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Periphytic Diatoms in the Polluted Linggi (*sensu stricto*) and Kundor Rivers, Negeri Sembilan, Malaysia

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The investigation in this paper aimed to describe periphytic diatom assemblage, species composition and distribution in tropical polluted Linggi (*sensu stricto or s.s.*) and Kundor rivers in Negeri Sembilan, Malaysia. Regardless of ecological and environmental conditions, diatoms were the numerically dominant flora among periphytic algae collected monthly over a period of 13 months at nine stations in the Linggi (*s.s.*) and Kundor rivers. The freshwater periphytic diatom samples were collected mainly using artificial substrates and supplemented with natural substrates. The periphytic diatoms thus collected from both natural and artificial substrates comprised 86 taxa (82 pennate and 4 centric forms) belonging to 21 genera. Of the 86 species, 71 species were found colonized in artificial substrates while the remaining 15 species were recorded exclusively on natural substrates. On the whole, the most common diatoms in both rivers combined were *Eunotia vanheurckii, Gomphonema parvulum, Nitzschia palea, Pinnularia braunii, Navicula cryptocephala, Achnanthes saxonica, Achnanthes minutissima* and *Pinnularia microstauron.* The most abundant species were *E. vanheurckii, N. palea, A. saxonica, G. parvulum* and *A. minutissima.*

Key words: Diatom, periphyton, biological assessment, aquatic ecology, lotic ecosystem, tropical river, river ecology, water pollution, water quality, Malaysia

There is a general paucity of scientific research on taxonomy, species composition and distribution of freshwater periphytic diatoms in Malaysia. Prowse (1962) provided the sole detailed taxonomic work on diatoms, although there were many general limnological studies that were carried out in Malaysian rivers, lakes and ponds covered some aspects of diatoms (Hirano 1967; Mizuno & Mori 1970; Prowse & Ratnasabapathy 1970; Arumugam 1972; Furtado & Mori 1982; Nather Khan & Haji Mohamed 1985). Bishop (1973) and Ho (1973) included freshwater algae in their studies on river ecology and attempted to correlate diatoms distribution with water quality and other ecological factors. Nather Khan (1985) conducted an extensive study on biological assessment of water pollution using diatoms community structure, species diversity and productivity in the Linggi River Basin (Nather Khan 1990a, b, c; 1991a, b; 1992a, b; Nather Khan *et al*. 1986a, b; 1987); Nather Khan & Lim 1991; Nather Khan & Firuza 2010, 2012).

Algae which live attached to surfaces of river substrates are called periphyton or Aufwuchs. Periphytons are important primary producers in *lotic* compared to *lentic* ecosystems where phytoplanktons are major primary producers. Normally diatoms are numerically most dominant algal group among periphyton community in lotic system and have been found to be reliable indicators of water pollution. In order to overcome difficulty in collecting

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quantitative samples from natural substrates, artificial substrates such as pieces of wood, sterilized smooth stones, plastic sheets or glass slides were used for quantitative assessment of periphytic diatoms in *lotic* environment (Sladecek & Sladekova 1964; King & Ball 1967; Bishop 1973; Nather Khan 1985; Nather Khan *et al.* 1987).

As diatoms were numerically abundant in periphyton community in the Linggi (*s.s.*) and Kundor rivers qualitative and quantitative assessment of diatom community was estimated through microscopic counting methods (Nather Khan *et al.* 1987). The investigation aimed to determine and describe the taxonomy, species composition, distribution, diversity, relative abundance and productivity of periphytic diatom community with reference to prevailing pollution and water quality in the rivers (Nather Khan 1990a; Nather Khan 1990b; 1991a; 1991b; 1992a; 1992b; Nather Khan *et al*. 1986a; 1986b; 1987; 1991; 2010; 2012). However, this paper describes mainly the taxonomy and distribution of periphytic diatoms at variatous locations at the Linggi (*s.s.*) and Kundor rivers with reference to water pollution.

MATERIALS AND METHODS

The Linggi (*s.s.*) and Kundor Rivers

The Linggi (*s.s.*) and Kundor were highly polluted sub-basins of Linggi River Basin, and located at 2°24'–2°50' N latitude and 101°53'–102°12' E longitude at south-western part of the state of Negeri Sembilan. The Linggi sub-basin has more than 21 major tributaries, of which seven are located above Seremban town, the state capital. The predominant types of land use in the basin were rubber and oil palm plantations, small areas of rice fields with urban and industrial areas. Water from these rivers were extensively used for domestic, industrial and irrigation purposes. The river sections under investigation at the Linggi (*s.s.*) river received mostly treated and untreated urban and industrial wastes from Seremban municipality area, though the domestic sanitary wastes from Seremban town ranked highest among all pollutants discharged.

The Kundor, a tributary of Pedas sub-basin was highly polluted tributary within the Linggi River Basin which was due to effluent discharged from rubber and oil palm factories from Ulu Kanchong estate. The upstream section of this tributary runs through rubber and oil palm plantations while the downstream section passes through lowland swampy areas including rice paddy fields, where a large volume of water was extracted from several small reservoirs built over the Kundor river for paddy irrigation.

Water Quality and Periphtyic Diatom Sampling Stations

Twelve sampling stations were established at both the rivers to assess water quality on monthly basis over 13 months. Of the twelve sampling stations, eight stations were selected only for quantitative periphytic diatom study. The first four stations (Stations 1 – 4) were located at the Linggi (*s.s.*) river while remaining four stations (Stations 9 – 12) were located at the Kundor river. The locations and general characteristic features of these stations are depicted in *Figure 1*. When selecting sampling stations, steps were taken to minimise habitat heterogeneity and other ecological variation between the stations. The dates, sampling location, sampling methods, effluent type and load discharged were described in detail in several other papers published earlier (Nather Khan 1990a; 1990b; 1990c; 1991a; 1991b; 1992a; 1992b).

Water Quality Measurement

Apart from monitoring river flow and river discharge, water samples were collected on a monthly basis at all the stations for a period of 13 months, from January 1983 to January

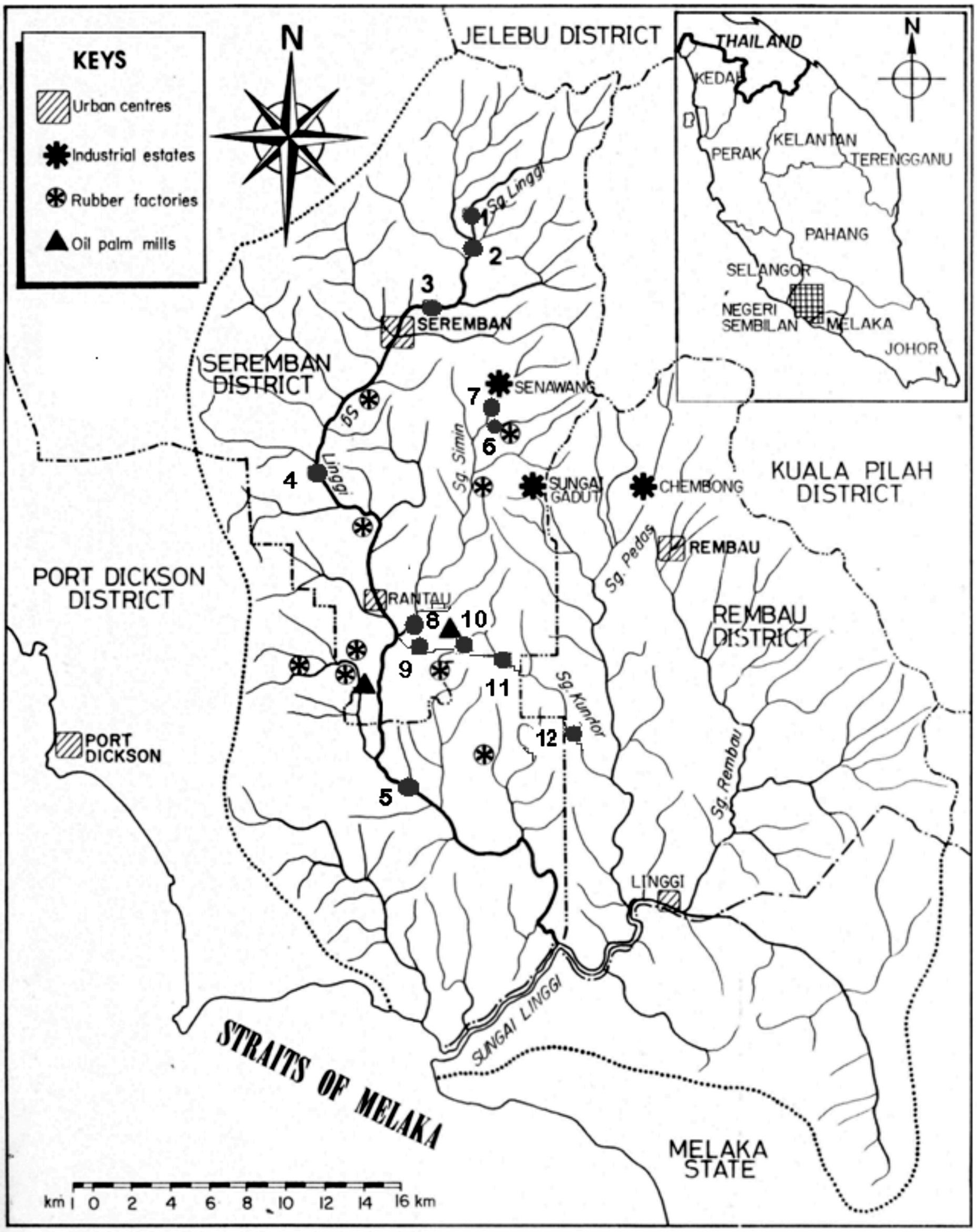


*Figure 1. Sampling stations at Linggi (*s.s.*) and Kundor rivers of Linggi River Basin.*

1984 to analyse 29 physical and chemical parameters. Water samples were collected from middle of the water column using prewashed polyethylene bottles. The temperature, pH, and conductivity were measured in the field and dissolved oxygen was determined immediately upon returning to laboratory. All samples were analysed within 48 hrs after collection except the biochemical oxygen demand (BOD). All determinations were made in duplicate and repeated when precision was needed. The physical and chemical parameters analysed were based on methods outlined in APHA (1975) and Mackereth *et al.* (1978). For details of the methods employed and extensive data collected were discussed in other earlier publications related to the studies (Nather Khan 1992a & 1992b).

Diatoms Sampling Methods

Diatoms were sampled from both natural and artificial substrates. Old leaves, stems and roots of submerged marginal plants were randomly collected within 10 metre river reaches of each station and preserved immediately in 80 ml of 4% formalin in wide mouthed bottles. Additional samples were collected from stones and rocks. Samples thus collected from natural substrates were used for qualitative study only, particularly for species composition and identification purposes (Whitford & Schumacher 1963; Nather Khan 1990a).

For detailed quantitative assessment, diatom samples were collected using glass microscope slides as artificial substrates from January 1983 until January 1984 at Stations 1 to 4 and from March 1983 until January 1984 at Stations 9 to 12. A special diatom collection device was constructed using wooden frames to hold 12 microscope slides (75 × 25 mm). At each station two such devices, one at each side of bank of the river were placed and held vertically parallel to the current and just below the water level by means of iron stakes and wire. Approximately after a month, exposed frames were removed and replaced with new frames for the next colonisation period. Two colonized slides were randomly chosen from frames and preserved immediately in 80 ml of 4% formalin. Additional slides were taken to laboratory in bottles containing river water to examine diatoms in fresh form.

Diatom Identification and Enumeration

In the laboratory, two slides preserved in formalin were scrapped to remove diatom colony and were 'cleaned' by adding nitric acid and potassium dichromate as described by Hohn and Hellerman (1963). The cleaned samples were made up to known quantities and one ml of aliquot of acid-free, homogenised suspension was placed on a 22 ml # 1 cover glass, dried on a hot plate and mounted on a slide with Hyrax mounting medium. In order to determine relative abundance and diversity of diatom species a numerical counting method was used. Each slide was randomly scanned until 500 diatom cells were counted under a magnification of ×600. For identification, diatom frustules were examined under oil immersion (×1000 magnification). The count data for each species were expressed as number of individuals per 500 cells counted. As far as possible, diatoms were identified to species level using taxonomic keys, drawings and descriptions given in such works as Prowse (1962), Sladecek (1963), Mizuno (1964), Patrick & Reimer (1966) and Ho (1973).

RESULTS AND DISCUSSION

Water Quality at Linggi (*s.s.*) and Kundor Rivers

The water quality measurement carried out over a year indicated that Station 1 and 2 were characterised by relatively low ionic content, slightly neutral pH, high silica and oxygen contents, low BOD and permanganate values (*Table 1*). The ammonia-nitrogen, nitrates

Table 1. Water quality at eight sampling stations in the Linggi (*s.s.*) and Kundor rivers.

Stations	Station 1			Station 2			Station 3			Station 4			Station 9			Station 10			Station 11			Station 12		
Parameter	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
pH	6.75	5.26	6.04	6.65	4.64	5.60	6.08	5.02	5.46	6.08	5.02	5.46	6.41	4.45	5.37	7.39	5.60	6.38	6.17	5.75	6.05	6.38	4.65	5.48
Umho / cm	44.00	23.00	29.30	45.00	25.00	32.73	130.00	66.00	86.77	130.00	66.00	86.77	300	42.00	135.20	1500.00	150.00	690.00	410.00	100.00	212.00	110.00	51.00	64.86
SiO_2	22.00	15.80	18.66	22.50	14.90	18.52	18.10	8.20	13.76	18.10	8.20	13.76	10.10	5.60	7.87	-	-	-	12.80	7.70	10.70	9.40	6.70	8.24
HCO^-_3alk	51.00	7.00	25.91	50.00	11.00	30.73	156.00	23.00	81.00	156.00	23.0	81.00	413.00	8.00	128.00	1388.00	53.00	519.60	325.00	116.00	183.50	101.00	13.00	38.43
Cl	7.48	0.90	3.34	7.48	1.00	3.53	19.00	2.30	9.90	19.00	2.30	9.90	23.90	1.50	10.80	160.90	3.30	55.30	53.90	16.90	28.00	22.50	1.80	10.61
PO_4-P	0.033	0.00	0.006	0.033	0.00	0.012	0.591	0.021	0.323	0.591	0.021	0.323	0.269	0.002	0.087	5.208	0.068	2.194	0.644	0.138	0.403	0.199	0.084	0.119
NH_3-N	0.026	0.08	0.13	0.28	0.01	0.12	8.05	1.82	5.17	8.05	1.82	5.17	30.50	0.55	9.70	53.75	3.76	30.17	8.85	0.16	2.95	2.62	0.11	0.76
NO_2-N	0.001	0.00	0.0002	0.001	0.00	0.0004	0.007	0.001	0.004	0.007	0.001	0.004	0.003	0.00	0.001	0.822	0.005	0.083	0.040	0.004	0.024	0.014	0.001	0.003
NO_3-N	0.16	0.03	0.07	0.14	0.03	0.10	0.73	0.1	0.35	0.73	0.1	0.35	0.51	0.05	0.19	2.59	0.13	1.30	6.77	0.45	2.51	0.93	0.40	0.544
O_2	9.20	6.50	8.27	8.80	6.00	7.46	5.80	0.34	2.08	5.80	0.34	2.08	8.01	0.46	3.72	6.67	0.11	3.41	7.93	5.05	6.19	8.10	5.89	6.78
BOD_5	2.03	0.32	1.17	2.82	0.42	1.38	42.23	4.37	11.87	42.23	4.37	11.87	82.40	6.71	21.36	384.00	12.78	117.71	9.50	18.20	12.31	4.12	11.21	6.48
Permanganate value	3.40	0.20	1.42	9.40	0.20	2.46	11.40	2.70	6.08	11.40	2.70	6.08	10.60	1.28	4.30	79.20	4.00	24.29	10.10	7.90	8.62	2.20	11.20	5.76

and phosphates were very low and nitrites were usually present in low or sometimes in undetectable level. Drastic changes in the above physical and chemical parameters were found at Station 3. Very high specific conductivity, ammonia, nitrate and BOD were recorded at this station. This was due to effluent discharged from nearby rubber processing factory. The water quality at Station 4, located south of the Seremban town, revealed increased concentration of substances associated with sewage and its decomposition products. The concentration of dissolved oxygen was reduced to a very low level here. This was due to the large amount of treated and untreated sewage discharged from Seremban town upstream of the Station 4.

Among all the stations, very high physical and chemical values were recorded at Stations 9, 10, 11 and 12 that located at Kundor river (*Table 1*). The conductivity, alkalinity, chloride, ammonical nitrogen, BOD and permanganate values were high at almost all the stations. This was due to oil palm effluent discharged into the river of low dilution capacity. Based on the concentrations of some important water quality parameters, Station 1 and 2 could be considered unpolluted, Station 3 moderately polluted and Stations 4, 9,10, 11 and 12 were severely polluted, though there was a great variation in pollution type and load, water quality river flow and discharge between these stations.

Species Composition of Periphytic Diatoms

The diatoms collected from both natural and artificial substrates comprised 86 taxa (82 pennate and 4 centric forms) belonging to 21 genera (*Table 2*). Of the 86 species, 71 species were found colonized in artificial substrates while the remaining 15 species were recorded exclusively on natural substrates. However, these 15 species were very rare and appeared only at certain stations (Stations 1, 2, 3 and 7) in certain months of the year (Nather Khan 1990b). The number of diatom species observed between stations varied from 22 to 47 species under 8 – 16 genera respectively. Stations 1, 2 and 3 had more than 50% of all species recorded. The maximum numbers of species recorded at Station 1 were 47 and the minimum number of species was recorded at Station 6 were 22. Out of 71 species observed on artificial substrates, 43 species were recorded at Station 1, 42 species at Stations 2 and 3; 27 species at Station 4; 22 species at Station 9; 26 Species at Station 10 and 34 species at Stations 11 and 12 together (*Tables 3* and *4*). On the whole, the annual mean number of species varied from 8 to 22; the minimum (8 species) at Station 9 and the maximum (22 species) at Station 3.

Almost all species of genera Achnanthes, Synedra and several species of genera Cymbella, Gomphonema and Surirella were recorded at Station 1. Several species of Eunotia were recorded at Station 2, several species of Navicula at Station 3, several species of Pinnularia at Station 6 and several species of Nitzschia at Station 7. Among all the genera, Navicula was the most dominant genus with 13 species followed by Cymbella and Eunotia with 9 species each while Achnanthes and Nitzschia were the next with 8 species each.

Spatial Variation of Periphytic Diatoms

The occurrence and abundance of diatoms varied from station to station. Within a few days of exposure at Station 1 thin layer of mucilage with scattered individuals of *Achnanthes minutissima, Cymbella javanica* and *Synedra rumpens* were found, while at Stations 2 and 3, *A. minutissima and Achnanthes saxonica* were the initial colonizers. *A. saxonica* and *A. minutissima* were two most common and abundant species at Station 1 comprising over 75% of cell counts. Both these species showed 100% constancy values which meant, these species were present in all the sampling months. The other common species at Station

Table 2. Periphytic diatoms flora in the Linggi (*s.s.*) and Kundor rivers.

No	Name of the species
1	*Achnanthes minutissima* Kuetz. var. *minutissima*
2	*Achnanthes linearis* (W. Sm.) Grun. var. linearis
3	*Achnanthes saxonica* Krasske
4	*Achnanthes lapidosa* var. *lanceolata* Hustest
5	*Achnanthes stauroneiformis* Prowse
6	*Achnanthes crenulata* Grun. *
7	*Achnanthes brevipes* C.A. Agardh var. intermedia Kuetz.
8	*Achnanthes exigua* Grun.
9	*Amphora normani* Rabenhorst
10	*Cyclotella meneghiniana* Kuetz.
11	*Cyclotella glomerata* Bachmann
12	*Cocconeis thumensis* A. Mayer
13	*Cymbella javanica* Hustedt
14	*Cymbella sumatrensis* Hustedt
15	*Cymbella turgida* Gregory
16	*Cymbella japonica* Reichert *
17	*Cymbella minuta* Hilse. ex. Rabh. var. *minuta* * (Syn. *C. ventricosa*)
18	*Cymbella sumatrensis fo. malayensis nov. fo* (Syn. *C. lanceolata*)
19	*Cymbella kolbei* Hustedt
20	*Cymbella tumida* (Brebisson) van. Heurek. *
21	*Cymbella cuspidata* Kuetz.
22	*Diploneis ovalis* (Hilsse) P. T. Cleve
23	*Desmogonium rabenhorstianum* Grun. *
24	*Eunotia monodon* Ehrenberg var. *constricta* A. Cleve-Euler
25	*Eunotia vanheurckii* Patr. var. *vanheurckii** (Syn.E.faba (Ehr.) Grun.
26	*Eunotia rhomboidea* Hustest *
27	*Eunotia major* (W. Smith) Rabenhorst var. *indica* (Grun.) A. Berg
28	*Eunotia pectinalis* (Kuetz) Rabenhorst *
29	*Eunotia polydentula* (Brun) A. Berg. var. *perminuta* Grun. *lunaris* (Ehr.) Grun. var. *capitata* Grun.
30	*Eunotia lunaris* (Ehr.) Grun. var. *capitata* Grun
31	*Eunotia camelus* Ehr. var. *karveerensis* Gandhi
32	*Eunotia major* (W. Smith) Rabenhorst
33	*Fragilaria vauncheriae* (Kuetz) Boye Petersen
34	*Fragilaria sp.* *
35	*Frustulia rhomboides* (Ehr.) de Toni
36	*Frustulia saxonica* Rabenhorst
37	*Frustulia javanica* Hustedt *
38	*Gomphonema parvulum* (Kuetz) Grun.
39	*Gomphonema gracile* Ehr.
40	*Gomphonema subventricosum* Hustedt
41	*Gomphonema longiceps* Ehr. var. *subclavata* Grun. *F. gracilis* Hustedt
42	*Gomphonema clevei* var. *inaequilongum* H. Kobayasi
43	*Gyrosigma attenuatum* (Kuetz) P.T. Cleve
44	*Melosira granulata* (Ehr.) Ralfs
45	*Melosira italica* (Ehr.) Kuetz.

Table 2 (Cont.). Periphytic diatoms flora in the Linggi (*s.s.*) and Kundor rivers.

No	Name of the species
46	*Navicula senjoensis* H. Kobayasi ?
47	*Navicula liboensis* Schoeman ?
48	*Navicula veneta* Kuetz (Syn. *N. crytocephala* var. *veneta* (Kuetz.) Grun.)
49	*Navicula globosa* Meister
50	*Navicula trituberculata* Prowse
51	*Navicula antiqua* A. Cleve *
52	*Navicula mutica fo. intermedia* Hustedt *
53	*Navicula pupula fo. capitata* Skvortzow u. Mayer
54	*Navicula minima* Grun.
55	*Navicula gastrum* Ehr.
56	*Navicula rhyncocephala* Kuetz.
57	*Navicula cuspidata* Kuetz. var. *ambigua* (Ehr.) P.T. Cleve
58	*Navicula amphibola* P.T. Cleve
59	*Neidium productum* (W. Smith). *P.T. Cleve var. *minor* A. Cleve
60	*Neidium hitchcockii* (Ehr.) P.T. Cleve
61	*Nitzschia palea* (Kuetz) W. Smith
62	*Nitzschia amphioxys* (Ehr.) Grun. *
63	*Nitzschia sigma* (Kuetz.) W. Smith var. *clausii* (Hantz.) Grun.
64	*Nitzschia stagnorum* Rabenhorst
65	*Nitzschia acicularis* (Kuetz.) W. Smith *
66	*Nitzschia sigma* (kuetz.) W. Smith
67	*Nitzschia obtusa* W. Smith var. *scalpelliformis* Grun.
68	*Nitzschia fonticola* Grun.
69	*Pinnularia biceps* Gregory var. *minor* (Boye Petersen). A. Cleve
70	*Pinnularia braunii* var. *amphicephala* (A. Mayer) Hustedt
71	*Pinnularia microstauran* (Ehr.) P.T. Cleve
72	*Pinnularia microstauron* var. *ambigua*
73	*Pinnularia bogotensis* (Grun.) P.T. Cleve var. *continue* A. Cleve
74	*Pinnularia borealis* Ehr.
75	*Pinnularia brevicostata* P.T. Cleve
76	*Pinnularia stauroptera* (Grun.) P.T. Cleve var. *subparallela* Mayer
77	*Rhopalodia gibberula* (Ehr.) O. Muller
78	*Synedra rumpens* var. *fragilarioides* Grun.
79	*Surirella tenuissima* Hustedt
80	*Surirella angusta* Kuetz.
81	*Surirella linearis* W. Smith
82	*Surirella lemmermanii* Hustedt
83	*Surirella robusta Ehr.* var. *splendida* (Ehr.) van. Heurck
84	*Surirella angusticostata* Hustedt *
85	*Stauroneis pusilla* A. Cleve
86	*Stauroneis phoenicenteron* (Nitzsch) Ehr. var. *intermedia* (Dipp.) A. Cleve-Eular

(*) indicates species recorded exclusively from natural substrates.

Table 3. Periphytic diatom occurrence at various stations (in alphabetical order).

No	Diatom species	Stations						
		Linggi (s.s) River				Kundur River		
		St. 1	St. 2	St. 3	St. 4	St. 9	St. 10	St. 11 & 12
1	*Achnanthes minutissima*	√	√	√	√	√	√	√
2	*Achnanthes linearis*	√	√	√	√	√	√	–
3	*Achnanthes saxonica*	√	√	√	√	√	√	–
4	*Achnanthes lapidosa*	√	√	–	–	–	–	–
5	*Achnanthes stauroneiformis*	√	–	√	–	–	–	–
6	*Achnanthes crenulata**	√	–	–	–	–	–	–
7	*Achnanthes brevipes*	√	√	√	–	–	–	–
8	*Achnanthes exigua*	√	√	–	√	–	√	√
9	*Amphora normani*	√	–	√	√	–	–	–
10	*Cyclotella meneghiniana*	–	√	√	√	–	–	√
11	*Cyclotella glomerata*	√	√	–	–	–	–	–
12	*Cocconeis thumensis*	–	√	–	–	–	–	–
13	*Cymbella javanica*	√	√	√	√	√	–	√
14	*Cymbella sumatrensis*	√	√	√	–	–	–	–
15	*Cymbella turgida*	√	√	√	–	–	–	√
16	*Cymbella japonica**	√	–	–	–	–	–	–
17	*Cymbella minuta**	√	√	–	–	–	–	–
18	*Cymbella sumatrensis fo. malayensis*	√	–	–	√	–	–	–
19	*Cymbella kolbei* var. *lanceolata*	√	–	√	–	–	√	–
20	*Cymbella tumida**	√	–	–	–	–	–	–
21	*Cymbella cuspidata*	–	–	–	√	–	–	–
22	*Diploneis ovalis*	√	–	√	–	–	–	–
23	*Desmogonium rabenhorstianum**	–	√	–	–	–	–	–
24	*Eunotia monodon*	√	√	√	√	√	√	√
25	*Eunotia vanheurckii**	–	–	–	–	–	–	√
26	*Eunotia rhomboidea**	–	√	–	–	–	–	–
27	*Eunotia major*	–	√	√	√	√	–	–
28	*Eunotia pectinalis**	–	√	–	–	–	–	–
29	*Eunotia polydentula*	–	–	√	–	–	–	–
30	*Eunotia lunaris*	–	–	–	–	√	–	–
31	*Eunotia camelus*	–	–	–	–	–	√	–
32	*Eunotia major* var. *indica*	–	–	–	–	–	–	√
33	*Fragilaria vaucheriae*	√	–	–	–	–	–	–
34	*Fragilaria sp.**	√	–	–	–	–	–	–
35	*Frustulia rhomboides*	–	–	√	–	–	–	–
36	*Frustulia saxonica*	√	√	√	√	√	√	√
37	*Frustulia javanica**	–	√	–	–	–	–	–
38	*Gomphonema parvulum*	√	√	√	√	√	√	√
39	*Gomphonema gracile*	√	√	√	√	√	√	√
40	*Gomphonema subventricosum*	√	√	√	–	–	–	–
41	*Gomphonema longiceps*	√	√	–	√	√	–	–
42	*Gomphonema Clevei*	√	√	√	–	–	–	–
43	*Gyrosigma attenuatum*	–	√	√	–	–	–	–
44	*Melosira granulata*	–	–	√	–	–	–	–

Table 3 (Cont.). Periphytic diatom occurrence at various stations (in alphabetical order).

No	Diatom species	Stations						
		Linggi (s.s) River				Kundur River		
		St. 1	St. 2	St. 3	St. 4	St. 9	St. 10	St. 11 & 12
45	*Melosira italica*	√	–	√	–	√	–	–
46	*Navicula senjoensis*	√	√	√	–	–	√	–
47	*Navicula liboensis*	√	√	√	–	–	–	–
48	*Navicula veneta*	√	√	√	√	√	√	√
49	*Navicula globosa*	√	√	√	√	–	√	√
50	*Navicula trituberculata*	√	–	–	–	√	–	√
51	*Navicula antigua**	–	–	√	–	–	–	–
52	*Navicula mutica**	–	–	√	–	–	–	–
53	*Navicula pupula*	–	√	√	–	–	√	√
54	*Navicula minima*	–	–	–	–	–	–	√
55	*Navicula gastrum*	√	–	√	–	–	√	√
56	*Navicula rhyncocephala*	–	√	√	√	–	–	√
57	*Navicula cuspidata*	–	–	–	–	–	√	√
58	*Navicula ambhibola*	–	–	–	–	–	–	√
59	*Neidium productum**	–	–	√	–	–	–	–
60	*Neidium hitchockii*	–	–	–	–	–	–	√
61	*Nitzschia palea*	√	√	√	√	√	√	√
62	*Nitzschia amphioxys**	–	–	–	–	–	√	–
63	*Nitzschia sigma* var. *clausii*	√	√	√	√	√	–	–
64	*Nitzschia stagnorum*	–	–	–	√	–	√	√
65	*Nitzschia acicularis**	–	–	–	–	–	√	–
66	*Nitzshia sigma*	–	–	–	–	–	√	√
67	*Nitzschia obtusa*	–	–	–	–	√	–	√
68	*Nitzschia fonticola*	√	–	–	√	–	–	–
69	*Pinnularia biceps*	√	√	√	√	√	√	√
70	*Pinnularia Braunii*	–	√	√	√	√	√	√
71	*Pinnularia microstauron*	√	√	√	√	√	√	√
72	*Pinnularia microstauron* var. *ambigua*	–	√	–	–	–	–	–
73	*Pinnularia bogotensis*	–	√	–	–	√	–	–
74	*Pinnularia borealis*	–	–	–	–	√	√	√
75	*Pinnularia brevicostata*	–	–	√	–	–	–	–
76	*Pinnularia stauroptera*	–	–	√	–	√	–	√
77	*Rhopalodia gibberula*	√	√	–	–	–	–	–
78	*Synedra rumpens*	√	√	√	–	–	–	–
79	*Surirella tenuissima*	√	√	√	√	–	√	√
80	*Surirella angusta*	√	√	–	–	–	√	√
81	*Surirella linearis*	√	–	√	–	–	–	–
82	*Surirella lemmermanii*	√	√	–	–	–	–	–
83	*Surirella robusta*	–	√	√	–	–	–	–
84	*Surirella angusticostata**	–	–	–	–	–	√	—
85	*Stauroneis pusilla*	√	–	√	–	–	–	√
86	*Stauroneis phoenicenteron*	√	–	–	–	–	–	√
	Total	48	45	46	26	23	28	34

Table 4. Periphytic diatom occurrence at various stations based on constancy values.

No	Diatom Species	Stations							
		Linggi River				Kundur River			
		St. 1	St. 2	St. 3	St. 4	St. 9	St. 10	St. 11&12	All
1	*Achnanthes minutissima*	√	√	√	√	√	√	√	7
2	*Eunotia monodon*	√	√	√	√	√	√	√	7
3	*Frustulia saxonica*	√	√	√	√	√	√	√	7
4	*Gophonema parvulum*	√	√	√	√	√	√	√	7
5	*Gophonema gracile*	√	√	√	√	√	√	√	7
6	*Navicula veneta*	√	√	√	√	√	√	√	7
7	*Nitzschia palea*	√	√	√	√	√	√	√	7
8	*Pinnularia microstauron*	√	√	√	√	√	√	√	7
9	*Pinnularia biceps*	√	√	√	√	√	√	√	7
10	*Achnanthes linearis*	√	√	√	√	√	√	–	6
11	*Achnanthes saxonica*	√	√	√	√	√	√	–	6
12	*Cymbella javanica*	√	√	√	√	√	–	√	6
13	*Navicula globosa*	√	√	√	√	–	√	√	6
14	*Pinnularia Braunii*	–	√	√	√	√	√	√	6
15	*Surirella tenuissima*	√	√	√	√	–	√	√	6
16	*Achnanthes exigua*	√	√	–	√	–	√	√	5
17	*Nitzschia sigma* var. *clausii*	√	√	√	√	√	–	–	5
18	*Cyclotella meneghiniana*	–	√	√	√	–	–	√	4
19	*Cymbella turgida*	√	√	√	–	–	–	√	4
20	*Eunotia major*	–	√	√	√	√	–	–	4
21	*Gomphonema longiceps*	√	√	–	√	√	–	–	4
22	*Navicula gastrum*	√	–	√	–	–	√	√	4
23	*Navicula rhyncocephala*	–	√	√	√	–	–	√	4
24	*Navicula senjoensis*	√	√	√	–	–	√	–	4
25	*Navicula pupula*	–	√	√	–	–	√	√	4
26	*Surirella angusta*	√	√	–	–	–	√	√	4
27	*Achnanthes brevipes*	√	√	√	–	–	–	–	3
28	*Amphora normani*	√	–	√	√	–	–	–	3
29	*Cymbella sumatrensis*	√	√	√	–	–	–	–	3
30	*Cymbella kolbei*	√	–	√	–	–	√	–	3
31	*Gomphonema Clevi*	√	√	√	–	–	–	–	3
32	*Gomphonema subventricosum*	√	√	√	–	–	–	–	3
33	*Melosira italica*	√	–	√	–	√	–	–	3
34	*Navicula liboensis*	√	√	√	–	–	–	–	3
35	*Navicula trituberculata*	√	–	–	–	√	–	√	3
36	*Nitzschia stagnorum*	–	–	–	√	–	√	√	3
37	*Pinnularia borealis*	–	–	–	–	√	√	√	3
38	*Pinnularia stauroptera*	–	–	√	–	√	–	√	3
39	*Synedra rumpens*	√	√	√	–	–	–	–	3
40	*Stauroneis pusilla*	√	–	√	–	–	–	√	3
41	*Achnanthes lapidosa*	√	√	–	–	–	–	–	2
42	*Achnanthes stauroneiformis*	√	–	√	–	–	–	–	2
43	*Cyclotella glomerata*	√	√	–	–	–	–	–	2
44	*Cymbella minuta*	√	√	–	–	–	–	–	2

Table 4 (Cont.). Periphytic diatom occurrence at various stations based on constancy values.

No	Diatom Species	Stations							
		Linggi River				Kundur River			
		St. 1	St. 2	St. 3	St. 4	St. 9	St. 10	St. 11&12	All
45	*Cymbella sumatrensis fo. malayensis*	√	–	–	√	–	–	–	2
46	*Diploneis ovalis*	√	–	√	–	–	–	–	2
47	*Gyrosigma attenuatum*	–	√	√	–	–	–	–	2
48	*Navicula cuspidata*	–	–	–	–	–	√	√	2
49	*Nitzschia fonticola*	√	–	–	√	–	–	–	2
50	*Nitzschia obtusa*	–	–	–	–	√	–	√	2
51	*Nitzschia sigma*	–	–	–	–	–	√	√	2
52	*Pinnularia Bogotensis*	–	√	–	–	√	–	–	2
53	*Rhopalodia gibberula*	√	√	–	–	–	–	–	2
54	*Surirella linearis*	√	–	√	–	–	–	–	2
55	*Surirella lemmermanii*	√	√	–	–	–	–	–	2
56	*Surirella robusta*	–	√	√	–	–	–	–	2
57	*Stauroneis phoenicenteron*	√	–	–	–	–	–	√	2
58	*Achnanthes crenulata*	√	–	–	–	–	–	–	1
59	*Cymbella cuspidata*	–	–	–	√	–	–	–	1
60	*Cymbella japonica*	√	–	–	–	–	–	–	1
61	*Cymbella tumida*	√	–	–	–	–	–	–	1
62	*Cocononeis thumensis*	–	√	–	–	–	–	–	1
63	*Desmogonium rabenhorstianum*	–	√	–	–	–	–	–	1
64	*Eunotia camelus*	–	–	–	–	–	√	–	1
65	*Eunotia lunaris*	–	–	–	–	√	–	–	1
66	*Eunotia major van indica*	–	–	–	–	–	–	√	1
67	*Eunotia polydentula*	–	–	√	–	–	–	–	1
68	*Eunotia pectinalis*	–	√	–	–	–	–	–	1
69	*Eunotia rhomboidea*	–	√	–	–	–	–	–	1
70	*Eunotia vanheurckii*	–	–	–	–	–	–	√	1
71	*Fragilaria sp.*	√	–	–	–	–	–	–	1
72	*Fragilaria vaucheriae*	√	–	–	–	–	–	–	1
73	*Frustulia rhomboides*	–	–	√	–	–	–	–	1
74	*Frustulia javanica*	–	√	–	–	–	–	–	1
75	*Melosira granulata*	–	–	√	–	–	–	–	1
76	*Navicula Antigua*	–	–	√	–	–	–	–	1
77	*Navicula mutica*	–	–	√	–	–	–	–	1
78	*Navicula minima*	–	–	–	–	–	–	√	1
79	*Navicula ambhibola*	–	–	–	–	–	–	√	1
80	*Neidium hitchockii*	–	–	–	–	–	–	√	1
81	*Neidium productum*	–	–	√	–	–	–	–	1
82	*Nitzschia acicularis*	–	–	–	–	–	√	–	1
83	*Nitzschia amphioxys*	–	–	–	–	–	√	–	1
84	*Pinnularia microstauron van. ambigua*	–	√	–	–	–	–	–	1
85	*Pinnularia brevicostata*	–	–	√	–	–	–	–	1
86	*Surirella angusticostata*	–	–	–	–	–	√	–	1
	Total	48	45	46	26	23	28	34	

1 were *Achnanthes linearis, C. javanica, Cymbella turgida, Gomphonema parvulum* and *S. rumpens* and also showed 100% constancy values. Most of the above-mentioned diatoms were commonly found in clean and rocky streams.

A. saxonica was the most dominant species *(59%)* at Station 2, followed by *Eunotia vanheurckii* (22%), they together constituted over 81% of total cell count. Except for these two species, all other species at this station showed less than 100% constancy values. *A. minutissima*, the second most dominant species at Station 1, constituted only 25% of cell count with a 75% constancy value here at Station 2. The lower abundance of *A. minutissima,* greater abundance of *E. vanheurckii* and appearance of new species *Gyrosigma attenuatum* differentiated Station 2 from Station1, though both the stations were more or less similar in water quality.

At Station 3, *E. vanheurckii*, *A. saxonica* and *A. minutissima* were the dominant species with percentage abundance of 29%, 20% and 11.4%, respectively. *A. saxonica*, the second most abundant species with constancy value of 92% while the other two species showed 100% constancy values. In addition, four more species namely *C. javanica*, *G. parvulum*, *Navicula cryptocephala* and *Pinnularia braunii*, also showed 100% constancy values and contributed significantly to the total percentage abundance with 4%, 7%, 6.4% and 4%, respectively. Thus, unlike the previous two stations, the Station 3 was not dominated by individuals of one or two species but many species.

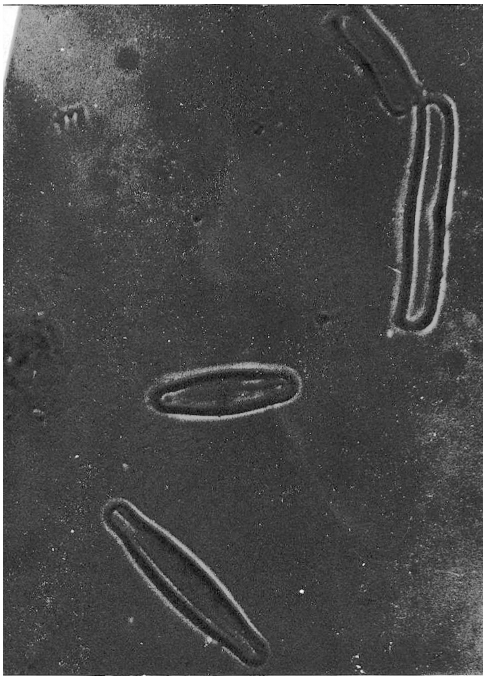
At Station 4, *Nitzschia palea*, *G. parvulum* and *P. braunii* were the most dominant species with percentage abundance of 43%, 37% and 7.2%, respectively. These three species showed 100% constancy values at Station 4. Other common diatoms recorded at this station were *Navicula globosa*, *Navicula gastrum*, *Navicula senjoensis* and *Pinnularia biceps*.

E. vanheurckii was the most dominant species at all three stations of Kundor river (40%, 33.4% and 44.2% at Station 9, 10 and 11, respectively), followed by *N. palea* (28%, 32% and 38% respectively) and *Gomphonema parvulum* (18%, 20% and 2.4%, respectively). Among them only *N. palea* showed 100% constancy values at all the four stations. *P. braunii* which showed 100% constancy values at these stations, but not in abundant in numbers (3.2%, 7.0%, less than 1%). All the species mentioned above were pollution tolerant species (Palmer 1969).

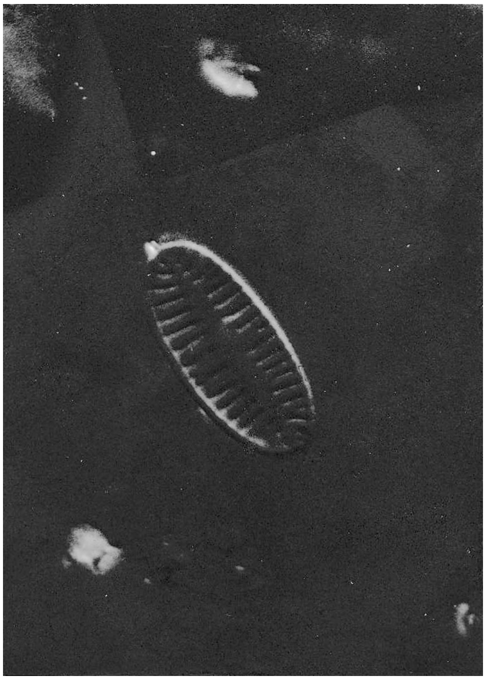
Diversity of Periphytic Diatoms

The most common and abundant species were *A. minutissima* and *A. saxonica* at Station 1, *A. saxonica* and *E. vanheurckii* at Station 2, *N. palea*, *G. parvulum* and *P. braunii* at Station 3, *G. parvulum* and *N. palea* at station 4. The lower abundance of *A. minutissima*, greater abundance of *E. vanheurckii*, and the appearance of *Gyrosigma* sp. differentiate Station 2 from Station 1 (*Tables 3* and *4*). Among the four stations in the Linggi (*s.s.*) river, the highest diversity was recorded at Station 3 which was polluted by mainly rubber effluent followed by Station 1 and 2 which were relatively unpolluted. Lowest mean diversity was recorded at Station 4, polluted mainly with urban domestic sewage and industrial wastes.

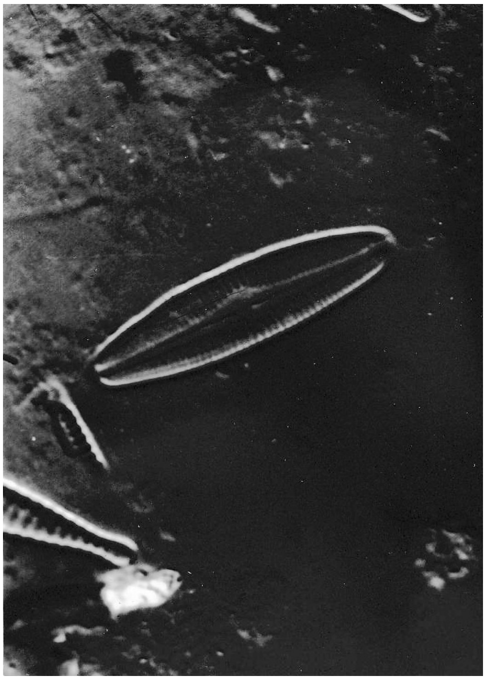
Among stations located in the Kundor river most common and abundant species of diatoms were *E. vanheurckii*, *Gomphonema parvulum* and *N. palea* at station 9, *E. vanheurckii*, *G. parvulum*, and *Nitzschia stagnorum* at station 10 and *Eunotia vanheurckii* and *N. palea* at station 11 and 12. Among four stations at Kundor river, the highest mean diversity value was recorded at Station 11 followed by Station 12, both located at the downstream pollution recovery zone. The lowest diversity was recorded at Station 9 polluted with rubber effluent (Nather Khan 1985, 1991a; Nather Khan *et al*. 1986a, b).



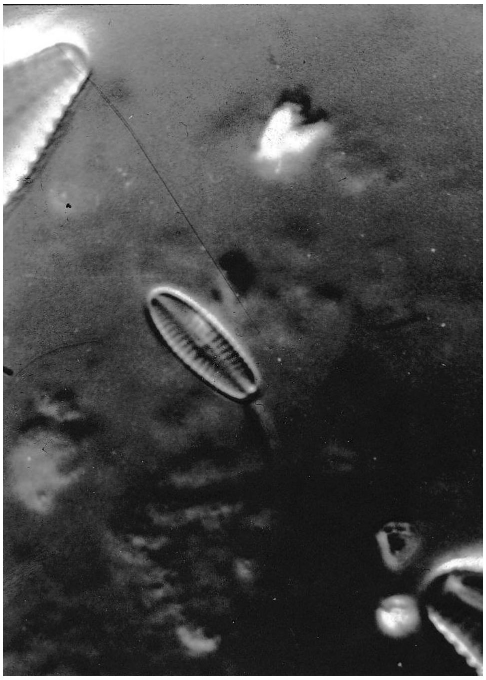
Achnanthes minutissima var. *minutissima*



Achnanthes saxonica

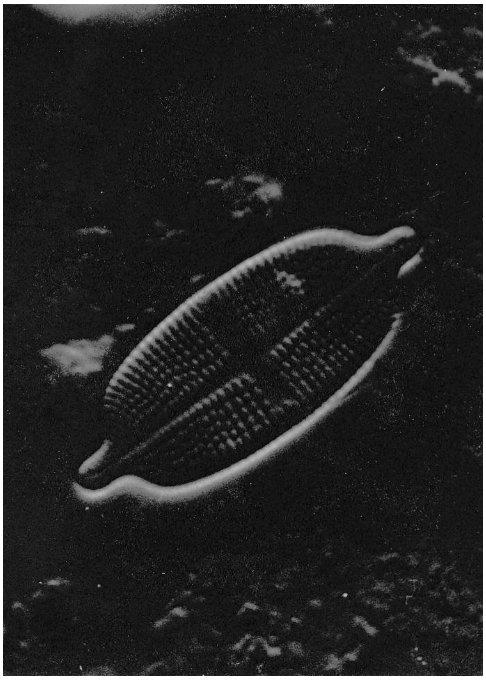


Achnanthes lapidosa var. *lanceolate*

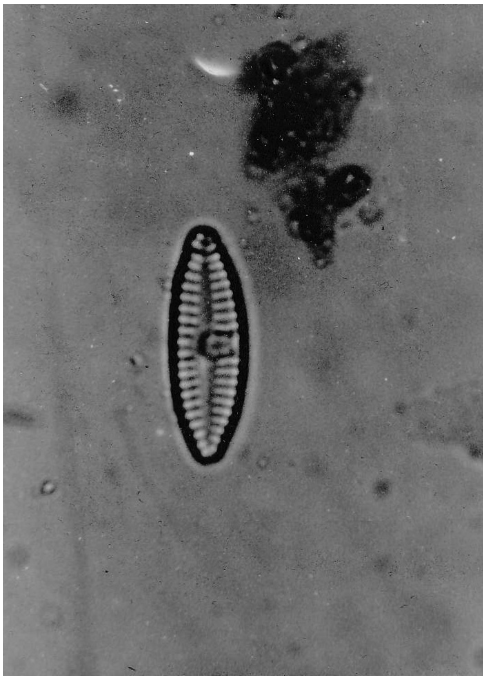


Achnanthes linearis var. *linearis*

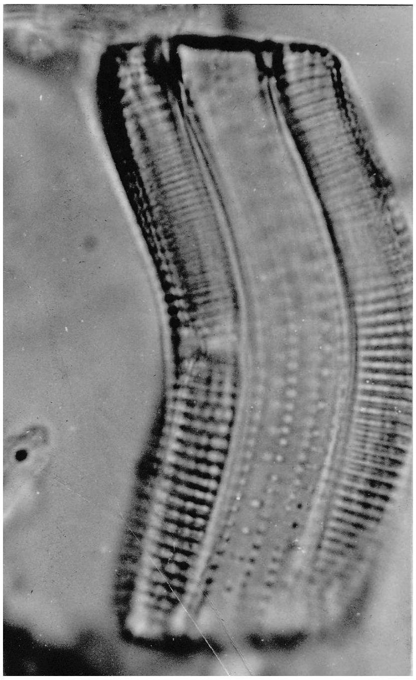
Figure 2. Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.



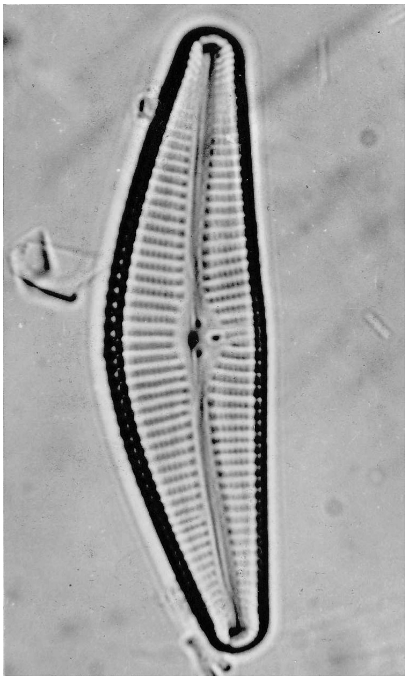
Achnanthes stauroneiformis



Achnanthes lapidosa var. *lanceolata*

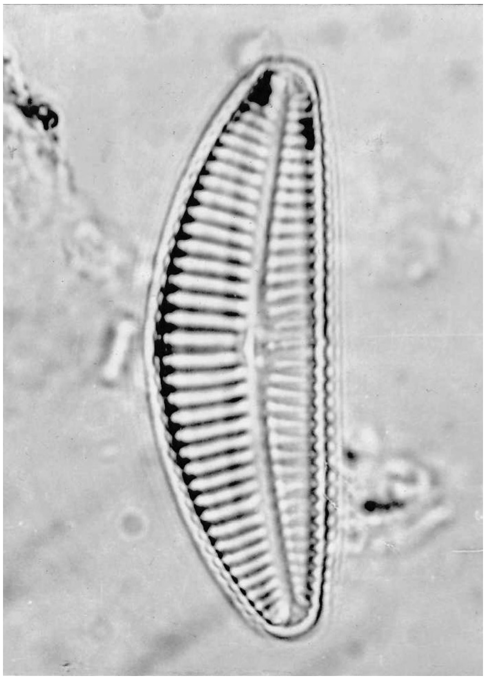


Achnanthes brevipes var. *intermedia*

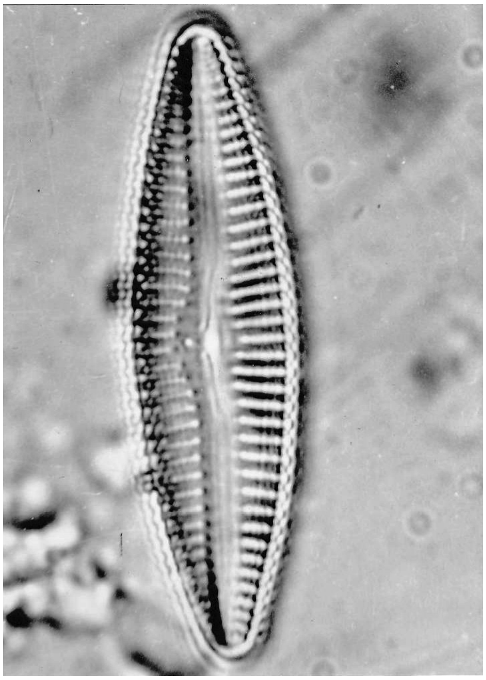


Cymbella sumatrensis fo. malayensis

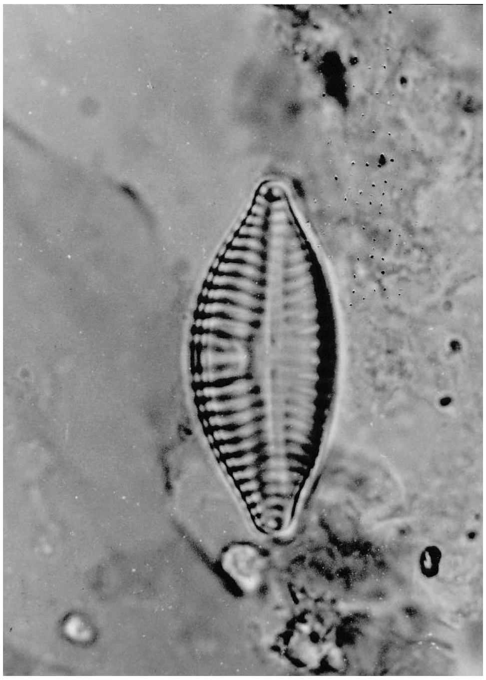
Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.



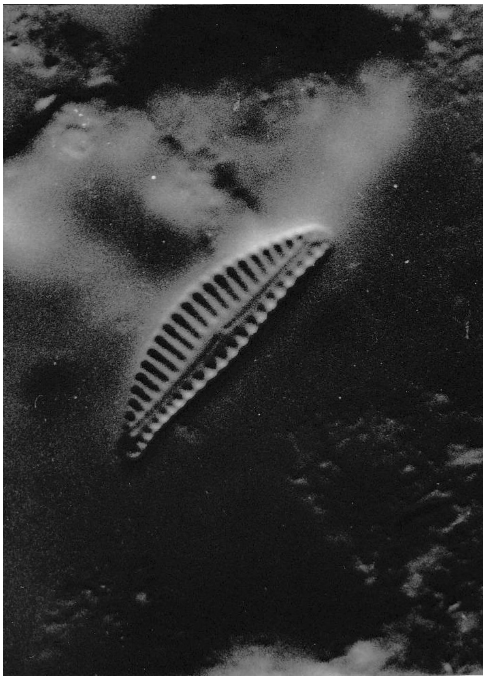
Cymbella sumatrensis



Cymbella japonica

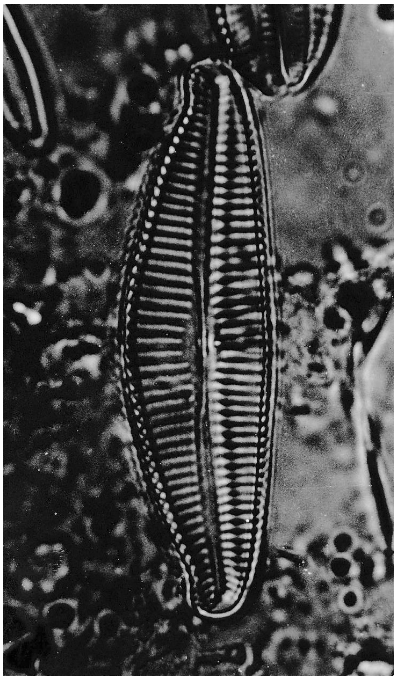


Cymbella cuspidata

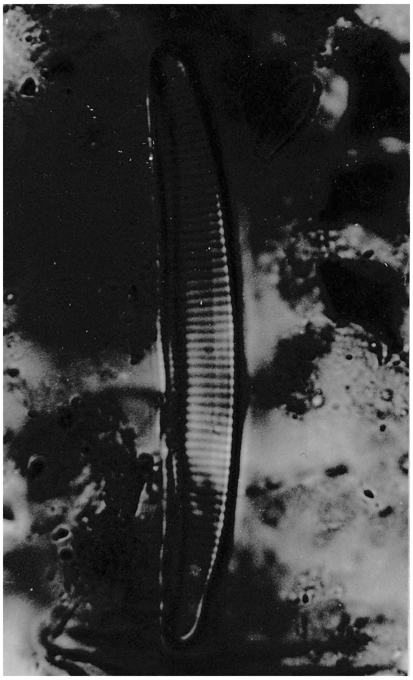


Cymbella minuta var. *minuta*

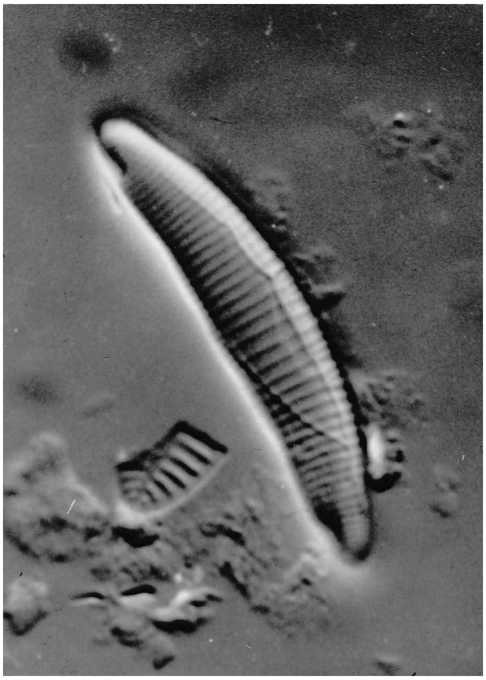
Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.



Cymbella turgida



Eunotia pectinalis

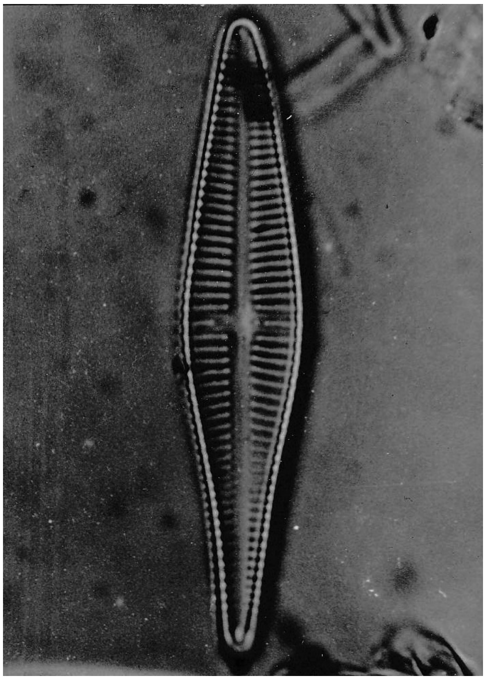


Eunotia vanheurckii

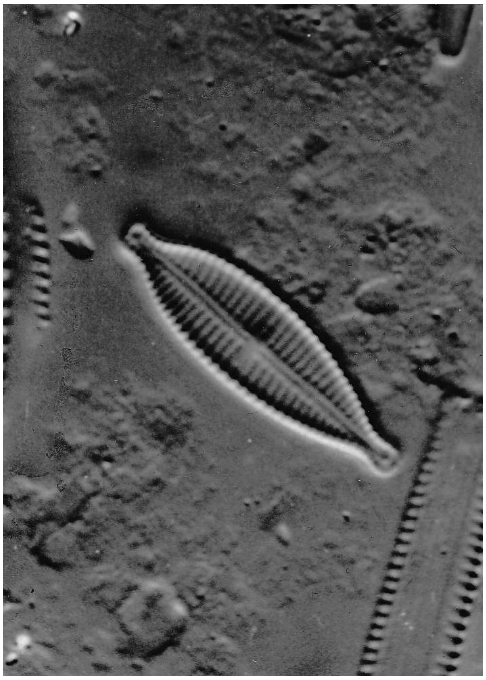
Eunotia rhomboidea

Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

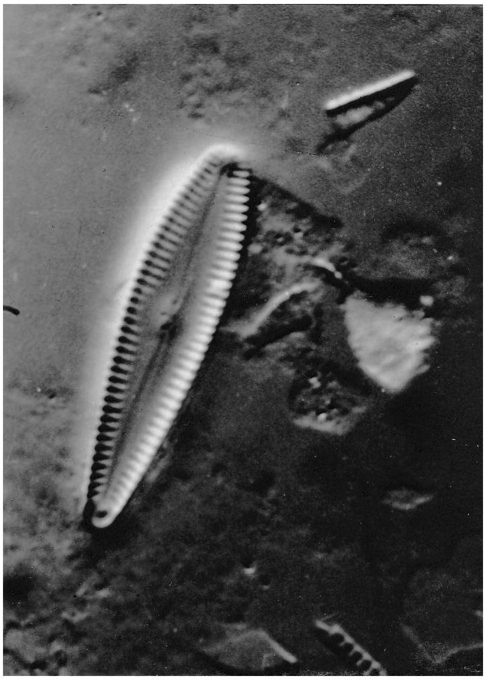
Gomphonema augustatum var. *producta*



Gomphonema longiceps



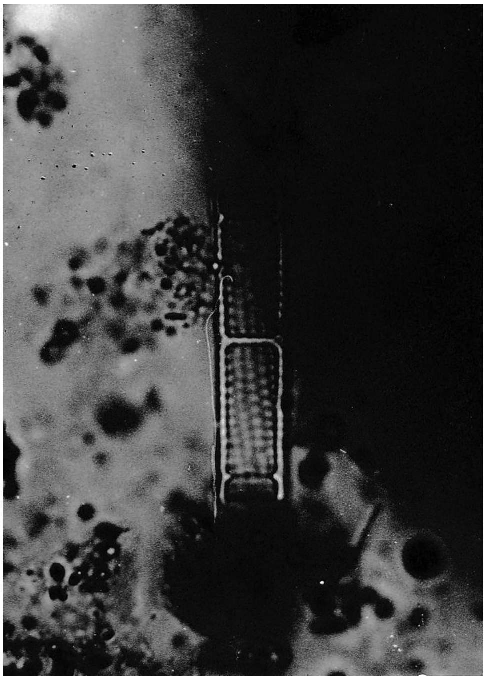
Gomphonema parvulum



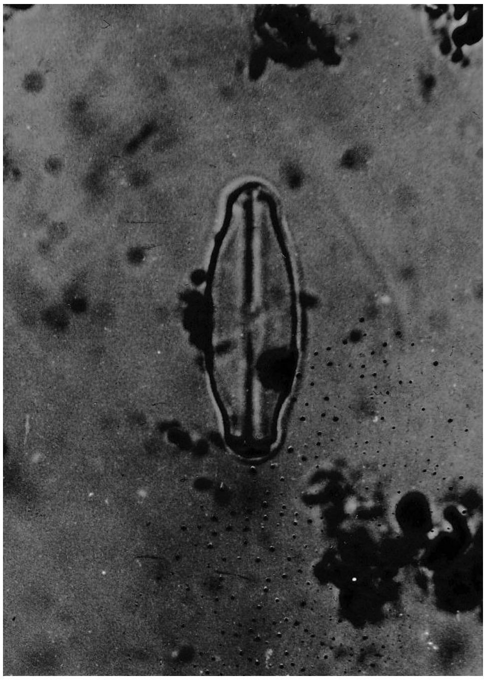
Gomphonema clevei var. *inaequilongum*

Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

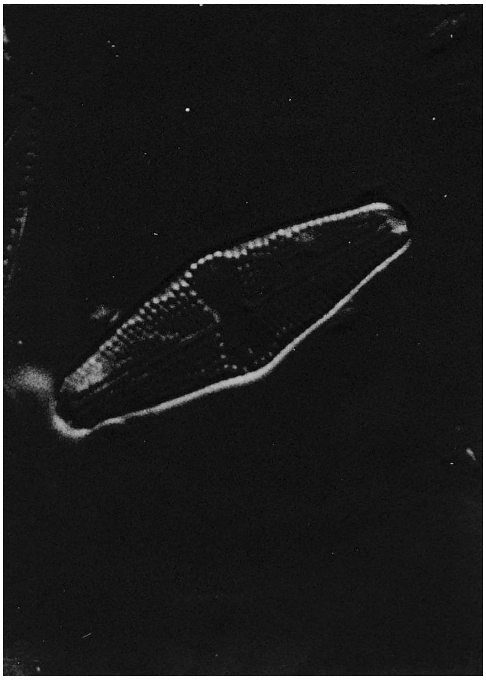
Gomphonema gracile



Melosira granulata



Navicula amphibola

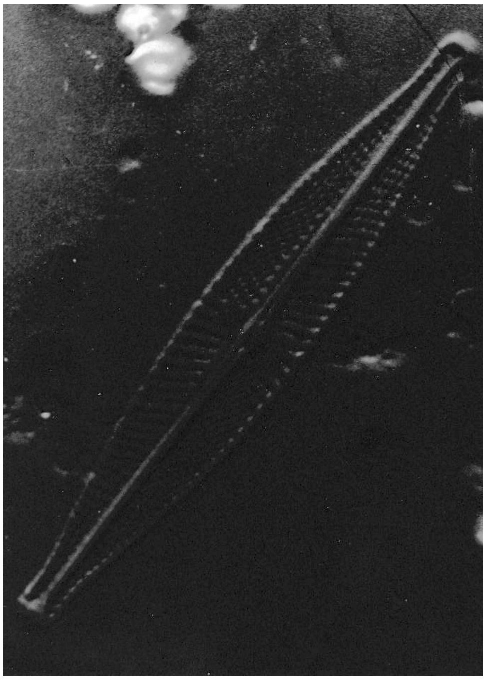


Navicula mutica fo. intermedia

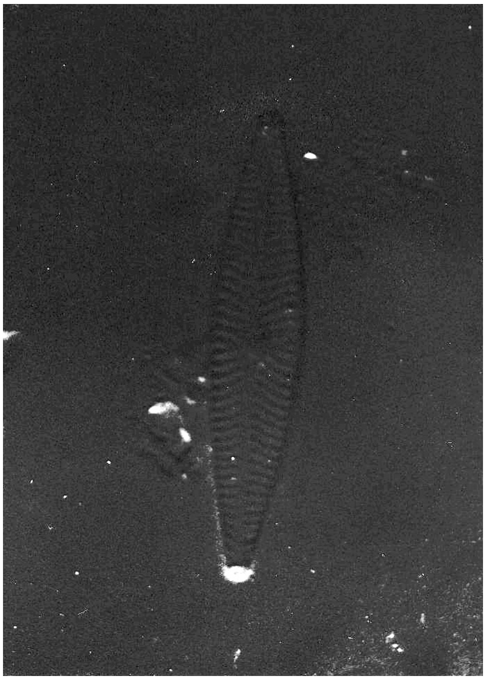
Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

Navicula pavillardi

Navicula pupula fo. capitata



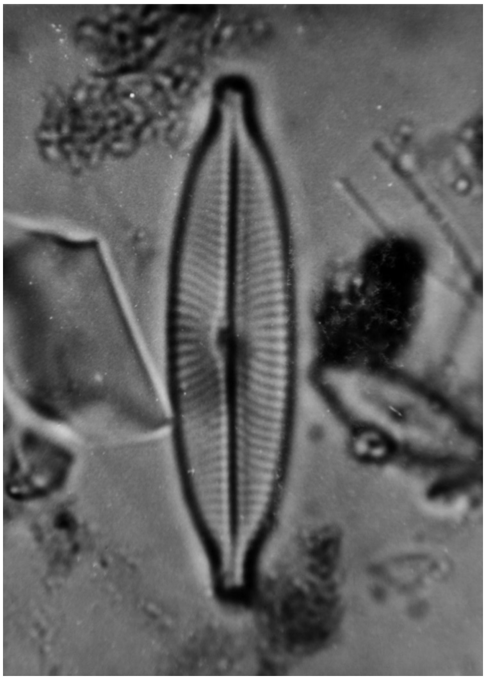
Navicula senjoensis



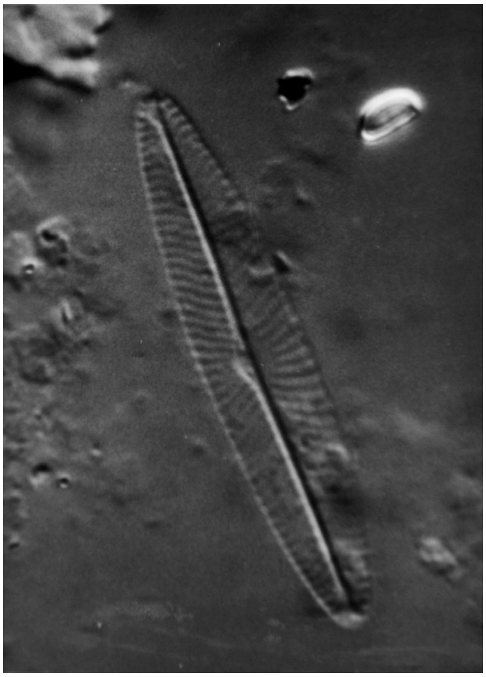
Navicula veneta

Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

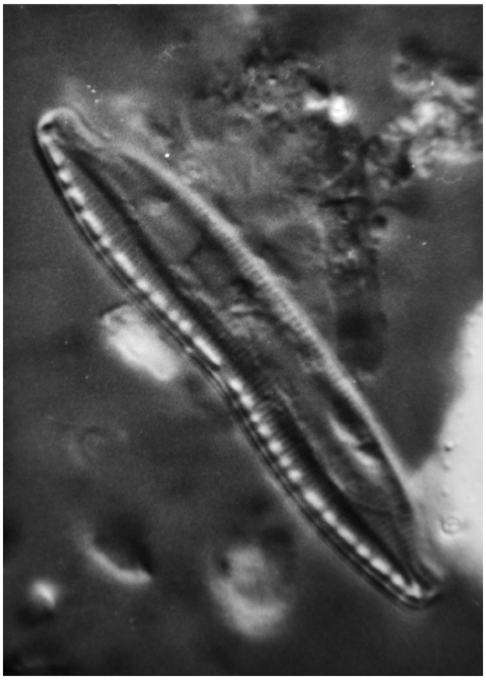
Navicula globosa



Navicula rhyncocephala



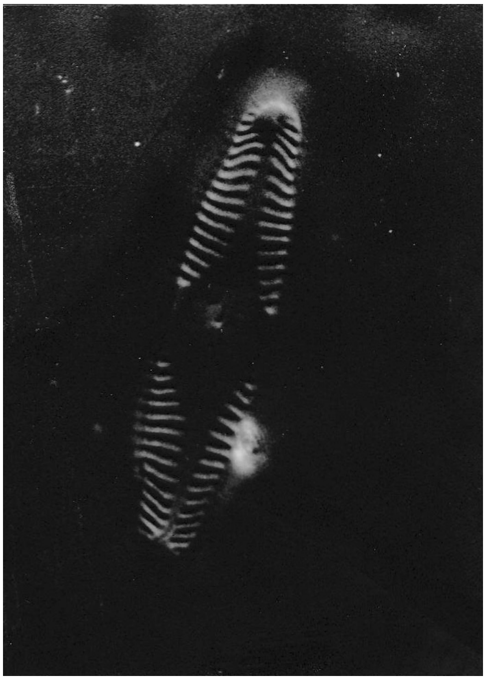
Navicula liboensis



Nitzschia amphioxys

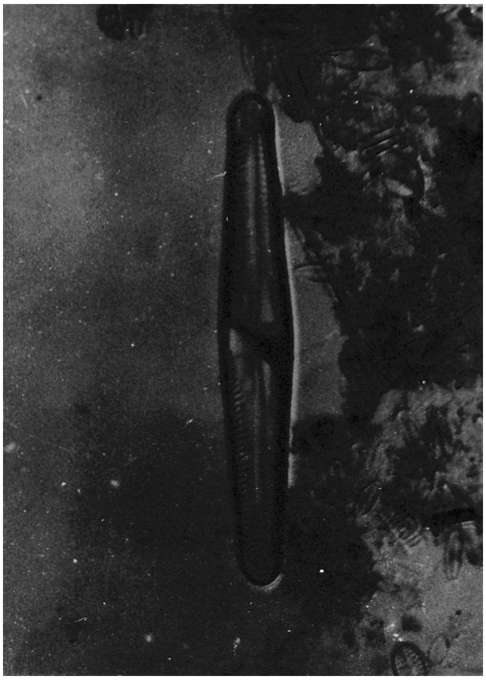
Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

Nitzschia palea var. *braunii*



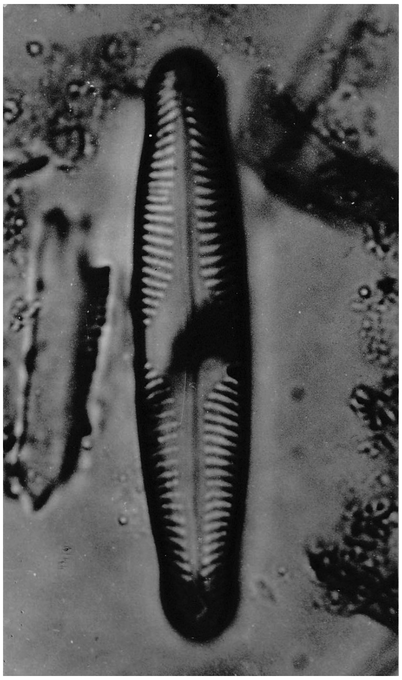
Pinnularia braunii

Pinnularia braunii var. *amphicephala*

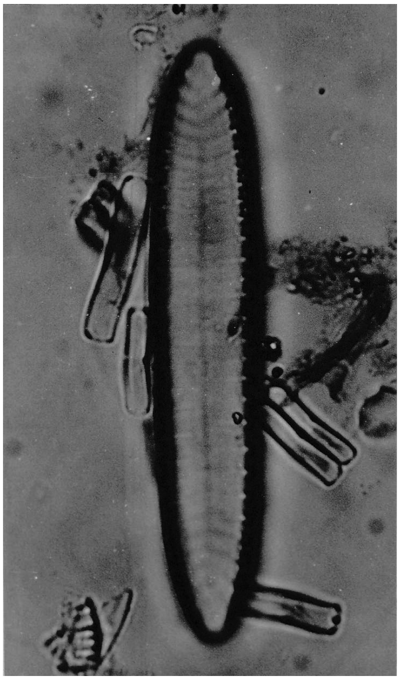


Pinnularia gibba var. *interrupta*

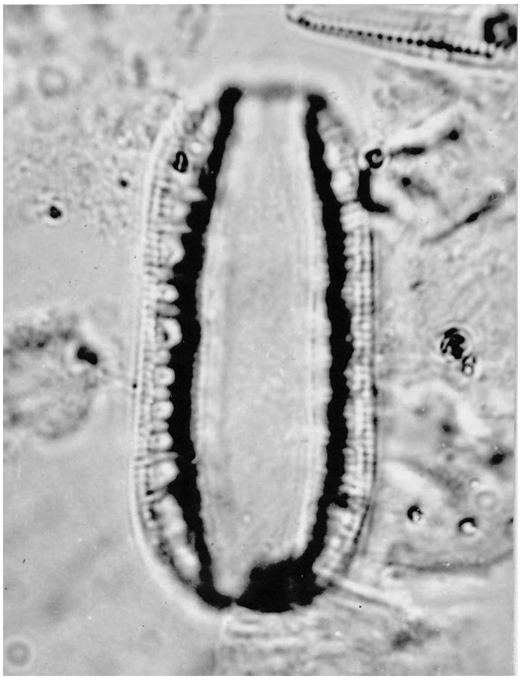
Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.



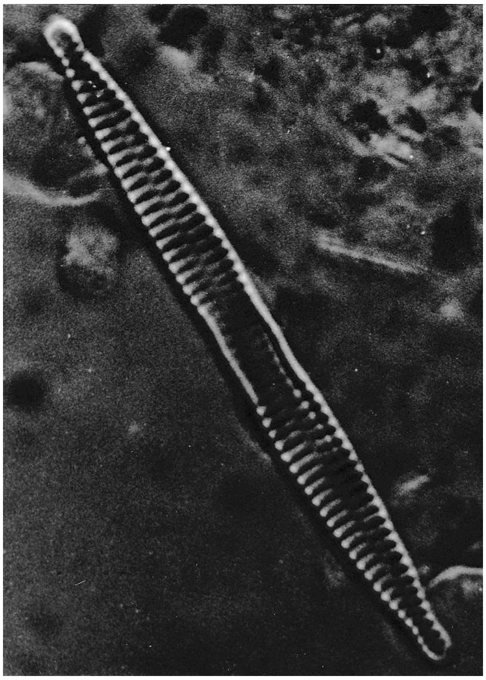
Pinnularia microstauron



Surirella tenuissima



Surirella angusta



Synedra rumpens var. *fragilarioides*

Figure 2. (Cont.) Periphytic diatoms recorded in the Linggi (s.s.) and Kundor rivers.

CONCLUSION

The periphytic diatoms were collected from both natural and artificial substrates comprised of 86 taxa (82 pennate and 4 centric forms) belonging to 21 genera. The number of diatom species observed between stations varied from 22 to 47 species under 8 to 16 genera respectively. On the whole, annual mean number of species varied from 8 to 22; the minimum species at Station 9, heavily polluted with rubber effluent and the maximum species at Station 3 mildly polluted with rubber effluent. The most common diatoms, if both the rivers combined were *E. vanheurckii*, *G. parvulum*, *N. palea*, *P. braunii*, *N. cryptocephala*, *A. saxonica*, *A. minutissima* and *P. microstauron*. The most abundant species were *E. vanheurckii*, *N. palea*, *A. saxonica*, *G. parvulum* and *A. minutissim*.

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