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THE BENTHIC DIATOM FLORA OF SALINE LAKE GREVELINGEN (S.W. NETHERLANDS)*

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SUMMARY

A floristic survey of the benthic diatom flora of brackish Lake Grevelingen, a former estuary in the S.W. Netherlands, revealed the presence of 189 pennate taxa (42 genera) and 31 centrical taxa (18 genera). Information on habitat, presence and abundance of the diatom species has been added. Of these 220 taxa 21 species are reported as new for the Netherlands' diatom flora. The diatom assemblage of Lake Grevelingen differs considerably from that of part of the Oosterschelde and of the Wadden Sea.

1. INTRODUCTION

The benthic diatomflora of marine and estuarine environments in The Netherlands has been studied incompletely. For the Wadden Sea (HUSTEDT 1939, BROCKMANN 1950, VAN DER WERFF 1960, COLIJN & KOEMAN 1975, COLIJN & DIJKEMA 1981) and the former Zuiderzee (VAN DER WERFF 1931–1936) only a small number of publications are available. For the Delta area (S.W. Netherlands) only two local preliminary studies on the benthic diatomflora exist (VAN DER TOORN 1960, MUNDA 1967).

HUSTEDT (1955) showed that in diatom taxonomy still a lot of work has to be done when he described 89 new species out of a total of 369 species found in only two mud samples collected in North Carolina (U.S.A.).

The primary aim of this study was to produce a survey of the diatom flora in an area of The Netherlands where very little information is available on taxonomy and ecology of benthic diatoms. A second aim was to discuss the possible changes in diatom species composition caused by the changed hydrographical situation in Lake Grevelingen during the last decade.

2. MATERIAL AND METHODS

Samples were taken in September 1978 and in the period January-July 1979. Sampling stations are shown in *fig. 1* and *table 1* together with a number of environmental parameters. In 1978 24 samples from seven localites (B_2; B_3; B_4; B_7; L_2; L_6; and L_{10}) were analysed. In 1979 sampling occurred more frequently, as indicated in *table 1*. A total number of approximately 50 samples were analysed in 1979. Benthic (B_1–B_7; sediment bottom deeper than 0.75 m below water level) and littoral (L_1–L_{10}; macrophytes, stones etc. in shallow nearshore

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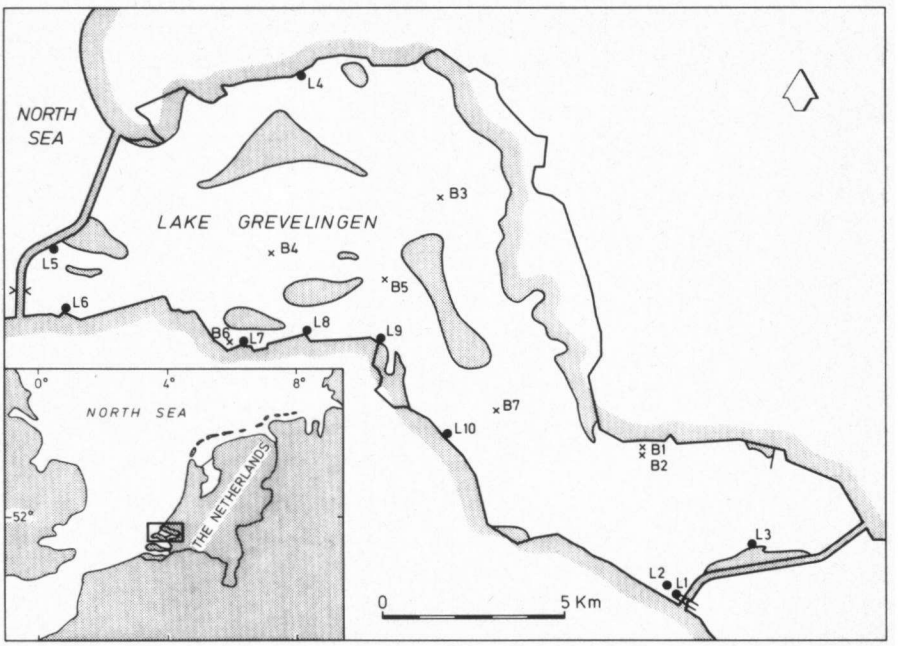

Fig. 1. Lake Grevelingen with sampling stations for diatoms.

areas) samples were distinguished (*fig. 1*). Benthic sampling occurred by means of perspex tubes (surface area 1–4 cm^2), that were pushed into the sediment, either from a ship or by means of SCUBA-divers. The upper 0.5 cm of a number (1–5) of cores from the same locality were mixed. Subsamples were used for preparing microscopic slides (cover slip 24 × 24 mm). Epilithic and epiphytic samples were taken by scraping off the microphytobenthos from its

Table 1. Benthic and littoral sampling stations and sedimentparameters in Lake Grevelingen

Stations	Water depth	% silt	Median grainsize	Sampling dates 1978	1979			
B_1	1 m	< 3%	125μ		7-2	13-3	10-5	
B_2	2 m	< 3%	130μ	21-9	7-2	13-3	5-4	4-5
B_3	2.5 m	5%	155μ	21-9	7-2	13-3	5-4	4-5
B_4	3 m	< 3%	250μ	21-9	7-2	13-3	5-4	4-5
B_5	17 m	10%	155μ			13-3	5-4	
B_6	0.75 m	20%	90μ			24-1		
B_7	3 m	15%	100μ	21-9				
L_1	<0.75 m	–	–		5-4			
$L_{2,6,10}$	<0.75 m	–	–	28-9	3-7			
$L_{3,4,5,7,9}$	<0.75 m	–	–		24-1			
L_8	<0.75	–	–		29-5			

substratum. A total number of approximately 300 microscopic slides (150 littoral, 150 benthic) were searched for diatoms. Samples were oxidized with H_2O_2 and a saturated $KMnO_4$ solution as described by VAN DER WERFF (1957–1974). Permanent slides were made using Clearax (Gurr) as a mounting medium. For the identifications a Beck microscope (Beck, Kassel) magnification × 1000, with phase-contrast illumination was used. A rough estimate for presence and abundance of the diatoms in the microscopic slide was added to the identifications (*table 2*). Microphotographs were taken on a Zeiss Groszes Universal Forschungs-microscope using Agfa Ortho 25 professional film. Most species identified have been documented by permanent slides and by photographs (Delta Institute).

The literature most frequently used for the identifications was HUSTEDT (1930–1966, 1930, 1939, 1955), HENDEY (1951, 1964), CLEVE-EULER (1951–1955) and VAN DER WERFF & HULS (1957–1974). Besides the following literature has been consulted: BROCKMANN (1950), COLIJN & KOEMAN (1975), COLIJN & NIENHUIS (1978), EDSBAGGE (1978), PANKOW (1976), PERAGALLO & PERAGALLO (1897–1908) and SIMONSEN (1959, 1960, 1962). For nomenclature of the taxa Van Landingham (1967–1979) was followed.

Table 2 Alphabetic list of the diatoms in Lake Grevelingen
A = habitat: littoral (l), benthic (b), both (lb), unknown, mostly planktonic (x).
B = presence (quantitative distribution over the samples): common (c), rather common (rc), rather rare (rr), rare (r)
C = abundance (quantitative distribution within the samples): very abundant (va), abundant (a), frequent (f), occasional (o), scarce (s)

I. Pennales	A	B	C
Achnanthes brevipes Ag.	l	rr	o
var. intermedia (Kütz.) Cl.	l	rc	f
A. brockmannii Simonsen	b	r	s
A. clevei var. rostrata Hust.	b	c	o
A. hauckiana Grun.	lb	rr	s
A. lemmermannii Hust.	l	r	o
A. cf. linkei Hust.	b	c	a
A. longipes Ag.	l	rc	o
A. stroemii Hust. syn. A. fimbriata (Grun.) Ross.	b	rr	o
Amphipleura pellucida Kütz.	l	r	s
A. rutilans (Trentepohl ex Roth) Cl.	l	c	a
Amphiprora alata (Ehr.) Kütz.	b	r	s
Amphora angusta Greg.	lb	rc	f
A. arcus Greg.	l	rc	o
A. coffeaeformis (Ag.) Kütz.	b	rc	s
A. exiqua Greg.	lb	rc	o
A. holsatica Hust.	b	r	s
A. laevis var. laevissima (Greg.) Cl.	b	rc	o
A. marina (W. Sm.) v. Heurck	l	rc	s
A. normanii Rabenhorst	lb	r	s
A. ostrearia Bréb.	lb	r	s
A. ovalis Kütz.	b	c	a

	A	B	C
A. proteus Greg.	b	c	f
A. ventricosa Greg.	lb	rr	o
A. wisei (Salah) Simonsen	x	r	s
Anomoeoneis sculpta (Ehr.) Cl.	l	r	s
Bacillaria paradoxa Gmelin	lb	rc	f
Caloneis brevis Greg.) Cl.	b	c	f
C. liber (W. Sm.) Cl.	b	rr	s
C. linearis (Grun.) Boyer	b	r	s
Campylodiscus clypeus Ehr.	b	r	s
C. echeneis Ehr.	b	rr	s
C. fastuosus Ehr.	l	r	s
Campylosira cymbelliformis (A. Schmidt) Grun.	b	rr	s
Catenula adhaerens Mereschkowsky	b	rc	f
Cocconeis californica Grun	l	r	o
C. costata Greg.	lb	rr	o
C. disculus (Schumann) Cl.	b	r	s
C. distans Greg.	b	r	s
C. pediculus Ehr.	b	r	s
C. peltoides Hust.	b	c	a
C. placentula Ehr.	lb	rc	o
var. euglypta (Ehr.) Grun.	lb	rc	o
C. scutellum Ehr.	lb	c	f
var. stauroneiformis (v. Heurck) Okuno	lb	rc	o
C. sublittoralis Hendey	l	r	s
C. tenuis Hust.	x	r	s
Cylindrotheca closterium (Ehr.) Reimann et Lewin	lb	c	o
C. gracilis (Bréb.) Grun.	lb	rc	o
Cymatopleura elliptica (Bréb.) W. Sm.	l	r	s
C. solea (Bréb.) W. Sm.	b	c	s
Cymatosira belgica Grun.	lb	c	o
Cymbella helvetica Kütz.	l	r	s
C. prostrata (Berkeley) Cl.	lb	c	s
C. sinuata Greg.	lb	r	s
Denticula subtilis Grun.	l	r	o
Dimerogramma fulvum (Greg.) Ralfs	b	r	s
D. minor (Greg.) Ralfs	lb	c	o
var. nana (Greg.) v. Heurck	lb	rr	o
Diploneis aestuarii Hust.	b	rc	s
D. didyma Ehr.	lb	c	f
D. fusca (Greg.) Cl.	b	rr	s
D. lineata (Donk.) Cl.	lb	r	s
D. notabilis (Greville) Cl.	b	rc	o
D. ovalis (Hilse) Cl.	b	c	o
D. smithii (Bréb.) Cl.	b	rc	o
D. weissflogii (A. Schmidt) Cl.	b	r	s
Epithemia zebra (Ehr.) Kütz.	b	r	s
Fragilaria construens var. binodis (Ehr.) Grun.	b	c	s
var. subsalina Hust.	b	c	s
F. heidenii Östrup (syn. F. inflata (Heiden) Hust.)	b	r	s
F. leptostauron (Ehr.) Hust.	b	c	f
F. cf. striatula Lyngb.	l	rc	f
Gomphoneis olivaceum (Hornemann) P. Dawson ex Ross et Simms syn. Gomphonema olivaceum (Lyngb.) Kütz.	b	c	s

	A	B	C
Grammatophora angulosa Ehr.	b	c	s
G. marina (Lyngb.) Kütz.	l	rc	o
G. oceanica (Ehr.) Grun.	l	rc	o
var. macilenta (W. Sm.) Grun.	l	rc	s
Gyrosigma compactum (Greville) Cl.	b	rr	o
G. fasciola (Ehr.) Griffith et Henfrey	lb	rc	o
G. littorale Griffith et Henfrey	lb	rc	s
G. prolongatum (W. Sm.) Griffith et Henfrey	lb	c	f
G. prolongatum var. closterioides (Grun.) Cl.	lb	c	f
G. rectum (Donk.) Cl.	b	r	s
G. spencerii (W. Sm.) Griffith et Henfrey	b	r	s
G. tenuissimum (W. Sm.) Griffith et Henfrey	b	r	s
Hantzschia vivax (W. Sm.) M. Peragallo	b	r	s
Licmophora abbreviata Ag.	l	rc	a
L. ehrenbergii (Kütz.) Grun.	l	rc	f
L. ehrenbergii f. angustata Grun.	l	rc	o
L. nubecula (Kütz.) Grun.	l	rc	o
L. paradoxa (Lyngb.) Ag.	l	rc	f
var. tincta (Ag.) Hust.	l	rc	o
Mastogloia smithii Thwaites ex W. Sm.	b	c	s
Navicula abrupta (Greg.) Donk.	b	rc	o
N. abscondita Hust.	b	r	o
N. arenaria Donk.	lb	rr	o
N. avenacea (Bréb.) Cl.	b	r	s
N. cancellata Donk.	b	rr	o
N. capitata var. hungarica (Grun.) Ross	b	r	s
N. cincta (Ehr.) Ralfs	b	c	f
N. comoides (Dillwyn) H. et M. Peragallo	l	rc	f
N. complanatula Hust.	l	rr	o
N. crucicula (W. Sm.) Donk.	b	r	s
N. crucifera Grun.	b	rc	o
N. crucigera (W. Sm.) Cl.	lb	c	a
N. digitoradiata (Greg.) Ralfs	lb	rc	o
N. directa (W. Sm.) Ralfs	lb	c	a
N. dissipata Hust.	b	r	s
N. dithmarsica König	b	c	a
N. finnmarchica (Cl. et Grun.) Cl.	b	rr	o
N. forcipata Greville	b	rc	s
N. gracilis Ehr.	l	rc	o
N. granulata J. W. Bailey	lb	r	o
N. grevillei (Ag.) Heiberg	l	c	a
N. hennedyi W. Sm.	lb	s	o
N. humerosa Bréb. ex W. Sm.	l	r	s
N. hyalinula De Toni	l	r	s
N. latissima f. constricta Karsten	l	rc	s
N. lyra Ehr.	b	r	s
var. atlantica A. Schmidt	b	rr	o
N. marina Ralfs	b	r	s
N. menisculus Schumann	b	rc	f
N. mollis (W. Sm.) Cleve	lb	rc	f
N. mutica Kütz.	b	c	s
N. palpebralis Bréb. ex W. Sm.	l	c	s
N. peregrina (Ehr.) Kütz	b	r	s

	A	B	C
N. pygmaea Kütz.	b	r	s
N. rhynchocephala var. amphiceros (Kütz.) Grun.	x	r	s
N. rostellata Kütz.	b	rc	o
N. salinarum Grun.	b	r	s
N. trivialis Lange – Bertalot syn. N. lanceolata (Ag.) Kütz.	l	rc	s
Nitzschia acuminata (W. Sm.) Grun.	lb	rr	p
N. angularis W. Sm.	lb	rr	o
N. bilobata W. Sm.	lb	rr	o
N. coarctata Grun.	b	rc	o
syn. N. punctata var. coarctata Grun.			
N. constricta (Kütz.) Ralfs	b	r	s
syn. N. apiculata (Greg.) Grun.			
N. frustulum (Kütz..) Grun.	lb	rc	f
N. hummii Hust.	b	rr	f
N. hungarica Grun.	b	rr	o
N. kützingiana Hilse	lb	r	s
N. longissima (Bréb.) Grun.	b	r	s
var. reversa Grun.	b	r	s
var. closterium (Ehr.) v. Heurck	b	r	s
N. navicularis (Bréb.) Grun.	lb	r	s
N. panduriformis Greg.	x	r	s
N. punctata (W. Sm.) Grun.	b	r	s
N. pungens var. atlantica Cl.	b	r	s
N. sigma (Kütz.) W. Sm.	b	rr	o
N. sigmoidea (Nitzch) W. Sm.	b	c	s
N. socialis Greg.	b	rc	s
N. tryblionella var. levidensis (W. Sm.) Grun.	b	r	s
Opephora martyi Héribaud	lb	r	s
O. pacifica (Grun.) Petit	lb	c	o
Pinnularia cruciformis (Donk.) Cl.	b	r	s
Plagiogramma cf. laevis (Greg.) Ralfs	b	r	s
P. staurophorum (Greg.) Heiberg	lb	rc	f
Pleurosigma aestuarii (Bréb.) W. Sm.	lb	rr	s
P. angulatum (Quekett) W. Sm.	b	r	s
P. elongatum W. Sm.	lb	c	s
P. formosum W. Sm.	lb	c	o
P. intermedium var. nubecula (W. Sm.) v. Heurck	lb	rr	o
P. normannii Ralfs	l	rc	f
Rhabdonema arcuatum (Ag.) Kütz.	l	rc	f
var. robusta (Grun.) Hust.	l	rc	f
R. minutum Kütz	l	rr	o
Rhaphoneis amphiceros Ehr.	lb	c	o
R. nitida (Greg.) Grun.	b	r	s
R. surirella (Ehr.) Grun.	lb	c	o
Rhoicosphenia curvata (Kütz.) Grun.	l	c	a
R. marina (W. Sm.) Schmidt	l	rr	s
Rhopalodia gibberula var. musculus (Kütz.) Cl.	b	r	s
Scoliopleura tumida (Bréb.) Rabenhorst	b	r	s
Stauroneis cf. decipiens Hust.	l	rc	o
Striatella unipunctata (Lyngb.) Ag.	l	r	s
Surirella fastuosa Ehr.	b	rr	s
S. gemma Ehr.	b	r	s
S. ovata var. crumena (Bréb. ex Kütz.) Hust.	b	r	s

	A	B	C
S. striatula Turpin	b	r	s
Synedra closterioides Grun.	b	r	s
S. crystallina (Ag.) Kütz	b	rc	s
S. gaillonii (Bory) Ehr.	l	r	s
S. investiens W. Sm.	l	rr	f
S. tabulata (Ag.) Kütz.	lb	c	va
var. acuminata (Grun.) Hust.	lb	rc	s
S. tabulata var. fasciculata (Kütz.) Hust.	lb	c	a
S. ulna (Nitzsch) Ehr.	l	r	s
Thalassionema nitzschioides (Grun.) v. Heurck	lb	rr	o
Trachyneis aspera (Ehr.) Cl.	b	r	s
II. *Centrales*			
Actinocyclus ehrenbergii Ralfs syn. A. octonarius Ehr.	x	r	s
Actinophtychus splendens (Shadbolt) Ralfs	l	c	o
A. undulatus (J. W. Bailey) Ralfs	lb	rr	s
Aulacodiscus argus (Ehr.) A. Schmidt	l	r	s
Auliscus sculptus (W. Sm.) Ralfs	b	rr	o
Biddulphia aurita (Lyngbye) Bréb. et Godey	l	rc	f
B. pulchella S. F. Gray	lb	c	o
B. rhombus (Ehr.) W. Sm.	x	c	o
Cerataulus turgidus Ehr.	b	r	s
Chaetoceros brevis Schütt	x	rc	o
Coscinodiscus concinnus W. Sm.	x	r	s
C. nodulifer A. Schmidt	l	rc	s
Cyclotella meneghiniana Kütz.	lb	c	o
C. striata (Kütz.) Grun.	l	c	o
C. trichonidea Economou-Amilli	l	r	s
Ditylum brightwellii (T. West) Grun.	x	rc	o
Hyalodiscus scoticus (Kütz.) Grun.	l	c	a
Melosira granulata (Ehr.) Ralfs	l	c	s
M. moniliformis (O. F. Müller) Ag.	x	rc	o
M. nummuloides (Dillwyn) Ag.	x	rr	o
M. westii W. Sm.	x	rr	o
Paralia sulcata (Ehr.) Cl.	x	rr	o
Podosira stelliger (J. W. Bailey) Mann	lb	r	s
Porosira glacialis (Grun.) E. Jörgensen	x	r	s
Rhizosolenia hebetata f. semispina (Hensen) Gran	l	c	o
Stephanodiscus astraea var. minutula (Kütz.) Grun.	l	c	o
Thalassiosira eccentrica (Ehr.) Cl.	l	c	o
Triceratium alternans J. W. Bailey	x	r	s
T. antediluvianum (Ehr.) Grun.	x	r	s
T. favus Ehr.	x	r	s
T. reticulum Ehr.	x	r	s

3. RESULTS

In *table 2* all identified pennate and centrical species are listed in alphabetical order. Most centrical diatoms are planktonic species, which indicates that a number of the centrical species identified in littoral and benthic samples in fact belong to sedimented plankton. Most species reported in *table* 2 are common

in Dutch estuarine or marine waters. Below, special attention will be paid to those species that are new for the Dutch diatomflora.

Species new for the Dutch diatom flora

Achnanthes brockmannii Simonsen. *Plate 1, 1–2.*
SIMONSEN (1962) p. 40, table I, fig. 1 and 2.
Valves elliptic-lanceolate with rostrate ends. 28–44 μm long (Simonsen: 40–53 μm), 16–22 μm broad (Simonsen: 20–25 μm).
Raphe valve 20, terminal up to 25 striae in 10 μm. Rapheless valve 13–15 striae in 10μm. Raphe straight, central area sigmoid, narrow, reaching the margin of the valve. Scarce, present almost exclusively at Archipel (B4). Both raphe and rapheless valves were found.

Achnanthes stroemii Hustedt. *Plate 1, 3–4.*
HUSTEDT (1930–1966) II, p. 393, fig. 841B.
Valves lanceolate with hardly rostrate ends. Length 38–48 μm (Hustedt 28–38 μm), breadth about 14 μm (Hustedt 10–13 μm). Rapheless valve 13–14 striae in 10 μm (Hustedt 15–16 in 10 μm) and raphe-valve about 19 striae in 10 μm (Hustedt 19). Central striae on raphe-valve alternately longer and shorter. Frequent on Archipel (B4), both valves were found. According to Hustedt *Achnanthes stroemii* is a marine species.

Amphora ventricosa Gregory
HENDEY (1964), p. 269, pl. XXXVIII, fig. 12.
Frustules narrowly elliptical. Valves somewhat elongated slender, semi-lanceolate with acute or sub-acute apices median line straight, and approximate to the ventral margin. Striation very fine and often indistinct 18–20 in 10 μm. Length of the valve 40–80 μm, breadth 8–12 μm. Occasional (B_1, B_2, B_3).

Amphora wisei (Salah) Simonsen
SALAH (1955) p. 101.
SIMONSEN (1962) p. 94, Table III, fig. 11
Small, less than 20 μm long; about 18 course striae in 10 μm. Ventral side of the frustule slightly constricted in the middle. Ends rostrate and curved backwards. Raphe curved, parallel and close to the ventral margin. Only one valve observed but there is no doubt about the determination because of the very characteristic shape of this species.

Caloneis linearis (Grunow) Boyer. *Plate 1,9.*
syn. *Caloneis liber* var. *linearis* (Grunow) Cleve
HENDEY, (1964) p. 230, pl. XXIX, fig. 3.
Valves linear, with parallel sides and broadly rounded apices. Axial area narrow. Central area small, circular. Striation fine, 20–25 striae in 10 μm. Length of valve 50–80 μm, breadth 8–10 μm. Scarce (B_2, B_3, B_4).

Cocconeis californica Grunow. *Plate I, 5–6.*
HUSTEDT (1930–1966), II, p. 343, fig. 796.
Valves elliptic, about 22 μm long and 12 μm broad. Raphe-valve with 16 punctated striae in 10 μm. Raphe straight with narrow, central hardly wider axial area. Narrow hyaline zone along the margin. Rhapheless valve with 13 punctated striae in 10 μm. Striation absent in a zone between the margin and the striated zone along the pseudoraphe, so on the rapheless valve a more or less broad hyaline ring is present. In some epiphytical and epilithical samples, rather scarce (Bruinisse, L2 and Nieuw Bommenede, L8).

Cocconeis sublittoralis Hendey. *Plate 1, 7–8.*
HENDEY (1951) p. 44, pl. XIII, Fig. 1–9.
Valves broadly oval or elliptic lanceolate with rounded apices. Length 25–40 μm, breadth 15–20 μm. Rapheless valve areolated, areoles large, about 8 in 10 μm, arranged in irregular transverse lines, 7–9 in 10 μm. Pseudoraphe curved. Each apex of the valve furnished with one large areole, both of which are situated on the same site of the pseudoraphe. Raphevalve with punctated striae, 10–12 in 10 μm (Hendey 5–7 in 10 μm). Raphe central widening to form a clear central area. Scarce. Identified in epilithic samples from the Grevelingendam (L3).

Cyclotella trichonidea Economou-Amilli
ECONOMOU-AMILLI 1979, p. 468, figs. 1–20.
Frustules undulate; valve 10–31 μm in diameter; marginal zone radially striate, broad, usually exceeding half the valve radius; striae radial, somewhat curved, 13–17 in 10 μm, of variable length, alternately longer and shorter; central zone either bluntly or acutely triangular, infrequently circular or irregular. Up till now this species has been observed only in a lake in Greece.

Dimerogramma fulvum (Gregory) Ralfs.
HUSTEDT (1930–1966), II, p. 120, fig. 643.
Length 42 μm; breadth 10 μm. 10 areolated striae in 10 μm. Striae at the apices slightly radiate. Valves narrowly lanceolate with slightly produced subcapitate apices.
Pseudoraphe very narrow but expanded slightly in the centre of the valve. Scarce, (Archipel, B4).

Gyrosigma compactum (Greville) Cleve
PANKOW (1976) p. 180, fig. 389.
Cells in girdle view rectangular. Valves lanceolate, very slightly sigmoid. Length about 120 μm; breadth 20–25 μm. Raphe strongly sigmoid towards the apices forming one line with the margin of the valve. Transapical striae about 20 in 10 μm, apical striae about 25 in 10 μm. Benthic species, occasional (B_2, B_3, B_7).

Gyrosigma prolongatum (W. Smith) Cleve.
CLEVE-EULER (1952), V, 3 (3), p. 13, fig. 1342a.
Valves narrow, linear lanceolate, with greatly produced and gradually tapering apices, which are turned in opposite directions. Raphe central, central area small, subcircular. Valve surface striate, striation very fine (finer than *Gyrosigma fasciola* (Ehrenberg) Cleve). Length 120–140 μm; breadth 12–14 μm. According to HENDEY (1964) it is a common species from the North Sea. Common, mostly in benthic samples (B_2, B_3, B_4).

Gyrosigma prolongatum var. *closterioides* Grunow.
CLEVE-EULER (1952), V, 3 (3) p. 13, fig. 1342 b.
Valves as the type but the produced apices turned in the same direction. Distribution as the type.

Gyrosigma tenuissimum (W. Smith) Griffith et Henfrey
CLEVE-EULER (1952), V, 3 (3), p. 14, fig. 1343a.
Valve linear lanceolate; 130 μm long, 7 μm broad. About 20 transapical striae in 10 μm; number of apical striae not distinguisable with the used optics. Raphe sigmoid and central. Valve slightly sigmoid with tapering apices. Scarce; Herkingen (B2).

Licmophora nubecula (Kützing) Grunow
HUSTEDT (1930–1966), II, p. 74, fig. 604.
Cells colonial, united by means of mucous stipes. Valves clavate with rounded apices, produced to a narrow linear base, not inflated. Frustules with internal septa, appearing in girdle view as lines

at the upper end of the cell. Valve surface having a distinct pseudoraphe and faint transverse striae. Striae more than 25 in 10 μm. Length of the cell 28–75 μm, breadth 5–10μm.

Navicula comoides (Dillwyn) H. et M. Peragallo. *Plate 1, 10.*
HUSTEDT (1930–1966), III, p. 304, fig. 1423.
PERAGALLO (1897–1907), p. 64, Pl. 8, fig. 13.

Valves elliptic lanceolate with rounded apices; length 16–30 μm, breadth 7–9 μm. Valve surface striate, striae radiate and punctate, 14–18 in 10 μm. In the centre the striation is less dense than towards the apices. Raphe straight, polar nodules removed from the ends of the cell. Axial area narrow, in the centre somewhat widened. Cells in girdle-view quadrate, girdle composed of numerous plicae. *Navicula comoides* lives in mucous tubes. Epilithic or epiphytic common; benthic scarce (B7).

Nitzschia pungens var. *atlantica* Cleve
RYTTER-HASLE (1965) p. 13.

Valves very narrow; needlelike cells with sharp ends. Length 120 μm, breadth 2.5–3 μm. Keel excentric with 15–17 keelpunctae in 10 μm. About 15 punctate striae in 10 μm. Scarce; the species is found in benthic samples (B4) as well as in plankton material.

Pleurosigma intermedium var. *nubecula* (W. Smith) van Heurck
CLEVE-EULER (1952), V, 3 (3), p. 23, fig. 1375c.
PANKOW (1976), p. 184, fig. 388.

Valve lanceolate, very slightly sigmoid with acute apices. Rhaphe central, on the ends of the valve curved slightly in opposite directions. Axial area very narrow with small central area. Length about 120 μm, breadth 16–18 μm. In both directions about 20 striae in 10 μm. Benthic scarce (B1); epilithic common at some places (L3) near the shore.

Rhaphoneis nitida (Gregory) Grunow. *Plate I, 11.*
HUSTEDT (1930–1966) II, p. 177, fig. 683.
CLEVE-EULER (1953a), II, 4 (1) p. 29, fig. 342.
PERAGALLO (1897–1908) p. 330, Pl. 83, fig. 31–34.

Valves broad elliptic with rounded apices; striae radial with clear areoles. The margin is softly punctated. Starting at the margin, shorter striae are formed. The latter do not reach the narrow lanceolate pseudoraphe. About the dimensions there is some disagreement in literature:

Valves from Lake Grevelingen	:	25 μm long, 20 μm broad, 6 striae in 10 μm
Hustedt	:	30–85 μm long, 25–65 μm broad, 4 striae in 10 μm
Cleve-Euler	:	25–30 μm long, 20 μm broad, 5 striae in 10 μm
Peragallo	:	35–90 μm long, 3–4 striae in 10 μm

Peragallo reports a small rounded form of the type: *Rhaphoneis nitida* f. *lyburnica*. The species from Lake Grevelingen fits the best with Cleve-Eulers description and Peragallos figure. It seems not necessary to us to distinguish a separate form of the species because this form only differs in dimensions and number of striae; these should be: length 25–90 μm, width 20–65 μm and 3–6 striae in 10 μm. In Lake-Grevelingen *Rhaphoneis nitida* is present in small numbers mostly in benthic samples (B_3, B_4).

Rhoicosphenia marina (W. Smith). M. Schmidt
HUSTEDT (1930–1966), II, p. 432, fig 880.

Cells cuneate in girdle view, bent. Valves dissimilar, linear-lanceolate, clavate, with both apices obtusely rounded. Internal septa present. One valve: straight raphe, 15–20 striae in 10 μm. The other valve two indistinct polar nodules (better developed than in *R. curvata* a species that resembles *R. marina* strongly) and a narrow pseudoraphe, striae 18–24 in 10 μm. Length of the valve about 30 μm, width 5 μm. Scarce (L_1, L_2).

Synedra investiens W. Smith

HUSTEDT (1930–1966), II, p. 209, fig. 699.

Cells usually solitary but sometimes in short ribbon-like colonies, epiphytic upon the larger algae. Valves small, linear-lanceolate, narrow, with rounded apices. Pseudoraphe narrow, clearly defined. Striae marginal, short, costate, 9–10 in 10 μm. Length of the valve 8 μm - 46 μm, breadth 2–5 μm. Scarce (L_{10}).

Achnanthes cf. *linkei* Hustedt. *Plate I, 12–13.*

HUSTEDT (1939), p. 607, fig. 28–32.

Valves lanceolate or lanceolate-rhombic with strongly produced apices. Both valves are coarsly striated, 10–11 striae in 10 μm. Striae slightly radiate. Raphe-valve with straight and narrow axial area; central striae on one or both sides of the valve sometimes shortened, forming an indistinct central area. The latter varies in shape: very small, more or less quadrangular, or developed more on one side of the valve. On the rapheless valve the central area is often absent but in many cases one or a few central striae are shortened forming a small asymmetric central area. Length of the cells 25–45 μm; width 11–12 μm. Abundant at Archipel (B_4). As for its shape, dimensions and number of striae the species resembles *A. linkei* Hustedt but the shape of the central area especially on the rapheless valve does not correspond to Hustedts description. Examination of slides in Hustedts collection (Institute für Meeresforschung, Bremerhaven) of *A. linkei* revealed that some slide specimens correspond to the material from Lake Grevelingen as for the shape of the central area on both valves. According to Hustedts description the striation on the rapheless valve should always be interrupted centrally in *A. linkei*, but examination of some type-slides showed that this is not necessary. As the striation of *A. linkei* Hustedt is less coarse than that of the Lake Grevelingen specimens it is still doubtful whether the specimens from Lake Grevelingen are really *A. linkei*. (The slides examined in Bremerhaven were number 252/61–63 from Strandwatt vor der Juister Helle, Leg. Linke, nr. J. 1. 28–7–38).

4. DISCUSSION

The hydrographical situation of Lake Grevelingen has changed drastically during the past 20 years and consequently the flora and fauna changed concomitantly (BAKKER 1978; NIENHUIS 1978a, b). Grevelingen estuary was closed by dams at both ends during the period 1964–1971. Tidal movements were extinguished by this operation and saline Lake Grevelingen originated. In 1978 a sluice, connecting Lake Grevelingen with the adjacent North Sea, was opened. The salinity of the water during the period of observation amounted to $13–16^0/_{00}$ Cl^-.

In this study 189 pennate diatom taxa (belonging to 42 genera) and 31 centrical taxa (belonging to 18 genera) were identified. As the study dealt with the benthic flora, most attention was paid to the pennales because centrales are usually planktonic species. For the characteristic species combinations of planktonic diatoms see BAKKER (1978).

It is difficult to trace to which extent the species composition has changed after the closure of the Grevelingen, because data about benthic diatoms before 1971 are completely lacking. The occurrence of ampotixene species (species not adapted to the changeable physical tidal environments; SIMONSEN 1962) in our samples points into the direction of a change from a relatively exposed to a sheltered habitat. Ampotixene species occurring in Lake Grevelingen are: *Achnanthes stroemii, Campylodiscus fastuosus, Cerataulus turgidus, Cocconeis dis-*

tans, Gyrosigma compactum, Licmophora abbreviata, Licmophora ehrenbergii, Licmophora paradoxa, Navicula hennedyi, Rhabdonema arcuatum, Rhabdonema minutum, Striatella unipunctata, Synedra crystallina, (SIMONSEN 1962).

The overall picture reveals a large number of diatom species; most of them are already known from tidal marine and brackish-water habitats along the coast of The Netherlands. The finding of a relatively large number of new species in a relatively short research period should mainly be attributed to the fact that very little research on benthic diatoms was carried out so far in The Netherlands.

Among the large number of pennate species (189) only a few occur commonly in Lake Grevelingen (23). Only 11 out of these taxa occur abundantly or very abundantly viz. *Achnanthes* cf. *linkei, Amphipleura rutilans, Amphora ovalis, Cocconeis peltoides, Navicula crucigera, N. directa, N. dithmarsica, N. grevillei, Rhoicosphenia curvata, Synedra tabulata, S. tabulata* var. *fasciculata.* None of these species is an ubiquist occurring abundantly both in littoral and benthic sites. *Synedra tabulata* approaches this mode of living best, but the diatom is sometimes absent in benthic samples.

VAN DER TOORN (1960) examined the benthic flora of the Zandkreek, part of the Oosterschelde estuary. In the former Grevelingen estuary the discharge of fresh river water was much higher than in the present Zandkreek and it might be expected that the diatom flora of both biotopes showed considerable differences. A comparison of the lists of pennate species of the Zandkreek (1979) and Lake Grevelingen (1979) revealed that only 20% of the Grevelingen species occurred both in the former and latter estuary.

COLIJN & NIENHUIS (1978) investigated the benthic diatom-flora of a part of the Waddensea: about 40% of the species identified for Lake Grevelingen was also found in the tidal Waddensea.

It appears that stagnant Lake Grevelingen has only 20–40% of the benthic diatom species in common with the two tidal coastal habitats. Because of taxonomical and nomenclatural problems it is difficult to unravel which part of the floral differences between the habitats mentioned should be attributed to proper ecological differences.

One might compare Lake Grevelingen morphologically with saline lagoons bordering the Balthic sea. Only a few of the diatom species characteristic for these lagoons (SIMONSEN 1962) do occur actually in Lake Grevelingen. Besides the taxonomical and nomenclatural discrepancies this could be explained by the fact that Lake Grevelingen is a young and evolving biotope.

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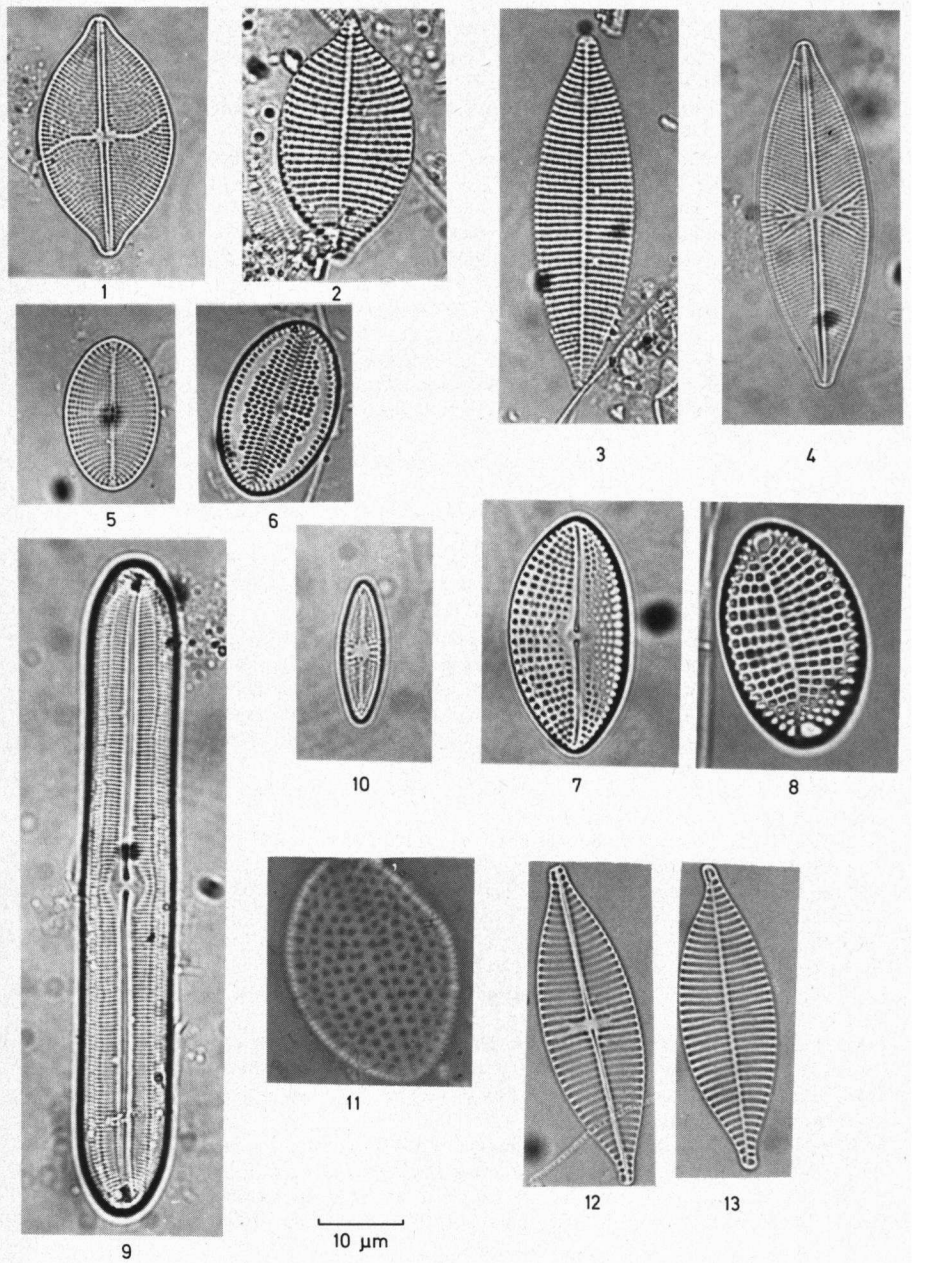

Plate 1. 1,2. Achnanthes brockmannii Simonsen; 3,4. Achnanthes stroemii Hustedt; 5,6. Cocconeis californica Hustedt; 7,8. Cocconeis sublittoralis Hendey; 9. Caloneis linearis (Grunow) Cleve; 10. Navicula comoides (Dillwyn) H. et M. Peragallo; 11. Rhaphoneis nitida (Gregory) Grunow; 12,13. Achnanthes cf. linkei Hustedt.

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