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SHANNON's diversity index applied to some freshwater diatom assemblages in the Sakawa River System (Kanagawa Pref., Japan) and its use as an indicator of water quality

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The reliability of SHANNON's diversity index as an indicator of water quality was evaluated using samples of benthic diatom assemblages collected from the Sakawa River System (Kanagawa Prefecture, Japan). The accuracy of SHANNON's index was determined in correlation with the diversity values obtained and the saprobic index calculated by using KOBAYASI and MAYAMA's grouping of river diatoms and the formula of PANTLE and BUCK. The results indicated that diatom assemblages growing in clean waters had diversity values lower than those of moderately polluted conditions and critically polluted ones, therefore, diversity in itself did not accurately coincide with water quality. Some taxonomical and ecological comments for each one of the diatom taxa identified are given.

Key Index Words: diatom assemblage—saprobic index—Shannon's diversity index—water quality.

In order to estimate the degree of water pollution using freshwater communities, especially diatoms, many diversity indices have been applied. However, mutual agreement among investigators seems to be incomplete on the following two important points: (1) Which index is more appropriate to measure the diversity of the community? (2) Can the diversity indices be used as an indicator of water quality?

As to the first question, MARGALEF (1974) and PIELOU (1975) have pointed out that an adequate diversity index must take account of some statistical requisites such as independence of the size of the sample and sampling techniques (e.g. random selection, stratified, etc.). Furthermore, the ecological point of view has to be also considered because the diversity depends not only on the numbers of the species (richness) and the number of individuals but also on the evenness (the property of a community that relates to the relative frequency of the species). Thus, the diversity is the result of the interaction between these basal indicators of the community structure. For this reason, according to PIELOU (1966), the indices belonging to the information theories such as SHANNON are adequate and the diversity value of the population, when the material is taken from a sample, should be better estimated using SHANNON's diversity index.

As to the second question, the problem has been discussed by some authors (e.g. ARCHIBALD 1972, HENDEY 1977), however, their conclusions are not in agreement. For example, ARCHIBALD (1972) working with the sequential comparison index as a measure of diatom population diversity concluded that diversity was not a reliable estimate of water quality. On the contrary, HENDEY (1977) working with inshore diatom communities concluded that SHANNON's index provided a good indication of the impact of the environment upon the diatom community and he suggested a scale for diversity values ranging from 0 to 4 where 0–1 means severe pollution, 1–2 means moderate pollution, 2–3 means slight pollution and 3–4 means slight passing to negligible pollution.

Thus, the principal aim of this work is to test the reliability of SHANNON's diversity index as an indicator of water quality using freshwater diatom assemblages.

Materials and methods

On 28 August 1987, samples of benthic diatom assemblages were collected from Dotene Haisuiro (Dotene Drainage) (St. 1), Sakawa-gawa (Sakawa River) (St. 2), Kari-kawa (Kari River) (St. 3) and Ayu-sawa (Ayu River) (Sts. 4, 5) (Fig. 1). All rivers are located in Kanagawa Prefecture, south-eastern Central Japan.

For qualitative analyses, samples of attached diatoms were scraped off from stones more than 10 cm in diameter and fixed with formalin (KOBAYASI and MAYAMA 1982). The diatoms in these samples were cleaned with sulfuric acid and hydrochloric acid and mounted in Pleurax.

For quantitative analyses, samples were collected from 5 × 5 cm^2 quadrates established at random on flat surfaces of submerged stones more than 10 cm in diameter and cleaned in the same manner as described above. A minimum of 600 valves on each prepared slide were examined and all species encountered were identified and counted (KOBAYASI and MAYAMA 1982). When identification problems arose at the time of LM counting (e.g. for correct identification of *Nitzschia frustulum*, *N. hantzschiana* and *N. romana*), adjustment using SEM counting was made as described in LOBO *et al.* (1990).

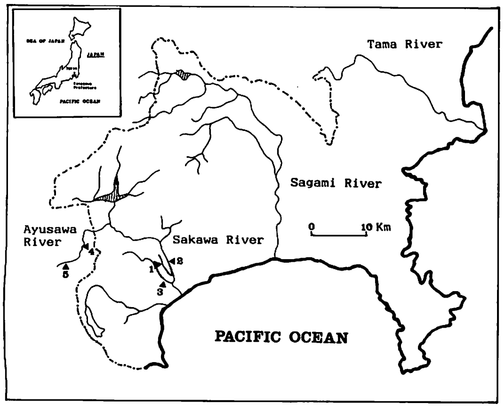

Fig. 1. Map of the study area showing the sampling stations. 1, Dotene Drainage; 2, Sakawa River; 3, Kari River; 4, downstream of the Ayusawa River; 5, upstream of the Ayusawa River.

The accuracy of SHANNON's index as an indicator of water quality was evaluated in correlation with the diversity values obtained and the saprobic indices calculated using KOBAYASI and MAYAMA's (1982) method. The method, using their grouping of species and PANTLE and BUCK's (1955) formula, is simple and easy and the results of applying this method to the Japanese river waters are in good agreement with chemical analyses (KOBAYASI and MAYAMA 1990). In the present work, the saprobic zone rating and the occurrence rating in PANTLE and BUCK's (1955) formula are replaced with the group rating (g) and the relative frequency (f%), after which the SI values of our sampling stations were calculated.

The chemical and bacteriological data of each sampling station from January 1986 to September 1987 measured by the technicians of the Kanagawa Water Supply Authority (Kanagawa Prefecture) were presented and discussed.

Results and discussion

The water quality estimation using the saprobic index indicates that the rivers examined can be rated into the following three pollution levels (Fig. 2): Level I, oligosaprobic conditions or clean water (St. 2); Level II, β-mesosaprobic conditions or moderately polluted water (Sts. 5, 4, 3); Level III, α-mesosaprobic conditions or critically polluted water (St. 1).

In addition, the chemical and bacteriological data (averages of BOD_5, total number of coliforms and conductivity) at these sampling stations are also given in Fig. 2. These data show an approximate correlation with the levels of pollution estimated by

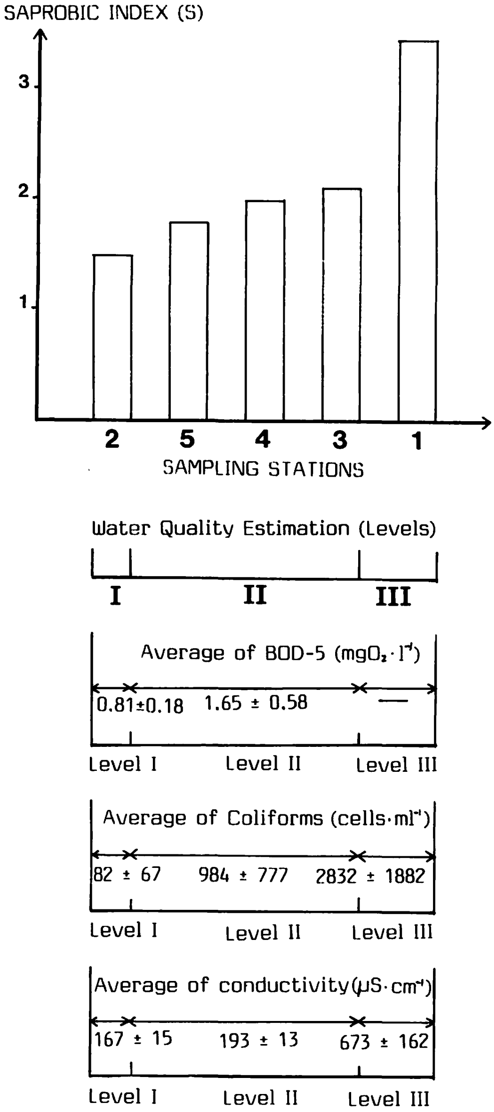

Fig. 2. Water quality estimation expressed by the saprobic index (S) using KOBAYASI and MAYAMA's (1990) grouping of river diatoms and PANTLE and BUCK's (1955) formula. Level I, oligosaprobic; Level II, β-mesosaprobic; Level III, α-mesosaprobic. For each level of saprobity, the average values of BOD_5, total number of coliforms and conductivity are given. No datum for BOD_5 at Station 1 is available.

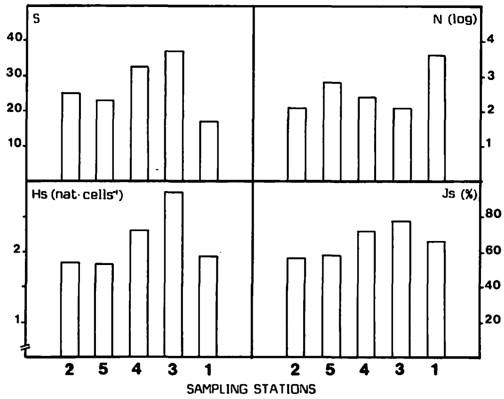

Fig. 3. Diversity indices computed. S, richness of the species; N, total cell number; Hs, SHANNON's diversity index; Js, evenness index. The stations arrangement is in agreement with in Fig. 2.

KOBAYASI and MAYAMA's (1990) method. The average of BOD_5 estimated at Stations 2, 5, 4 and 3 was less than 2.0 $mgO_2 \cdot l^{-1}$ and the sampling points can be rated to be oligosaprobic according to SLÁDEČEK (1973). On the other hand, the average total number of coliforms at Station 2 was 82 cells·ml^{-1} and the average at Stations belonging to Level II was 984 cells·ml^{-1}. These values indicate oligosaprobic conditions in the former and β-mesosaprobic ones in the latter. The average number of coliforms at Station 1 was 2,832 cells·ml^{-1} and indicates polysaprobic conditions. Regarding the conductivity, the average value at Station 1 can be connected with polysaprobic conditions and the values at Stations 2, 5, 4 and 3 can be connected with β-mesosaprobic conditions according to MAYAMA and KOBAYASI (1984). From all the data commented on above, it can be assumed that Station 1 is α-mesosaprobic, Stations 5, 4 and 3 are β-mesosaprobic and Station 2 is oligosaprobic.

As pointed out by HENDEY (1977), in order to use SHANNON's index as a measure of water quality, it should be expected that diversity values decrease significantly from oligosaprobic to polysaprobic conditions. However, as seen in Fig. 3, the Hs value (SHANNON's diversity index) of the clean water (St. 2) was lower than those of the moderately polluted waters (Sts. 4, 3) and the critically polluted one (St. 1). These results did not follow the principle established by HENDEY (1977).

The reason why the Hs value at Station 2 was lower than those of the other stations must be considered. Regarding the other indicators of the community structure, the number of individuals (N in Fig. 3) did not show significant differences between the diatom assemblages of Levels I and II, however, the relative frequency of the species was clearly different as seen in Table 1. The community at Station 2 had fewer species than those of Stations 4 and 3 and was dominated by one taxon. As shown in Fig. 4, *Nitzschia frustulum* which is classified as a member of the pollution-sensitive Group C of Kobayasi and Mayama (1990) when occurring in freshwater was dominant, being 53.8% of the relative frequency, and consequently the diversity value becomes lower.

The Hs value at Station 5 was lowest but it was classified in Level II. This situation can be explained also based on the dominant species. *Nitzschia hantzschiana* occupied 50.5% of the relative frequency and this species is classified in the less pollution-tolerant Group B of Kobayasi and Mayama (1990), though this species is treated as exceptional because it was an intermediate value between sensitive and less pollution-tolerant when occurring in freshwater. For this reason, Station 5 was classified to be a moderately polluted one (β-mesosaprobic conditions) and the high percentage occurrence of *N. hantzschiana* made the value of the diversity index of diatom assemblage lower.

In the case of Stations 4 and 3, the diatom communities showed the highest values of evenness (Js in Fig. 3), i.e. the relative frequency of each species was more homogeneous than those in the communities of Levels I and III. *Nitzschia amphibia* was dominant, 23.6%, at Station 3 and *N. hantzschiana* was dominant, 20.6%, at Station 4, however, no species was exceptionally dominant over any other and consequently the Hs values of these assemblages became higher.

As the environmental conditions become worse, the number of species decreases, the sensitive species are progressively eliminated, and finally only a few of the most tolerant species remain usually in great number. This situation is illustrated at Station 1 (α-

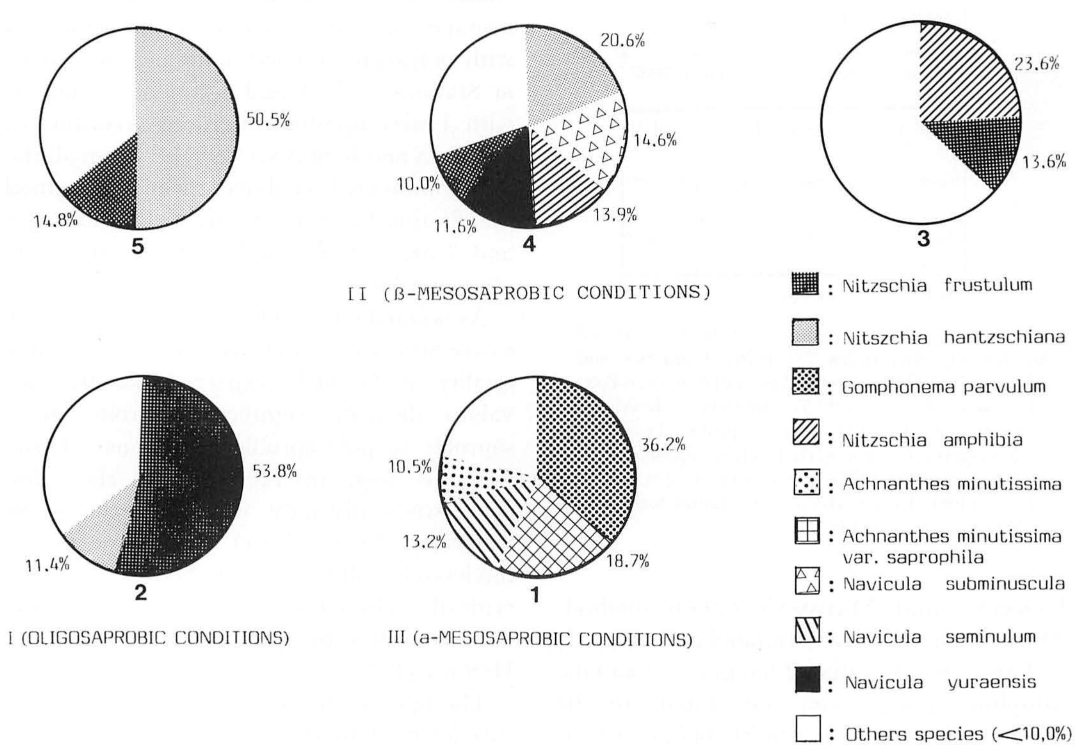

Fig. 4. Relative frequency of each species at each station.

Table 1. Relative frequencies (%) of each taxon in each sample collected from Dotene Drainage (St. 1), Sakawa River (St. 2), Kari River (St. 3) and Ayusawa River (St. 4, downstream; St. 5, upstream). g=group rating of each taxon.

Diatoms observed	g	Relative frequencies (%)				
		St. 1	St. 2	St. 3	St. 4	St. 5
Achnanthes convergens	1		0.3	0.3		
A. exigua	2.5	2.7		2.3		
A. lanceolata	1		0.3	1.8		
A. minutissima	1	10.5	4.7	3.2	1.1	5.2
A. minutissima v. *saprophila*	4	18.7				1.0
A. rostrata	1			0.3		
A. subhudsonis	1		0.3	0.3		
A. sp.	1			0.2		
Amphora veneta	1				0.2	
Anomoeoneis vitrea	1		0.3			
Asterionella formosa	1		0.9	0.3		
Bacillaria paradoxa	2.5			0.7		
Cocconeis placentula	1	0.1	2.2	4.7	0.9	1.6
Cyclotella comta v. *affinis*	1	0.3				
C. meneghiniana	2.5		0.6	0.3	0.2	
Cymbella sinuata	1		0.9	1.1	0.4	0.4
C. tumida	1				1.0	
Diatoma vulgare	1	0.1				0.2
Fragilaria brevistriata	2.5			6.5	1.8	0.2
F. capucina	1			0.2		
F. capucina v. *vaucheriae*	2.5		0.2			
F. construens	2.5	0.1		0.7	0.1	0.2
F. construens v. *subsalina*	1			0.3		
F. elliptica	2.5	0.2			0.2	
F. pinnata	2.5			6.4	1.1	
Gomphonema parvulum	4	36.2	4.3	1.4	2.0	1.9
G. gracile	1	0.4				
Navicula atomus	4				1.8	0.2
N. confervacea	2.5			1.4		
N. constans v. *symmetrica*	1			0.3		
N. cryptocephala	1			0.9		
N. cryptotenella	1			0.3	0.4	
N. goeppertiana	3.25	0.2		0.7	0.4	0.2
N. gregaria	2.5		0.5	2.6	2.7	0.6
N. minima	4	3.3	2.9	1.6	0.2	23.3
N. pupula	2.5			0.7		
N. seminulum	4	13.2	1.9	3.8	1.1	0.9
N. schoenfeldii	1	0.2				
N. subminuscula	2.5	8.9	2.0		14.6	1.3
N. tridentula	1				0.2	
N. trivialis	2.5		0.3			
N. veneta	3.25		0.2		0.2	
N. viridula v. *rostellata*	1			0.6		
v. *rostrata*	1		0.3	0.9	0.7	
N. yuraensis	1		0.3	1.8	11.6	
Nitzschia amphibia	2.5	1.6	3.0	23.6	13.9	8.9
N. frustulum	1		53.8	13.6	10.0	14.8
N. hantzschiana	1.75		11.4	7.5	20.6	50.5
N. palea	4	3.2	0.9	5.0	5.3	2.5
N. paleacea	2.5				2.3	1.1
N. romana	1		7.0	2.3	2.7	
Pinnularia burckii	1			0.2		
P. subcapitata	2.5			0.7	0.2	
Rhoicosphenia abbreviata	1				1.4	4.9
Stephanodiscus minutulus	1				0.2	0.4
Stauroneis japonica	1					0.4
Synedra ulna	2.5				0.2	
S. ungeriana	1			0.5		

mesosaprobic) where the total number of species was lowest (Fig. 3) and *Gomphonema parvulum*, classified as one of the most pollution-tolerant taxa (Group A) in KOBAYASI and MAYAMA (1990), was the dominant species, being 36.2% in relative frequency (Table 1, Fig. 4). Thus, in polysaprobic conditions, the diversity of the diatom assemblages will always be low.

The results indicate that diatom assemblages growing in clean waters (Station 2, oligosaprobic) can have a low diversity value, especially when the environmental conditions favor the development of the particular sensitive taxa. This is not impossible. Thus, the diversity itself, using SHANNON's index, did not permit accurate differentiation of the levels of pollution and therefore cannot be used alone as an indicator of water quality. However, in order to get a complete description of the diatom assemblages as an indicator of water pollution, we suggest the inclusion of the diversity component as a useful element of the biological indicator systems because the structure of the community will be better understood.

The qualitative analyses of the diatom samples collected from the rivers examined indicate a total of 58 taxa belonging to 18 genera (Table 1). The taxa identified are given below in alphabetical order together with some comments on their dimensions, structure and ecology. The references following each of the listed taxa in parentheses are those used for their identification. Reference citations are in accordance with the guide attached to the ICBN (STAFLEU *et al.* 1972).

1. *Achnanthes convergens* H. Kob. (KOBAYASI *et al.* 1986. 4. *f. 1-17, 37-43, 51-54*). (Figs. 5, 6)

The specimens observed in the area are rather small but their identity was confirmed by SEM.

2. *Achnanthes exigua* Grun. var. *exigua* (SCHOEMAN and ASHTON 1982. 84, 86. *f. 1-8, 75-79, 105-110*). (Figs. 7, 8)

Though this species is extremely variable in valve shape and striation density, SCHOEMAN and ASHTON (*l. c.*) examined Kutzing's type material from Lake Taearigua, Trinidad and other materials, and synonymized var. *constricta* and var. *heterovalvata* with the nominate variety.

3. *Achnanthes lanceolata* (Breb.) Grun. var. *lanceolata* (MOSS and CARTER 1982. 160, 161. *pl. 1. f. 1, 2, 8-15*).

Specimens with cavum are separated from this taxon under the name of *A. rostrata* Oestr.

4. *Achnanthes minutissima* Kuetz. var. *minutissima* (LANGE-BERTALOT and RUPPEL 1980. 18. *f. 74-112, 126-132, 218-304*). (Figs. 9-12, 37, 38)
5. *Achnanthes minutissima* var. *saprophila* H. Kob. & Mayama (KOBAYASI and MAYAMA 1982. 195. f. 2a-h). (Figs. 9-12, 37, 38)

In contrast to the distribution of the nominate variety, this variety was found only in heavily to excessively polluted waters in Japan.

6. *Achnanthes rostrata* Oestr. (MOSS and CARTER 1982. 160. *pl. 1. f. 3-7, 16-25*).

This taxon has long been considered by many authors to be a variety of *A. lanceolata*, however, it was clearly distinguished by Moss and CARTER (*l. c.*) in their detailed examination of the type material. The araphid valve has a central cavum on one side.

7. *Achnanthes subhudsonis* Hust. var. *subhudsonis* (SIMONSEN 1987. 54. *pl. 68. f. 1-9*).

Specimens observed in the area are rather smaller than those in the lectotype slide, photographed by SIMONSEN (*l. c.*).

8. *Achnanthes* sp.

This species resembles *A. minutissima*, however, observations using SEM showed

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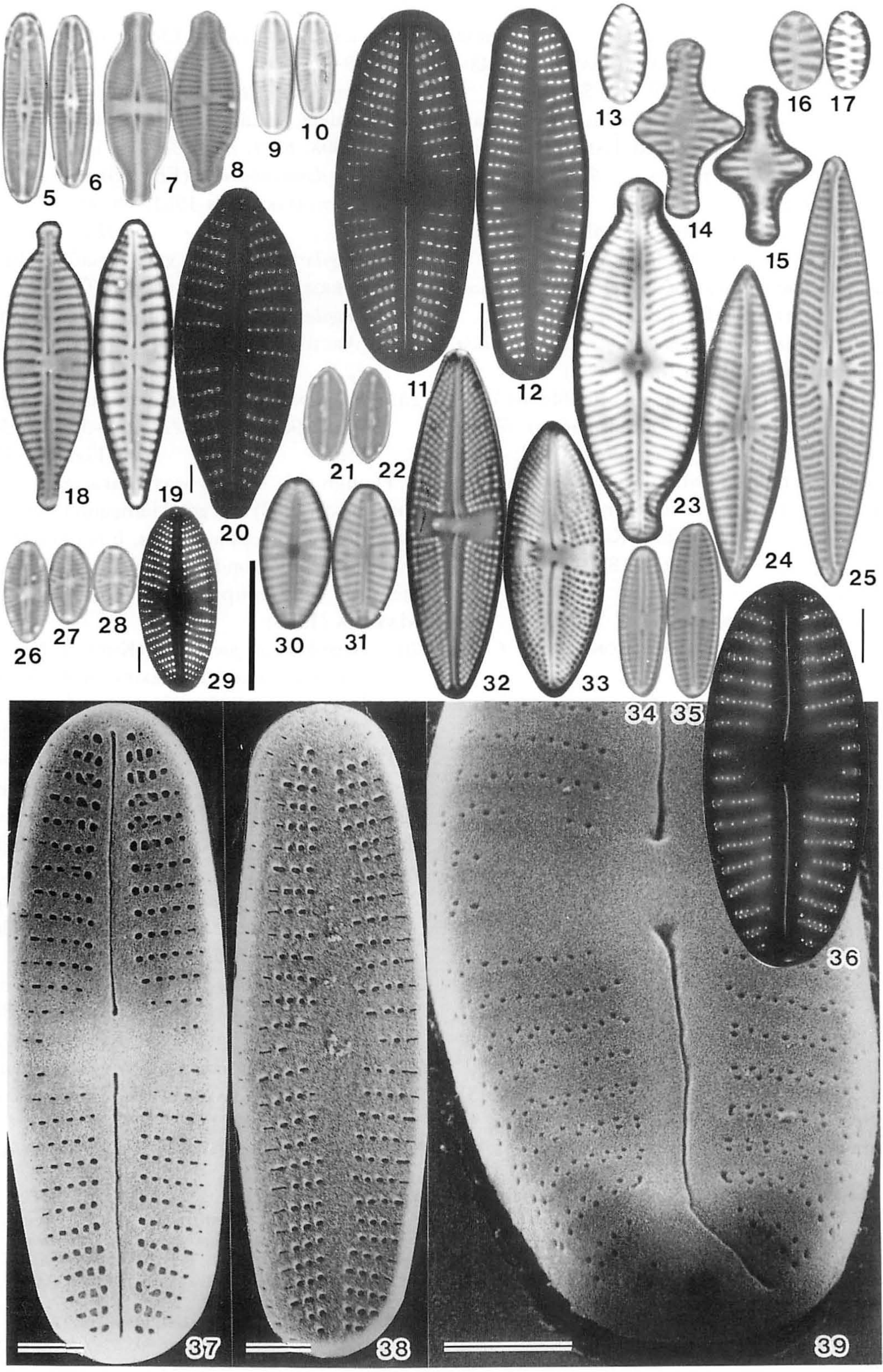
Plate 1. × 2,000 unless otherwise noted (broad bar = 10 μm, narrow bar = 1 μm). Figs. 5, 6. *Achnanthes convergens*. Figs. 7, 8. *A. exigua*. Figs. 9–12, 37, 38. *A. minutissima* var. *saprophila* (11, 12. TEM × 6,000; 37, 38. Exterior RV and AV, SEM × 10,000). Fig. 13. *Fragilaria brevistriata*. Figs. 14, 15. *F. construens*. Figs. 16, 17. *F. pinnata*. Figs. 18–20. *Gomphonema parvulum* (20. TEM × 4,000). Figs. 21, 22. *Navicula atomus*. Fig. 23. *N. constans* var. *symmetrica*. Figs. 24, 25. *N. cryptotenella*. Figs. 26–29. *N. minima* (29. TEM × 4,000). Figs. 30, 31. *N. schoenfeldii*. Figs. 32, 33. *N. goeppertiana*. Figs. 34–36, 39. *N. seminulum* (36. TEM × 8,000; 39. External valve, SEM × 20,000).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that these two species were not conspecific.

9. *Amphora veneta* Kuetz. var. *veneta* (SCHOEMAN and ARCHIBALD 1976-80. no. 4. *f. 1-34*, 1979. no. 5. *f. 1-38*).
10. *Anomoeoneis vitrea* (Grun.) Ross var. *vitrea* (KRAMMER and LANGE-BERTALOT 1986. 256 *f. 15/6, 94/21-28, 30, 103a/14*).
11. *Asterionella formosa* Hassal var. *formosa* (HUSTEDT 1930. 146. *f. 755*).
12. *Bacillaria paradoxa* Gmel. var. *paradoxa* (HUSTEDT 1930. 189. *f. 755*).
13. *Cocconeis placentula* Ehr. var. *placentula* (HUSTEDT 1930. 189. *f. 260*).

In the area, specimens identifiable not only as the nominate variety but also as var. *lineata* (Ehr.) V. H., var. *pseudolineata* Geitl. were found, but their variation was continuous and these were counted altogether as one taxon.

14. *Cyclotella comta* (Ehr.) Kuetz. var. *affinis* Grun. (VAN HEURCK 1880-83. *pl. 93. f. 11-13*).
15. *Cyclotella meneghiniana* Kuetz. var. *meneghiniana* (HÅKANSSON 1981. *f. 7-8, 11-13, 16*).
16. *Cymbella sinuata* Greg. var. *sinuata* (KRAMMER and LANGE-BERTALOT 1986. 341. *f. 148/10-17*).
17. *Cymbella tumida* (Breb.) V. Heurck var. *tumida* (KRAMMER and LANGE-BERTALOT 1986. 318. *f. 130/4-6*).
18. *Diatoma vulgare* Bory var. *vulgare* (WILLIAMS 1985. 75. *pl. 1. f. 1-9; pl. 6. f. 58-63; pl. 7. f. 64-70*).

Specimens found are identical with those in the lectotype slide presented by WILLIAMS (*l. c.*).

19. *Fragilaria brevistriata* Grun. var. *brevistriata* (GERMAIN 1981. 68. *pl. 20. f. 22-31*). (Fig. 13)

Specimens in the area are small, being 4-7 μm in valve length.

20. *Fragilaria capucina* Desml. var. *capucina* (LANGE-BERTALOT 1980a. 747. *pl. 2. f. 39-41*).
21. *Fragilaria capucina* var. *vaucheriae* (Kuetz.) Lange-B. (LANGE-BERTALOT 1980a. *pl. 1. f. 26-34*).
22. *Fragilaria construens* (Ehr.) Grun. var. *construens* (GERMAIN 1981. 68. *pl. 21. f. 1-19*). (Figs. 14, 15)
23. *Fragilaria construens* var. *subsalina* Hust. (GERMAIN 1981. 69. *pl. 21. f. 40-43)*
24. *Fragilaria elliptica* Schum. var. *elliptica* (ARCHIBALD 1983. 104. *f. 199-206, 519-522*).
25. *Fragilaria pinnata* Ehr. var. *pinnata* (GERMAIN 1981. 72. *pl. 21. f. 44-52; pl. 156. f. 8*). (Figs. 16, 17)

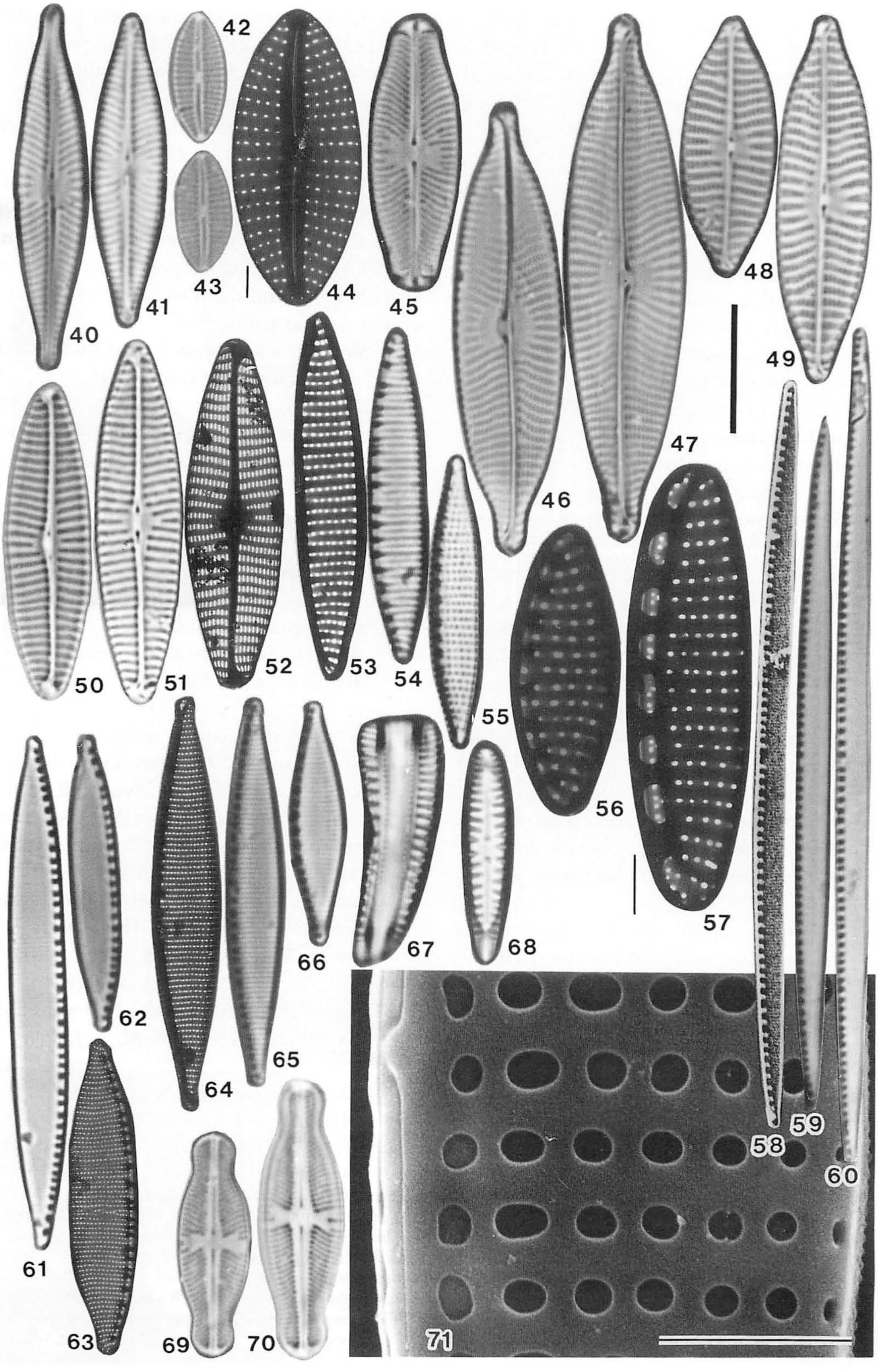
Though this species was characterized by CHOLNOKY (1968) as a good indicator of the oxygen rich oligotrophic waters, it is tolerant to α-mesosaprobic conditions and is rated as a member of Group B of KOBAYASI and MAYAMA (1990).

26. *Gomphonema parvulum* (Kuetz.) Kuetz. var. *paruvulum* (KRAMMER and LANGE-BERTALOT 1986. 358-360. *f. 154/1-25*). (Figs. 18-20)

This species is very variable in valve shape. Specimens in the area were found also to have all kinds of variations in valve shape as shown in KRAMMER and LANGE-BERTALOT (*l. c.*).

27. *Gomphonema gracile* Ehr. var. *gracile* (KRAMMER and LANGE-BERTALOT 1986. 361, 362. *f. 156/26, 27*).
28. *Navicula atomus* (Kuetz.) Grun. var. *atomus* (MAYAMA and KOBAYASI 1988. *f. 1-40*). (Figs. 21, 22)
29. *Navicula confervacea* (Kuetz.) Grun. var. *confervacea* (KRAMMER and LANGE-BERTALOT 1986. 221. *f. 75/29-31*).
30. *Navicula constans* Hust. var. *symmetrica*

Plate 2. ×2,000 unless otherwise noted (broad bar = 10 μm, narrow bar = 1 μm). Figs. 40, 41. *Navicula cryptocephala*. Figs. 42-44. *N. subminuscula* (44. TEM×5,000). Fig. 45. *N. pupula*. Figs. 46, 47. *N. viridula* var. *rostellata*. Figs. 48, 49. *N. viridula* var. *rostrata*. Figs. 50-52. *N. yuraensis* (52. SEM×2,000). Figs. 53-55. *Nitzschia amphibia* (53. TEM×2,000). Figs. 56, 71. *N. frustulum* (56. TEM×8,000; 71. Exterior valve center, SEM×30,000). Fig. 57. *N. hantzschiana* (TEM×9,000). Figs. 58-60. *N. paleacea* (58. Interior valve, SEM×2,000). Figs. 61-63. *N. palea* (63. TEM×2,000). Figs. 64-66. *N. romana* (64. SEM×2,000). Figs. 67, 68. *Rhoicosphenia abbreviata*. Figs. 69, 70. *Stauroneis japonica*.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Hust. (SIMONSEN 1987. 442. *pl. 658. f. 41-46*). (Fig. 23)

Specimens in the area are quite identical with HUSTEDT's (SIMONSEN *l.c.*) holotype specimen in all aspects.

31. *Navicula cryptocephala* Kuetz. var. *cryptocephala* (KRAMMER and LANGE-BERTALOT) 1986. 102. *f. 31/8-14*). (Figs. 40, 41)
32. *Navicula cryptotenella* Lange-B. (KRAMMER and LANGE-BERTALOT 1986. 106. *f. 33/9-11, 13-17*). (Figs. 24, 25)
33. *Navicula goeppertiana* (Bleish) Grun var. *goeppertiana* (MAYAMA and KOBAYASI 1986. 173-182. *f. 24-28*). (Figs. 32, 33)

The distribution pattern of this species was an intermediate one between Type A (most pollution-tolerant) and Type B (less pollution-tolerant) in the Japanese rivers (KOBAYASI and MAYAMA 1990). Therefore, in the present work, g=3.25 (g: group rating) was used for this species.

34. *Navicula gregaria* Donk. var. *gregaria* (KRAMMER and LANGE-BERTALOT 1986. 116. *f. 38/10-15*).
35. *Navicula minima* Grun. var. *minima* (KOBAYASI and MAYAMA 1982. 188-196. *f. 6*). (Figs. 26-29)

This species resembles *N. seminulum* Grun., however, the former has striae composed of a single row of poroids (Fig. 29) and the latter has those composed of a double row of poroids (Figs. 36, 39).

36. *Navicula pupula* Kuetz. var. *pupula* (SCHOEMAN and ARCHIBALD 1976-80. no. 5. *f. 1-74*). (Fig. 45)

Valves of this species are extremely variable as clearly shown by SCHOEMAN and ARCHIBALD (*l. c.*). Specimens found in the area are in the range of variation shown by them.

37. *Navicula seminulum* Grun. var. *seminulum* (KOBAYASI and MAYAMA 1982. 188-196. *f. 7*). (Figs. 34-36, 39)

The striae of this species are composed of a double row of poroids.

38. *Navicula shoenfeldii* Hust. var. *schoenfeldii* (SIMONSEN 1987. 93. *pl. 133. f. 7-12*). (Figs. 30, 31)

Specimens in the area are small and have more acutely round valve ends, but were identifiable by the annulate pattern of striation near the ends and the alternately longer and shorter central striae.

39. *Navicula subminuscula* Mang. (KRAMMER and LANGE-BERTALOT 1986. 223. *f. 76/21-26*). (Figs. 42-44)

This species is one of the representative members of the less pollution-tolerant Group B.

40. *Navicula tridentula* Krasske var. *tridentula* (KRAMMER and LANGE-BERTALOT 1986. 210. *f. 80/1-3*).
41. *Navicula trivialis* Lange-B. (KRAMMER and LANGE-BERTALOT 1986. *f. 35/1-4*).
42. *Navicula veneta* Kuetz. var. *veneta* (KRAMMER and LANGE-BERTALOT 1986. 104. *f. 32/1-4*).

The distribution pattern of this species was an intermediate one between Type A (most pollution-tolerant) and Type B (less pollution-tolerant) in the Japanese rivers and the group rating g=3.25 was given (KOBAYASI and MAYAMA 1990).

43. *Navicula viridula* (Kuetz.) Ehr. var. *rostellata* (Kuetz.) Cl. (KRAMMER and LANGE-BERTALOT 1986. 115. *f. 37/5-9*). (Figs. 46, 47)
44. *Navicula viridula* var. *rostrata* Skv. (SKVORTZOW 1938. 56. *pl. 1. f. 17*). (Figs. 48, 49)
45. *Navicula yuraensis* Negoro & Gotoh (NEGORO and GOTOH 1983. 91. *f. 1a-c*). (Figs. 50-52)

Plate 3. Fine structure of small *Nitzschia* (narrow bar=1 μm, bar with dot=0.1 μm). Figs. 72-75. *Nitzschia amphibia*. 72. Oblique view of frustule showing the band morphology, SEM × 5,000; 73. Enlargement of exterior valve center showing cribra occluding areolae and striae each with bifurcation on the raphe canal, SEM × 30,000; 74. Areolar occlusions, TEM × 70,000; 75. Diagrammatic representation of the frustule showing the band morphology, × 5,000. Figs. 76, 77. *N. romana*. 76. Exterior valve end showing striae each with a furcate branch composed of two areolae on the raphe canal, SEM × 10,000; 77. Enlargement of the valve center showing the bifurcation of each stria, TEM × 30,000.


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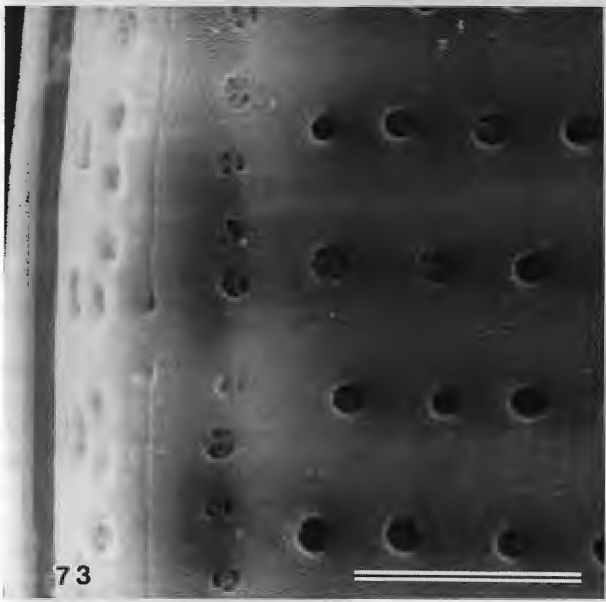
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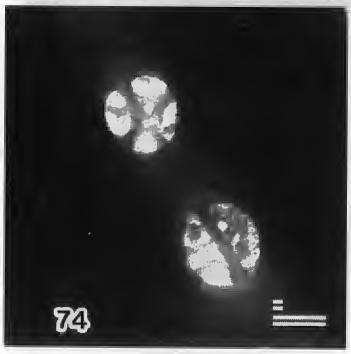
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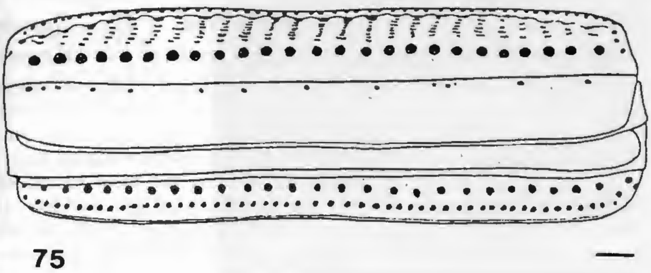
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This species is one of the widely distributed diatoms in the oligotrophic Japanese rivers.

46. *Nitzschia amphibia* Grun. var. *amphibia* (SCHOEMAN *et al.* 1984. 199-202. *f. 72-86*). (Figs. 53-55, 72-75)

The fine structure of our specimens coincides well with that of South African specimens. All valves have a central nodule as pointed out by SCHOEMAN *et al.* (*l. c.*) contrary to HUSTEDT's (1937-38) statement in that the central nodule appears only in larger specimens. The pore occlusions of this species are peculiar. External to the hymen with perforations arranged in a hexagonal array, a cribrum is present to form a double layer (Figs. 72-74). The cingulum consists of four open bands, a valvocopula and three bands, but as seen in Figs. 72, 73 and 75, the valvocopula and the third band are remarkably broader than the second and fourth bands.

47. *Nitzschia frustulum* (Kuetz.) Grun. var. *frustulum* (KOBAYASI 1985. 305. *pl. 3. f. 21-34*). (Figs. 56, 71)

This species is one of the most frequently and widely distributed taxa in the Japanese rivers. The striae are straight and without bifurcations on the canal raphe. The areolae composing striae are sometimes obviously irregular in both size and intervals.

48. *Nitzschia hantzschiana* Rabh. var. *hantzschiana* (KOBAYASI 1985. 312. *pl. 5. f. 44-49*). (Figs. 57, 78-81)

This species frequently occurs with *N. frustulum* in the Japanese rivers. In the area, these two species and *N. romana* have occurred mixed with each other. The clear recognition of these three species is very difficult without the employment of SEM. The striae of this species can be clearly distinguished from those of *N. frustulum* by the bifurcation of the stria on the raphe canal (Figs. 78, 81). The cingulum of this species consists of three open bands, a broad valvocopula with a row of round poroids on the pars exterior along the valve margin, and three narrow bands (Figs. 79, 80).

49. *Nitzschia palea* (Kuetz.) W. Smith (LANGE-BERTALOT 1977. 271-273. *pl. 3. f. 17-21*). (Figs. 61-63)

This species is one of the representative members of the most pollution-tolerant Group A (KOBAYASI and MAYAMA 1990).

50. *Nitzschia paleacea* Grun. (KOBAYASI 1985. 305. *pl. 1. f. 1-8*) (Figs. 58-60, 82, 83)

Valves of our specimens are 45-65 μm long and 2.1-3.0 μm wide. These measurements are somewhat larger than those hitherto observed in Japan (KOBAYASI *l.c.*). However, the fine structure is fully identical with our previous observations as well as with those of LANGE-BERTALOT (1977) and COSTE and RICARD (1980). Though LANGE-BERTALOT (*l. c.*) described this taxon as being a most frequently occurring diatom in the heavily polluted European rivers, and it was later placed in his No. 2 Group (LANGE-BERTALOT 1979), it has not been found in Japanese rivers as confirmed by SEM observations. Therefore, the present occurrence is the first recorded for Japanese rivers. We gave, tentatively, the group rating of g=2.5 to this taxon.

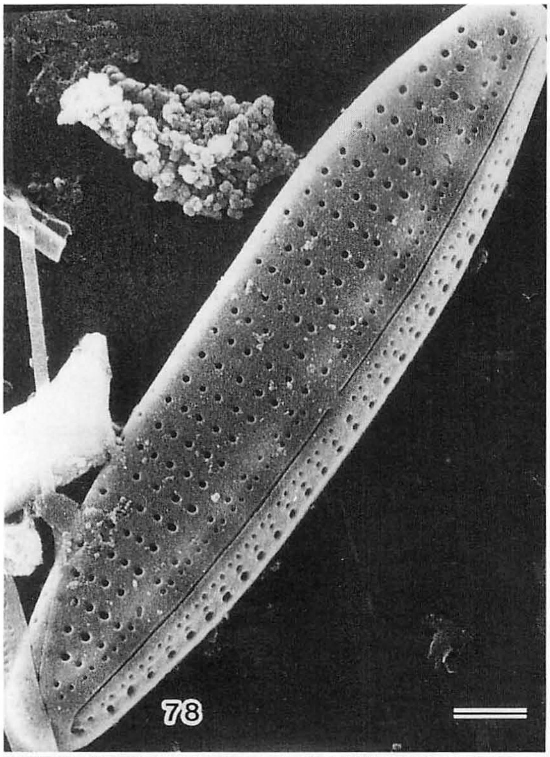
51. *Nitzschia romana* Grun. var. *romana* (KOBAYASI 1985. 312. *pl. 6. f. 56-64*). (Figs. 64-66, 76, 77)

The difficulty of identification of this species only by LM is already discussed under *N. hantzschiana*. The interstriae are strongly elevated forming a corrugated surface (Fig. 76). The bifurcate striae have a furcate branch with two areolae on the raphe canal (Figs. 76, 77).

52. *Pinnularia burckii* Patr. (PATRICK and REIMER 1966. 596. *pl. 55. f. 7*).

53. *Pinnularia subcapitata* Greg. var. *sub-*

Plate 4. Fine structure of small *Nitzschia* (narrow bar = 1 μm). Figs. 78–81. *Nitzschia hantzschiana*. 78. Whole valve, × 10,000; 79. Exterior frustule end showing the band morphology, SEM × 30,000; 80. Diagrammatic representation of the frustule showing the band morphology, × 10,000; 81. Enlargement of exterior valve center showing the bifurcate striae and the central raphe endings, SEM × 30,000. Figs. 82, 83. *N. paleacea*. 82. Broken valve end, SEM × 10,000; 83. External girdle view of the frustule end showing the band morphology, SEM × 20,000.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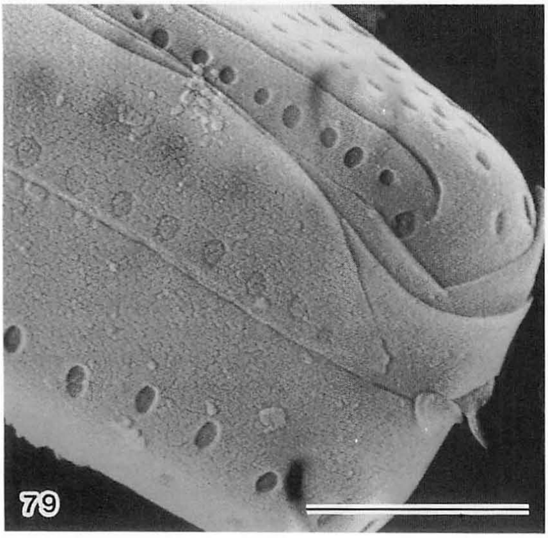
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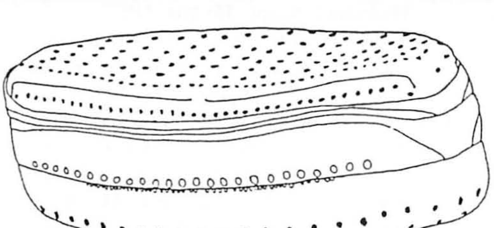
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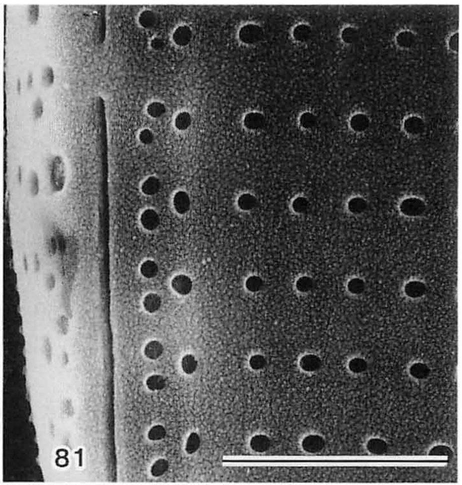
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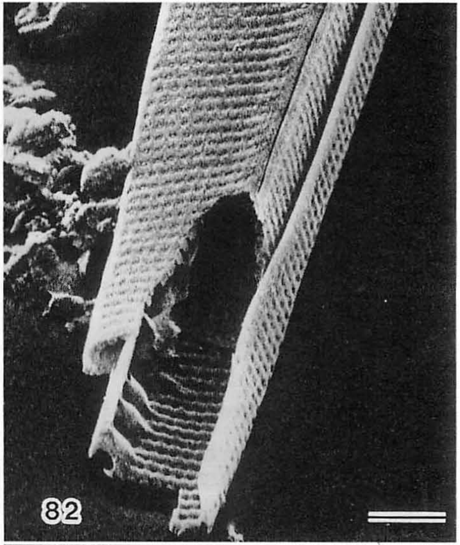
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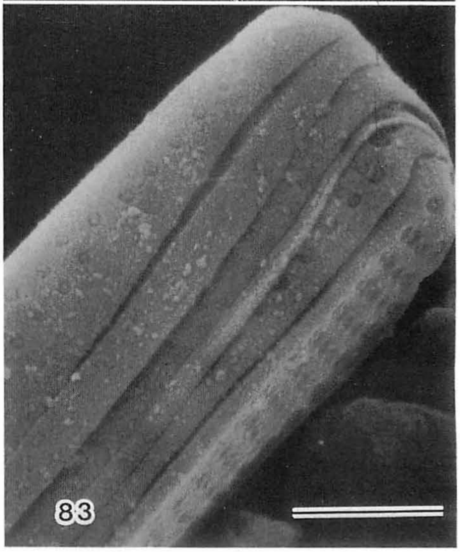
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capitata (KRAMMER and LANGE-BERTALOT 1986. 426. *f. 193/1-3*).

54. *Rhoicosphenia abbreviata* (C. Ag.) Lange-B. (LANGE-BERTALOT 1980b. 586-589. *f. 1A., 3CD, 5A*). (Figs. 67, 68)
55. *Stephanodiscus minutulus* (Kuetz.) Round (KOBAYASI *et al.* 1985. 293-300. *f. 1-25*).
56. *Stauroneis japonica* H. Kob. (KOBAYASI and MAYAMA 1986. 97. *f. 13-21*). (Figs. 69, 70)
57. *Synedra ungeriana* (Grun.) Williams (WILLIAMS 1986. 135. *f. 10-18*).
58. *Synedra ulna* (Nitzsch.) Ehr. var. *ulna* (WILLIAMS 1986. 133. *f. 1-9*).

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Lobo E. A.*・小林　弘**：酒匂川水系（神奈川県）の珪藻集団に対するシャノンの多様性指数の適用とその水質の指標としての使用の可否

シャノンの多様性指数が果してどの程度水質判定に役立つものであるかを，酒匂川水系の淡水域4地点から採取した珪藻集団を用いて検討した。小林・真山のグループ分けとパントル・バックの式を用いて計測した汚濁指数及び他のいくつかの指数とシャノンの多様性指数を比較したところ，比較的清澄な水域に生育する珪藻集団のそれは，適度に汚染されたところ（β-中腐水）や，より汚染の進行したところ（α/β-中腐水）の値よりも，より低く，シャノンの多様性指数それ自体は正確に水質を指示しないことが分かった。なお，出現した種類について，必要に応じて分類学的並びに生態学的考察を加えた。（*Faculdades Integrades de Santa Cruz do Sul, RS, Brasil.; **184 東京都小金井市本町3-8-9-813　東京珪藻研究所）