Occurrence in Relation to Water Quality

The trophic state index evaluated by Carlson's model ranged between 37 and 46 (average 42 ± 3), indicating a mesotrophic state. Nevertheless, the water quality differed markedly from site to site, particularly in the values of chlorophyll *a*, BOD_5, total P, and soluble phosphate. The measured values of these parameters were higher in the area near the stream inlet (S8) and lower near the dam site (S1) (cf. Figure 11), exhibiting a gradient between S1 and S8. Other parameters such as bacterial number, COD, and the concentrations of nitrate, NH_4^+, TOC and calcium did not significantly exhibit such a gradient change.

The chemical environment of the surface waters fluctuated during the year (cf. Figure 4). The abundance of *Peridinium* cells was well correlated with the concentrations of chlorophyll *a*, BOD_5, soluble P, total P, nitrate, and bacterial numbers in the water, whereas that of *Ceratium* was well correlated with COD, TOC and calcium (Table 1). The occurrence of both the *Peridinium* and *Ceratium* was not correlated well with N-sources such as ammonium or nitrate, suggesting that N-nutrient plays a less important role in triggering the outgrowth of dinoflagellates in this water reservoir.

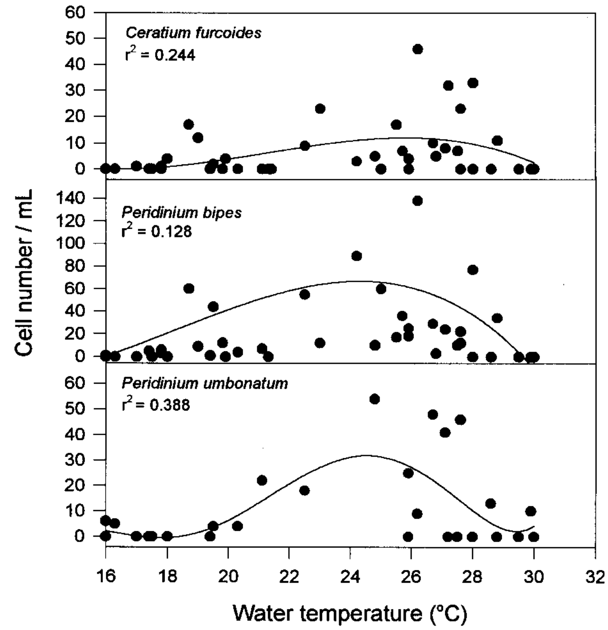

Figure 9. Relation of the cell densities of *Ceratium furcoides, Peridinium bipes*, and *P. umbonatum* var. *umbonatum* in Feitsui Reservoir to water temperature.

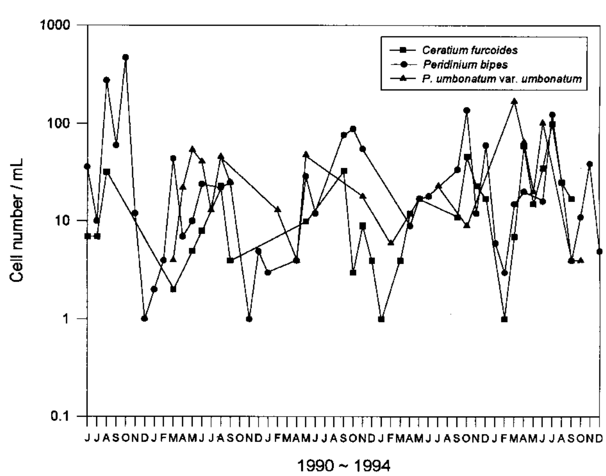

Figure 8. Temporal occurrence of *Ceratium furcoides, Peridinium bipes*, and *P. umbonatum* var. *umbonatum* in Feitsui Reservoir.

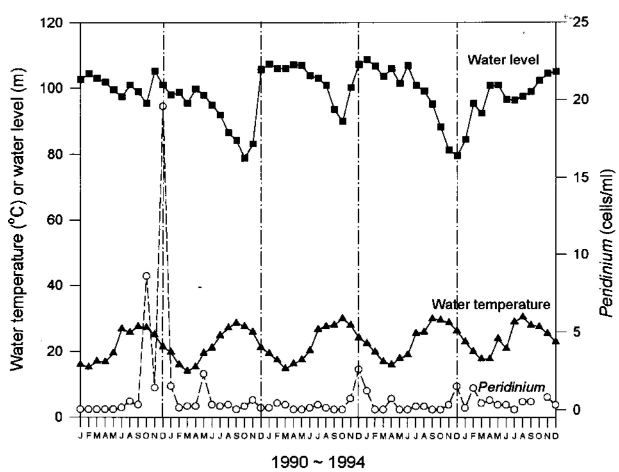

Figure 10. Temporal occurrence of *Peridinium bipes* in relation to water temperature and water level.

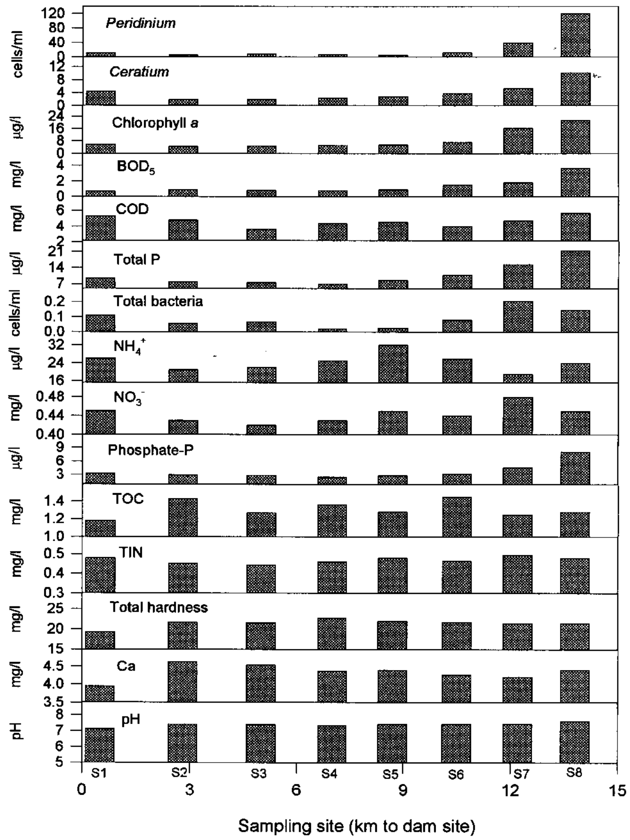

Figure 11. Variations in the average cell density of *Peridinium* and *Ceratium* at eight sampling sites in Feitsui Reservoir with respect to the concentration of various chemical parameters of waters measured during July 1991–December 1994. BOD_5 and COD are biochemical and chemical oxygen demand, respectively. The sampling sites are plotted against their relative distance to dam site.

The concentration of N- and P-nutrient in the water exhibited a periodic fluctuation during the period of this study (Figure 12A & B). A drastic increase in the concentration of total inorganic nitrogen (TIN) was observed between late summer and autumn in every year, which matched well with the time of elevated water level due to monsoon rainfalls (cf. Figure 10). The level of TIN in the water increased from year to year, indicating an increase in N-loading in the reservoir. In contrast to TIN, the level of P in the water did not increase with time, even though it also exhibited a seasonal fluctuation. Owing to a continuous increase in TIN, values of the N/P ratio rose (Figure 12C).

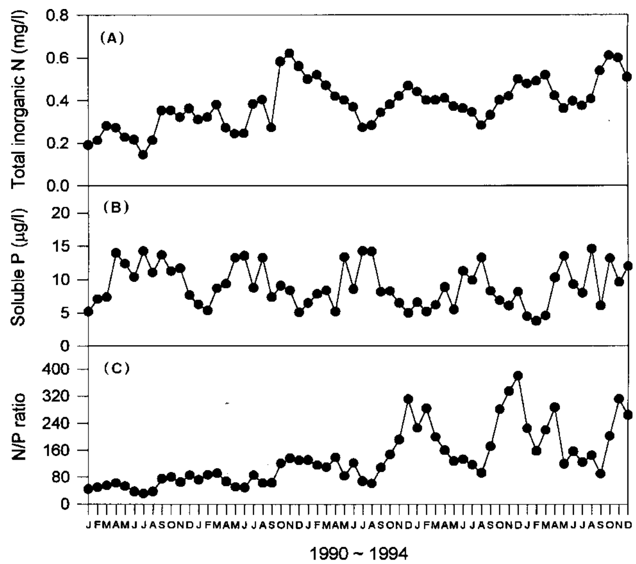

Figure 12. Fluctuation in the concentrations of total inorganic nitrogen (A), soluble phosphorus (B) and the values of N/P ratio (C) in Feitsui Reservoir during 1990–1994.

Table 1. Correlation coefficients between the cell densities of *Peridinium* (includes *P. bipes* and *P. umbonatum* var. *umbonatum*) and *Ceratium furcoides* and the physicochemical parameters of the water in Feitsui Reservoir.

	Chl.*a**	BOD_5*	COD*	TP*	TB*	NH_4^+-N	NO_3^--N	PO_4^{3-}	TOC*	N/P*	Ca	*Peridinium*
BOD_5*	0.94	1										
COD*	0.60	0.56	1									
TP*	0.98	0.96	0.63	1								
TB*	0.79	0.60	0.45	0.77	1							
NH_4^+-N	-0.31	-0.19	0.01	-0.23	-0.57	1						
NO_3^--N	0.62	0.39	0.47	0.59	0.77	-0.10	1					
PO_4^{3-}	0.95	0.97	0.69	0.97	0.66	-0.22	0.42	1				
TOC*	-0.27	-0.06	-0.38	-0.23	-0.42	-0.06	-0.44	-0.25	1			
N/P*	-0.62	-0.60	-0.76	-0.62	-0.49	0.40	-0.15	-0.73	0.28	1		
Ca	-0.12	0.05	-0.33	-0.15	-0.42	-0.18	-0.57	-0.04	0.55	0.20	1	
Peridinium	0.92	0.97	0.65	0.94	0.56	-0.17	0.32	0.99	-0.20	-0.72	0.04	1
Ceratium	0.18	0.14	0.68	0.26	0.33	0.11	0.22	0.31	-0.60	-0.61	-0.71	0.27

*Chl.*a*: chlorophyll *a*; BOD_5: 5-days biochemical oxygen demand; COD: chemical oxygen demand; TP: total phosphorus; TB: total bacterial number; TOC: total organic carbon; N/P: ratio of total inorganic N to soluble P.

Discussion

A variety of environmental factors are related to the outgrowth of dinoflagellates in the aquatic environment (Horne et al., 1971; Herrgesell et al., 1976; Watanabe and Shiraishi, 1983; Watanabe and Takada, 1983; Lindström, 1991). Wind, radiation, water temperature, and precipitation are the most important physical factors affecting the distribution of dinoflagellates in the reservoirs. In Feitsui Reservoir, the amount of precipitation strongly regulated the outgrowth of dinoflagellates. The peaks of the dinoflagellate numbers corresponded well with rapid elevation of the water level due to the monsoon rainfall. Such rainfall causes high runoff from the watershed, particularly from the village and mountains over the riverine region (i.e. S8), where a great part of the mountain slopes have been deforested for tea plants. The discharge from the village and the runoff from the watershed over S8 carried a variety of pollutants including inorganic and organic nutrients. The correlation analysis indicates that the density of dinoflagellates is closely correlated with the concentrations of ammonium, BOD_5, TOC, TP, and bacterial numbers in waters. Furthermore, the temporal and spatial distributions of dinoflagellates in the reservoir also clearly demonstrate the close correlation between the outgrowth of dinoflagellates and the runoff from watershed. These suggest that the outgrowth of dinoflagellates is a consequence of water pollution and that dinoflagellates exhibit some degree of heterotrophy in growth, as reported by other authors (Carefoot, 1968; Lindström, 1985; Gaines and Elbraechter, 1987).

In Feitsui Reservoir, P has been ascertained to be a limiting nutrient for the growth of phytoplankton (Huang, 1992). This may be why the variation in dinoflagellate density at sampling sites is closely related to the concentration of P in the water. In competition for resources, dinoflagellates are at a disadvantage against nannoplankton such as cyanobacteria or green algae (Berman and Dubinsky, 1985). In Lake Kinneret and in cultures, *Peridinium* prefers ammonium over nitrate (McCarthy et al., 1982). However, its affinity for ammonium, as well as for phosphorus, is much lower than that of nannoplankton, showing a disadvantage in exploiting these nutrients. In Feitsui Reservoir, the N-loading increased during the study. This favors the growth of nannoplankton rather than dinoflagellates. It can thus be the reason for prevalence of cyanobacteria and green algae over dinoflagellates after 1991, when the N-loading was elevated. In view of this, the possibility of developing dinoflagellate bloom in this reservoir will be low in the future, as long as the input of N-nutrients remains high.

Working with cultures, Ueda (1983) and Lindstrom (1983) found that the outgrowth of *P. bipes* and *P. cinctum* was related more to the concentration of Ca than to other nutrient ions. Nevertheless, the present study shows that the abundance of *P. bipes* in the Feitsui reservoir does not correlate well with the concentration of Ca. In Feitsui Reservoir, the concentration of Ca, averaging 4.82 ± 0.72 mg/l, is higher than that usually used in culture medium for optimum growth of dinoflagellates. Presumably, the content of Ca in Feitsui reservoir is sufficient for the best growth of this alga, so that the variation in Ca concentration does not relate to the abundance of dinoflagellates in the reservoir.

Different species of dinoflagellates have different environmental requirements for growth, e.g. vitamins and other nutrients (Bruno and McLaughlin, 1977; Holt and Pfiester, 1981). Lindström (1983) showed that micronutrients such as Se are related to the growth and distribution of dinoflagellates in lakes. In Feitsui Reservoir, the abundance of *Peridinium* and *Ceratium* are differently correlated with the parameters of their chemical environments. However, there are no data available showing that such a difference is related to Se or any particular nutrient except P. Apparently, the role of micronutrients in regulating the distributional and developmental patterns of the dinoflagellates in Feitsui reservoir is worthy of further study.

Dinoflagellates are known to perform diel vertical migration in response to the change in light, temperature, and nutrients (Harris et al., 1979; Heaney and Eppley, 1981). The vertical distribution of dinoflagellates in Feitsui Reservoir seems to be influenced more by light than by temperature conditions, because dinoflagellates are distributed in the euphotic zone rather than the isothermal layer. The effect of nutrients on the vertical distribution of dinoflagellates in Feitsui Reservoir is unknown. A further study is necessary in order to elucidate the role of nutrients.

Acknowledgements. The Feitsui Reservoir Administration (FRA) is acknowledged for its financial support of this study. The authors highly appreciate the provision of water quality data from the Taipei Water Works and the FRA. The authors also acknowledge the assistance of Misses Su-Huei Wan, Su-Lan Ou, and Mei-Chi Lee in the analysis of phytoplankton assemblages.

Literature Cited

American Public Health Association (APHA), American Water Works Association and Water Pollution Control Federation. 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed. Washington D.C.

Berman, T. and Z. Dubinsky. 1985. The autecology of *Peridinium cinctum* fa. *westii* from Lake Kinneret. Verh. Internat. Verein. Limnol. **22:** 2850–2854.

Bruno, S.F. and J.J.A. McLaughlin. 1977. The nutrition of the freshwater dinoflagellate *Ceratium hirundinella*. J. Protozool. **24:** 548–553.

Carefoot, J.R. 1968. Culture and heterotrophy of the freshwater dinoflagellate, *Peridinium cinctum* fa. *ovoplanum* Lindeman. J. Phycol. **4:** 129–131.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. **22:** 361–369.

Gaines, G. and M. Elbraechter. 1987. Heterotrophic nutrition. *In* F.J.R. Taylor (ed.), The Biology of Dinoflagellates. Bot. Monogr. 21, Blackwell Sci. Publ., Oxford, pp. 224–268.

Harris, G.P., S.I. Heaney, and J.F. Tailling. 1979. Physiological and environmental constraints in the ecology of the planktonic dinoflagellate *Ceratium hirundinella*. Freshwat. Biol. **9:** 413–428.

Heaney, S.I. and R.W. Eppley. 1981. Light, temperature and nitrogen as interacting factors affecting diel vertical migrations of dinoflagellates in culture. J. Plankton Res. **3:** 331–344.

Herrgesell, P.L., T.H. Sibley, and A.W. Knight. 1976. Some observations on dinoflagellate population density during a bloom in a California reservoir. Limnol. Oceanogr. **21:** 619–624.

Holt, J.R. and L.A. Pfiester. 1981. A survey of auxotrophy in five freshwater dinoflagellates (Pyrrhophyta). J. Phycol. **17:** 415–416.

Horne, A.J., P. Javornicky, and C.R. Goldman. 1971. A freshwater "red tide" on Clear lake, California. Limnol. Oceanogr. **16:** 684–689.

Huang, C.H. 1992. Environmental factors affecting the outgrowth of *Microcystis aeruginosa* in the reservoir. Master thesis, Natl. Taiwan Univ., Taiwan, pp. 46.

Huber-Pestalozzi, G. 1968. Das Phytoplankton des Susswassers. 3. Teil. W. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Lindström, K. 1983. Selenium as a growth factor for plankton algae in laboratory experiments and in some Swedish lakes. Hydrobiologia **101:** 325–328.

Lindström, K. 1985. Selenium requirement of the dinoflagellate *Peridiniopsis borgei* (Lemm). Int. Rev. Ges. Hydrobiol. **70:** 77–85.

Lindström, K. 1991. Nutrient requirements of the dinoflagellate *Peridinium gatunense*. J. Phycol. **27:** 207–219.

Lindström, K. 1992. *Ceratium* in Lake Erken: vertical distribution, migration and form variation. Nord. J. Bot. **12:** 541–556.

McCarthy, J.J., D. Wynne, and T. Berman. 1982. The uptake of dissolved nitrogenous nutrients by Lake Kinneret (Israel) microplankton. Limnol. Oceanogr. **27:** 673–680.

Olrik, K. 1992. Ecology of *Peridinium willei* and *P. volzii* (Dinophyceae) in Danish lakes. Nord. J. Bot. **12:** 557–568.

Pollingher, U. 1988. Freshwater armored dinoflagellates: growth, reproduction strategies, and population dynamics. *In* C.D. Sandgren (ed.), Growth and Reproductive Strategies of Freshwater Phytoplankton. Cambridge Univ. Press, Cambridge, pp. 134–174.

Pollingher, U. and C. Serruya. 1976. Phased division of *Peridinium cinctum* fa. *westii* and the development of the bloom in Lake Kinneret (Israel). J. Phycol. **12:** 162–170.

Popovský, J. and L.A. Pfiester. 1990. Dinophyceae (Dinoflagellida). Susswasserflora von Mitteleuropa vol. 6. Gustav Fischer Verlag, Jena, Stuttgart.

Rai, H. 1980. The measurement of photosynthetic pigments in fresh waters and standarization of methods. Erg. Limnol. **14:** 1–106.

Sournia, A. 1978. Phytoplankton manual. UNESCO, Paris, pp. 108–112.

Ueda, K. 1983. Effect of calcium, phosphate, and magnesium on the growth of *Peridinium bipes*. Res. Rep. Environ. Biol. Nara Women's Univ. **1:** 1–4.

Watanabe, T. and H. Shiraishi. 1983. Outbreak mechanism of freshwater red tide caused by the abundant occurrence of *Peridinium bipes* f. *occulatum* in Kazaya Reservoir. Res. Rep. Environ. Biol. Nara Women's Univ. **1:** 5–8.

Watanabe, T. and M. Takada. 1983. Outbreak mechanism of freshwater red tide caused by the abundant occurrence of *Peridinium cinctum* f. *westii* in Kazaya Reservoir. Res. Rep. Environ. Biol. Nara Women's Univ. **1:** 9–14.

Wu, J.T. 1987. Revision of Formosan *Pediastrum*. Nov. Hedwig. **44:** 497–508.