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# Diatom (Bacillariophyceae) flora of salt marshes along the Pacific coast of eastern Hokkaido, northern Japan

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Sixty-seven diatom taxa were identified from Akkeshi and Onnetoh salt marshes along the Pacific coast of eastern Hokkaido, northern Japan. The diatom assemblages consist of thirty-one genera; *Melosira* (1 sp.), *Hyalodiscus* (1 sp.), *Paralia* (1 sp.), *Pseudostaurosira* (1 sp.), *Rhaphoneis* (1 sp.), *Grammatophora* (1 sp.), *Lyrella* (1 sp.), *Mastogloia* (1 sp.), *Rhoicosphenia* (1 sp.), *Staurophora* (1 sp.), *Planothidium* (1 sp.), *Cocconeis* (2 spp.), *Cosmoneis* (1 sp.), *Scolioneis* (1 sp.), *Scolioleura* (1 sp.), *Biremis* (1 sp.), *Frallacia* (1 sp.), *Caloneis* (3 spp.), *Pinnunavis* (2 spp.), *Diploneis* (3 spp.), *Navicula* (7 spp.), *Frustulia* (1 sp.), *Pleuosigma* (1 sp.), *Gyrosigma* (2 spp.), *Amphora* (9 spp.), *Bacillaria* (1 sp.), *Tryblionella* (9 spp. including 2 varieties), *Nitzschia* (4 spp. including 1 variety), *Rhopalodia* (2 spp.), *Entomoneis* (1 sp.), and *Surirella* (3 spp.).

Key Index Words : *Bacillariophyceae, Diatom, flora, Pacific coast, salt marsh*

## Introduction

Diatoms (Bacillariophyceae) are widely distributed in coastal brackish water environments (Stoermer & Smol, 1999). In particular, salt marshes are well known as environments harboring diverse microhabitats for brackish diatoms. Statistical analysis of diatom distribution in salt marshes began with the studies of Sullivan (1975, 1978), as the previous studies were mainly floristic in nature. Some authors have identified specific zones within salt marshes in Europe and America based on the dominant diatoms present (Nelson & Kashima 1996; Sherrod 1999; Sullivan 1975, 1978; Zong & Horton 1998). Others have used salt marsh diatom assemblages to reconstruct sea-level changes (Atwater & Hemphill-Haley 1997; Shennan et al. 1999; Sherrod 1999; Zong & Horton 1999). Except for the study of Sawai (2001), the study of salt marsh diatoms has been ignored in Japan whereas there have been numerous studies of brackish diatoms from river mouths, rocky beaches, and brackish lakes (Goto 1986; Kobayashi et al. 1998; Nagumo & Tanaka 1990, 1994; Nagumo & Mayama 2000; Nigorikawa 1997; Suzuki et al. 1999, 2001a, 2001b, 2001c; Idei 2000). Here we provide preliminary floristic data of brackish diatoms from salt marshes, eastern Hokkaido, northern Japan.

## Study area

Lake Akkeshi is protected from the open sea by a narrow entrance dominated by oyster banks. The lake floor consists mainly of fine sand and mud, and the shore is exposed at low tide. Salt marshes occupy the eastern shores of this lake (Fig. 1). The spring-tide range is 1.2 m and the neap-tide range 0.9 m (Maritime Safety Agency, 1998, p. 386). The extreme tidal range, between the highest and lowest astronomical tides, is 1.7 m. A 200 m transect from the eastern salt marsh, where has a range in salinities of 5-34 ppt was studied and was covering a range of environments from high marsh to low marsh, and tidal flat. *Phragmites communis* and *Spiraea salicifolia* cover the high marsh where sediments are composed of mud (silts and clays). The narrow low marsh is dominated by *Triglochin maritimum* and *Carex subspathacea*. The intertidal tidal flat is about 100 m wide, and the sediments are composed entirely of sand with *Zostera marina* and *Z. japonica*.

The Onnetoh salt marsh is also protected from the sea by a sand barrier (Fig. 1). Lake Onnetoh has the same tidal range as the Akkeshi estuary but the salinity range here is narrower, 2-16 ppt. A transect was selected and the environments were divided into high marsh, low marsh, and tidal flat. Salt marshes occupy between the mean tide level (MTL) and the highest high

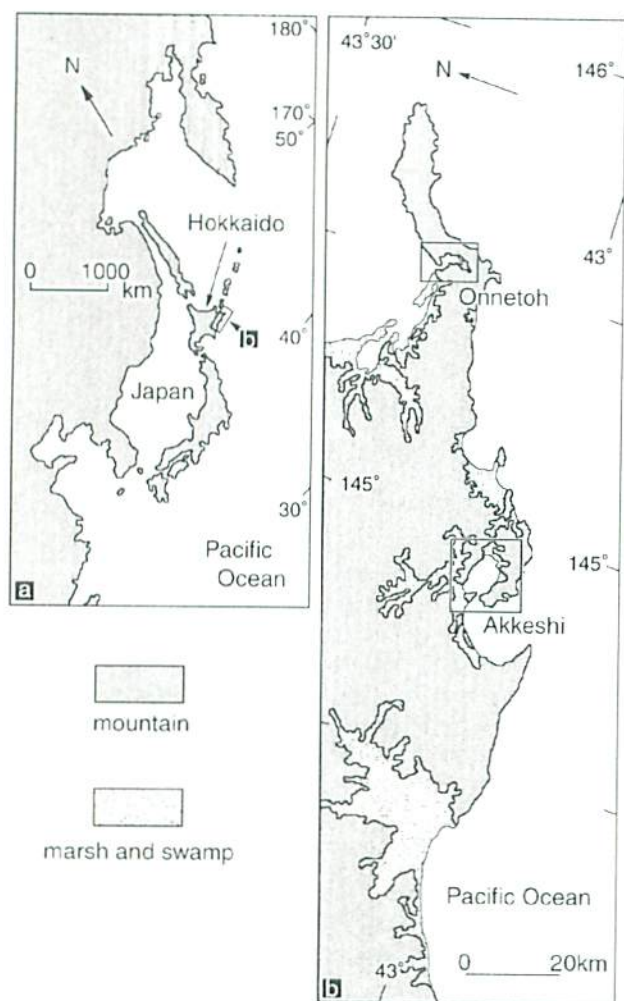


Fig. 1. a: Map of Japan showing Hokkaido. b: Pacific coasts of eastern Hokkaido, northern Japan.

tidal level (HHTL). The marshes are separated into high and low marshes by tide level and dominant species of vascular plants. High marsh is between the level slightly below the mean high tide level (MHTL) and the mean higher high tide level (MHHTL) (Sawai 2001). The high marsh is characterized mainly by *Phragmites communis*, but its downward slope is dominated by *Eleocharis kamschatcica* and *E. acicularis* var. *longiseta*. Low marsh is located below MHHTL and is dominated by *Triglochin maritimum* and *Carex subspathacea*. A little vegetation on intertidal tidal flat where borders the low marsh with a small beach ridge contains *Zostera marina* and *Z. japonica*.

### Materials and Methods

Samples were collected in two transects on 17th May 1999 and 30th May 1999 in Akkeshi and Onnetoh, respectively. Each sample, about 30 ml volume of the sediment, was collected from the sediment-water interface using disposable plastic syringes of 10 ml or a small spatula during low tides. After the original samples were mixed in the beakers, 1 cm<sup>3</sup> volume sub-samples were divided using disposable plastic syringes. The sub-samples were treated by a following method. A drop of sodium hypochlorite solution was added to the wet sample in a centrifuge tube. After a few minutes, samples were neutralized by repeated rinses in distilled water using a centrifuge. After the rinsing the samples, an aliquot of the treated samples was fixed to a glass slide using a synthetic resin with MGK-S.

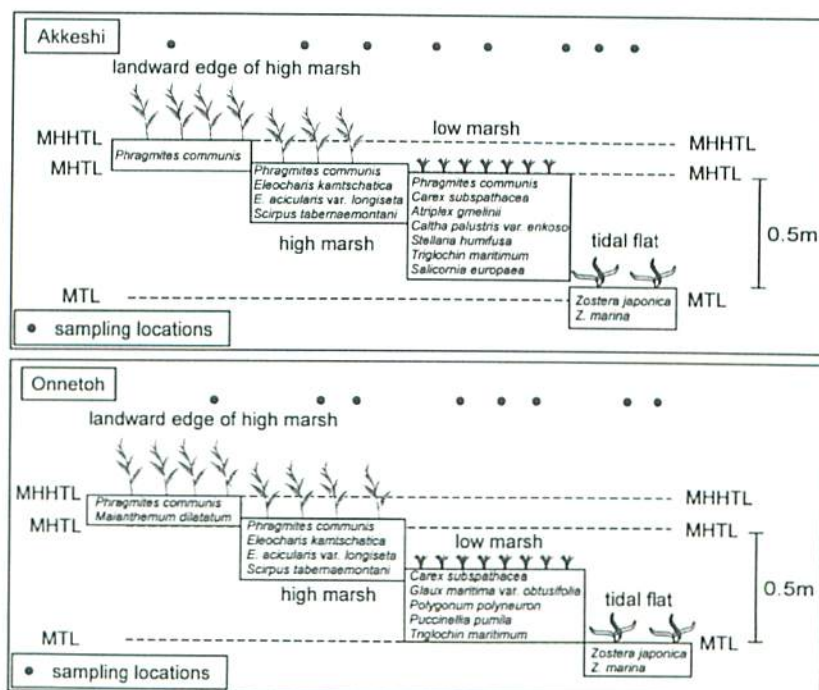


Fig. 2. Transects in Akkeshi and Onnetoh.

**Results**

Coccinodiscophyceae, Coccinodiscophycidae

## MELOSIRALES

*Melosira* Agardh*Melosira nummuloides* Agardh; Hustedt (1930) 231, 95, Krammer & Lange-Bertalot (1991a) 11, 8:1-8

Distribution: rare in salt pond on low marsh

*Hyalodiscus* Ehrenberg*Hyalodiscus* sp. cf. *scoticus* (Kützing) Grunow; Snoeijs & Vilbaste (1994) 59 **Plate 2. 25, 26**

Distribution: rare on tidal flat and low marsh in Akkeshi

## PARALIACEAE

*Paralia* Heiberg*Paralia sulcata* (Ehrenberg) Cleve; Hustedt (1930) 276, 120 (as *Melosira sulcata*), Crawford (1979) **Plate 3. 46, 47, 48, 49**

Cells cylindrical, united in straight chains. Valves circular, central area with fine radial markings on the valve face. Separating valves, a few structures and no marginal spines on the valve face. Mantles of sibling valves, with weakly fenestrae.

Distribution: common on low marsh

## FRAGILARIOPHYCEAE, FRAGILARIOPHYCIDAE

## FRAGILARIOPHYCIDAE

## FRAGILARIALES

*Pseudostaurosira* (Grunow) D.M. Williams & Round*Pseudostaurosira bravistriata* (Grunow) D.M. Williams & Round, in Williams & Round (1987)

Distribution: common on high marsh in Akkeshi

## RHAPHONEIDALES

*Rhaphoneis* Ehrenberg*Rhaphoneis surirella* (Ehrenberg) Grunow ex Van Heurek; Hendey (1964) 155, *XXVI:11-13*

Distribution: rare on tidal flat at Akkeshi

## STRIATELLALES

*Grammatophora* Ehrenberg*Grammatophora oceanica* Ehrenberg; Hustedt (1927-1966) 45, 573

Distribution: very rare on tidal flat in Akkeshi

## BACILLARIOPHYCEAE, BACILLARIOPHYCIDAE

## LYRELLALES

*Lyrella* Karajeva*Lyrella lyra* (Ehrenberg) Karajeva; Hustedt (1927-1966) 500, 1548, 1549 (as *Navicula lyra*)

Distribution: rare on sand tidal flat in Akkeshi

## MASTOGLOIALES

*Mastogloia* Thwaites et Smith*Mastogloia smithii* Thwaites; Hustedt (1927-1966) 502, 928a, Krammer & Lange-Bertalot (1986) 434, 201:2-5, 7-9**Plate 3. 36, 37**Valves linear-lanceolate, broadly rounded apices, 20-30  $\mu\text{m}$  long, 8-12  $\mu\text{m}$  wide. Raphe straight, axial area narrow, central area small to slight large, semi-circular. Striae, transapical, radiate, 13-18 in 10  $\mu\text{m}$ . Partectal ring, 1-2  $\mu\text{m}$  wide, rectangular with rounded square, 4-6 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

## CYMBELLALES

*Rhoicosphenia* Grunow*Rhoicosphenia marina* (W. Smith) M. Schmidt; Witkowski *et al.* (2000) 559, 58:8-18

Distribution: rare on low marsh in Onnetoh

*Staurophora* Mereschkowsky*Staurophora amphioxys* (Gregory) D.G. Mann, in Round *et al.* (1990) 482, Hendey (1964) 219, *XXXVII:13-14*, Witkowski *et al.* (2000) 353, 149:13

Distribution: common on low marsh in Onnetoh

## ACHNANTHALES

*Planothidium* Round & Bukhtiyarova*Planothidium delicatulum* (Kützing) Round & Bukhtiyarova; Krammer & Lange-Bertalot (1991b) 70, 39:1-14**Plate 3. 41, 42**Valve elliptical-lanceolate, 10-20  $\mu\text{m}$  long, 5-10  $\mu\text{m}$  wide. Raphid valve, axial area narrow. Central area small indistinct. Striae 9-13 in 10  $\mu\text{m}$ .

Distribution: common on tidal flat in Akkeshi

*Cocconeis* Ehrenberg*Cocconeis pseudomarginata* Gregory var. *intermedia* Grunow; Suzuki *et al.* (2001a)

Distribution: rare in Onnetoh

*Cocconeis scutellum* Ehrenberg; Krammer & Lange-Bertalot

(1991b) 93, 58:1-13, Suzuki *et al.* (1999) 150, 3:1-5

Distribution: common both in Akkeshi and Onnetoh

#### NAVICULALES

*Cosmioneis* D.G.Mann & A.J.Stickle

*Cosmioneis pusilla* (W.Smith) D.G.Mann & A.J.Stickle, in Round *et al.* (1990) 666, Krammer & Lange-Bertalot (1986) 167, 57:7-9 (as *Navicula pusilla*), Witkowski *et al.* (2000) 178, 106:3-4

#### Plate 1. 10

Valves elliptic to elliptic-lanceolate with strongly capitate apices, 30-80  $\mu\text{m}$  long, 15-30  $\mu\text{m}$  wide. Raphe straight, central endings expanded, apical endings bent in one side. Axial area narrow, linear, central area moderately large, circular. Striae coarse, punctate, radiate, 11-14 in 10  $\mu\text{m}$ .

Distribution: common in high marsh in Akkeshi

*Scolioneis* D.G.Mann

*Scolioneis tumida* (Brèbisson ex Kützing) D.G.Mann; Hendey (1964) 234, XXIX:6-7 (as *Scolioleura tumida*)

#### Plate 4. 53, 54, 55

Valves lanceolate or broadly lanceolate twisted about the apical axis, 70-170  $\mu\text{m}$  long, 20-40  $\mu\text{m}$  wide. Raphe external central endings approximate, axial area narrow. Striae transapical fine punctate, slightly radiate in the middle, 12-16 in 10  $\mu\text{m}$ .

Distribution: common on low marsh both in Akkeshi and Onnetoh.

*Scolioleura* Grunow

*Scolioleura peisonis* Grunow; Round *et al.* (1990) 544

Distribution: very rare on high marsh in Onnetoh

*Biremis* D.G. Mann & E.G. Cox

*Biremis ambigua* (P.T. Cleve) D.G.Mann, in Round *et al.* (1990) 548

#### Plate 1. 4

Valves linear, almost bilaterally symmetrical, 20-45  $\mu\text{m}$  long, 5-12  $\mu\text{m}$  wide. Raphe central to eccentric, biarcuate, lying in wide raphe-sternum. Striae slightly radiate, 5-9 in 10  $\mu\text{m}$ .

Distribution: rare on high marsh in Onnetoh

*Fallacia* A.J. Stickle & D.G.Mann

*Fallacia pygmaea* (Kützing) Stickle & D.G.Mann, in Round *et al.* (1990) 554, Hustedt (1927-66) 537, 1574 (as *Navicula pygmaea*), Krammer & Lange-Bertalot (1986) 171, 65:1-6 (as

*Navicula pygmaea*)

#### Plate 2. 19, 20

Valves elliptic-lanceolate, 10-60  $\mu\text{m}$  long, 7-25  $\mu\text{m}$  wide. Raphe not completely straight, external central endings expanded, axial area narrow. Central area small, connected lateral areas. Transapical striae punctate, radiate, 18-25 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

*Caloneis* Cleve

*Caloneis* has been traditionally separated from *Pinnularia* based on alveoli characteristics and the presence of longitudinal lines (Krammer & Lange-Bertalot 1985). However, this distinction is difficult for small species of *Caloneis* lacking clear longitudinal line which closely resemble small *Pinnularia* taxa (Mann 2001). Morphological studies have shown that striae of *Caloneis* are similar to those of the closely related genera, *Pinnularia*, *Oestrupia*, and *Pinnunavis* (elongated chamber or alveolus and areola rows per alveolus) and formed the longitudinal lines (Schrader 1971; Okuno 1975; Hein & Winsborough 2001). They have separated some genera from *Pinnularia* based on the observed structures (*Pinnunavis* in Okuno 1975), but this morphological diagnosis was not substantiated (Krammer 2000). From later 1980's, some studies have shown that plastids, invaginated pyrenoids, and mode of sexual reproduction, and perizonium structure are very similar in *Caloneis* and *Pinnularia* (Cox 1988; Mann 1989, 2001). On basis of these observations, Round *et al.* (1990) suggested to combine *Caloneis* with *Pinnularia*. In contrast to Round *et al.* (1990), Krammer (2000) recently established two new genera, *Hygropetra* Krammer & Lange-Bertalot and *Alveovallum* Lange-Bertalot & Krammer, separated from *Pinnularia* based on fine structure of their copulae, vela, and areolae. Furthermore, he suggested that some marine *Pinnularia* taxa (e.g. *Pinnulaira elegans*) might be tentatively placed to *Pinnunavis* based on physiological characteristics (Krammer 2000). If these Krammer's suggestions were accepted, many small genera including *Caloneis* and *Pinnunavis* could be separated from *Pinnularia*. Mann (2001) warned to this attempt that splitting these alveolate diatoms into a number of smaller genera could cause a "large paraphyletic genera" problem such as occurred in the Naviculaceae. As stated above, taxonomic problems between *Caloneis* and relating taxa are still under controversy. We studied specimens of relating taxa using LM and SEM, but it will need further studies. In this study, we tentatively used *Caloneis*, *Pinnularia*, and *Pinnunavis* based on Cleve's traditional separation and Okuno (1975).

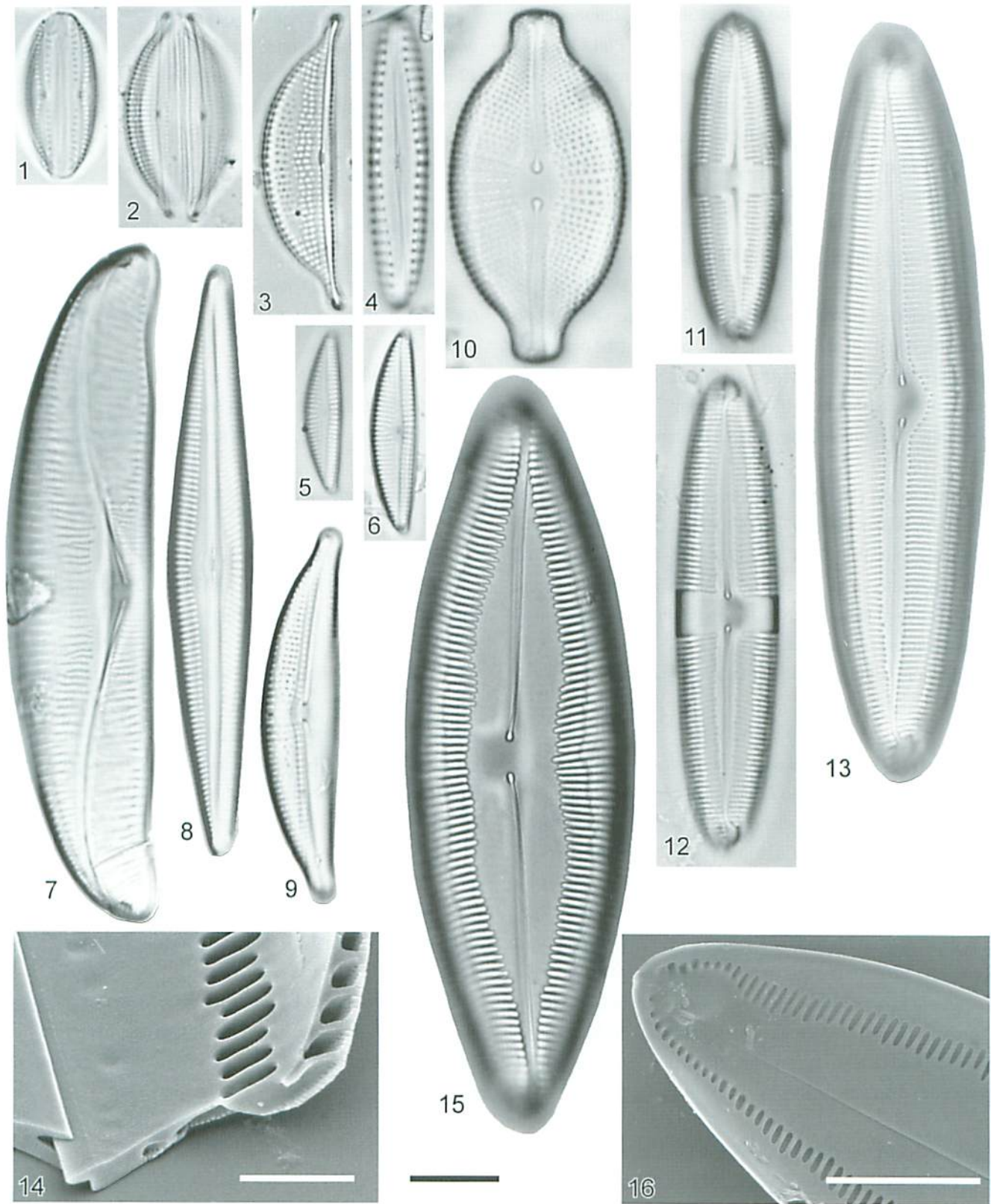


Plate 1.

1. *Amphora helenensis* Giffen, 2. *Amphora salina* W. Smith, 3. *Amphora holsatica* Hustedt, 4. *Biremis ambigua* (P.T. Cleve) D.G.Mann, 5, 6. *Amphora pusilla* Gregory, 7. *Amphora spectabilis* Gregory, 8. *Amphora ventricosa* Gregory, 9. *Amphora* sp.-1, 10. *Cosmioneis pusilla* (W.Smith) D.G.Mann & A.J.Stickle, 11, 12. *Caloneis bacillum* (Grunow) Cleve, 13, 14. *Caloneis oregonica* (Ehrenberg) Patrick, 15, 16. *Caloneis westii* (W.Smith) Hendey. Black scale bar = 10 µm for Figs. 1-13, 15. Scale bar in Fig. 14 = 2 µm. Scale bar in Fig. 16 = 5 µm.

*Caloneis bacillum* (Grunow) Cleve; Patrick & Reimer (1966) 586, 54:8 **Plate 1. 11, 12**

Valve linear or slightly linear lanceolate with rounded or rostrate apices, 15-60  $\mu\text{m}$  long, 4-15  $\mu\text{m}$  wide. Axial area narrow, relatively wide at the center of the valve, narrow at the apices. Central area moderately broad. Striae 15-27 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

*Caloneis oregonica* (Ehrenberg) Patrick, in Patrick & Reimer (1966) 581, 53:6 **Plate 1. 13, 15**

Valve lanceolate with rounded ends, 70-170  $\mu\text{m}$  long, 15-30  $\mu\text{m}$  wide. Axial are narrow at the ends, one-third the breadth at the center of the valve. Central area rounded. Striae radiate, sometimes parallel at the ends, 10-17 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

*Caloneis westii* (W. Smith) Hendey, in Hendey (1964) 230, *XLV:1-13*, Witkowski *et al.* (2000) 167, *152:11* **Plate 1. 14, 16**

Valves lanceolate, 70-170  $\mu\text{m}$  long, 25-40  $\mu\text{m}$  wide. Axial area lanceolate, often irregular, unilateral at the center of the valve. Striae radiate, 11-15 in 10  $\mu\text{m}$ . Outline of valve and of the axial area very variable.

Distribution: common on low marsh in Onnetoh

#### *Pinnunavis* Okuno

Okuno (1975) placed two species *Navicula elegans* and *N. yarrensensis* from *Navicula* to *Pinnunavis* based on *Pinnularia*-type alveolus and the valve shape. The lanceolate-elliptical valve-shape was the point for distinguishing *Pinnunavis* from *Pinnularia* (Okuno 1975) but the morphological characteristics was not substantiated (Krammer 2000). After that, these species were new combined by Krammer (1982) to *Pinnularia*. Recently, Krammer (2000) suggested that some marine *Pinnularia*-taxa such as *Pinnularia elegans* might be placed to *Pinnunavis* based on ecological views although SEM observations showed that the species had the typical construction of *Pinnularia*-taxa (stated above).

*Pinnunavis elegans* (W. Smith) Okuno, in Okuno (1975) 111, 8:1, Hendey (1964) 215, *XXXIV:1-4* (as *Navicula elegans*), Krammer & Lange-Bertalot (1986) 236, 82:7-8 (as *Navicula elegans*), Snoeijis & Balashova (1998), 89 (as *Pinnularia elegans*) **Plate 3. 43**

Valve elliptic-lanceolate with sub-acute apices, 40-130  $\mu\text{m}$  long, 15-30  $\mu\text{m}$  wide. Axial area narrow straight, central area

slightly large mostly circular to quadrangular. Striae coarse, radiate and curved in the middle and convergent at the apices, 8-12 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Akkeshi

*Pinnunavis yarrensensis* (Grunow) Okuno, in Okuno (1975) 111, 8:2 **Plate 3. 44, 45**

Distribution: common on low marsh in Akkeshi

#### *Diploneis* Ehrenberg

*Diploneis decipiens* var. *parallela* Cleve; Snoeijis & Balashova (1998) 43 **Plate 2. 21**

Valve elliptical with rounded apices, 11-20  $\mu\text{m}$  long, 5-10  $\mu\text{m}$  wide. Central nodule slightly large. Raphe sternum broad, relatively narrow in the apices. Transapical striae radiate, 10-14 in 10  $\mu\text{m}$ .

Distribution: abundant on tidal flat in Akkeshi

*Diploneis smithii* (Brébisson) Cleve; Hustedt (1927-1966) 647, *1051*, Hendey (1964) 225, *XXXII:10*, Krammer & Lange-Bertalot (1986) 291, *112:2-4*, Witkowski *et al.* (2000) 193, 88:2-5, 89:1 **Plate 2. 17, 18**

Valve elliptical, central nodule small or slightly large, rounded, with rhombic apices, 30-55  $\mu\text{m}$  long, 16-28  $\mu\text{m}$  wide. Raphe sternum broad. Furrows narrow, punctuate. Longitudinal canal in the middle relatively broad than the apices. Transapical striae radiate in the apices, with double rows of areolae.

Distribution: rare on tidal flat in Akkeshi

#### *Navicula* Bory

*Navicula cryptotenella* Lange-Bertalot; Krammer & Lange-Bertalot (1986) 106, *33:9-11*, Lange-Bertalot (2001) 28, *26:17-32*, *27:19-22*, 28:3, 69:5 **Plate 2. 31, 33**

Valve narrow lanceolate with acutely rounded apices, 10-35  $\mu\text{m}$  long, 5-6  $\mu\text{m}$  wide. Raphe weakly lateral, axial area narrow. Central area small or irregularly board. Striae radiate, parallel to convergent at the apices, 14-17 in 10  $\mu\text{m}$ .

Distribution: common on low marsh both in Akkeshi and Onnetoh

*Navicula digitoradiata* (Gregory) Ralfs; Hendey (1964) 202, *XXIX:8-9*, Witkowski *et al.* (2000) *114:1-6* **Plate 2. 29, 30**

Valve lanceolate to elliptic-lanceolate with rounded apices, 40-100  $\mu\text{m}$  long, 10-20  $\mu\text{m}$  wide. Raphe lateral, axial area moderately broad, central area moderately large, circular. Transapical

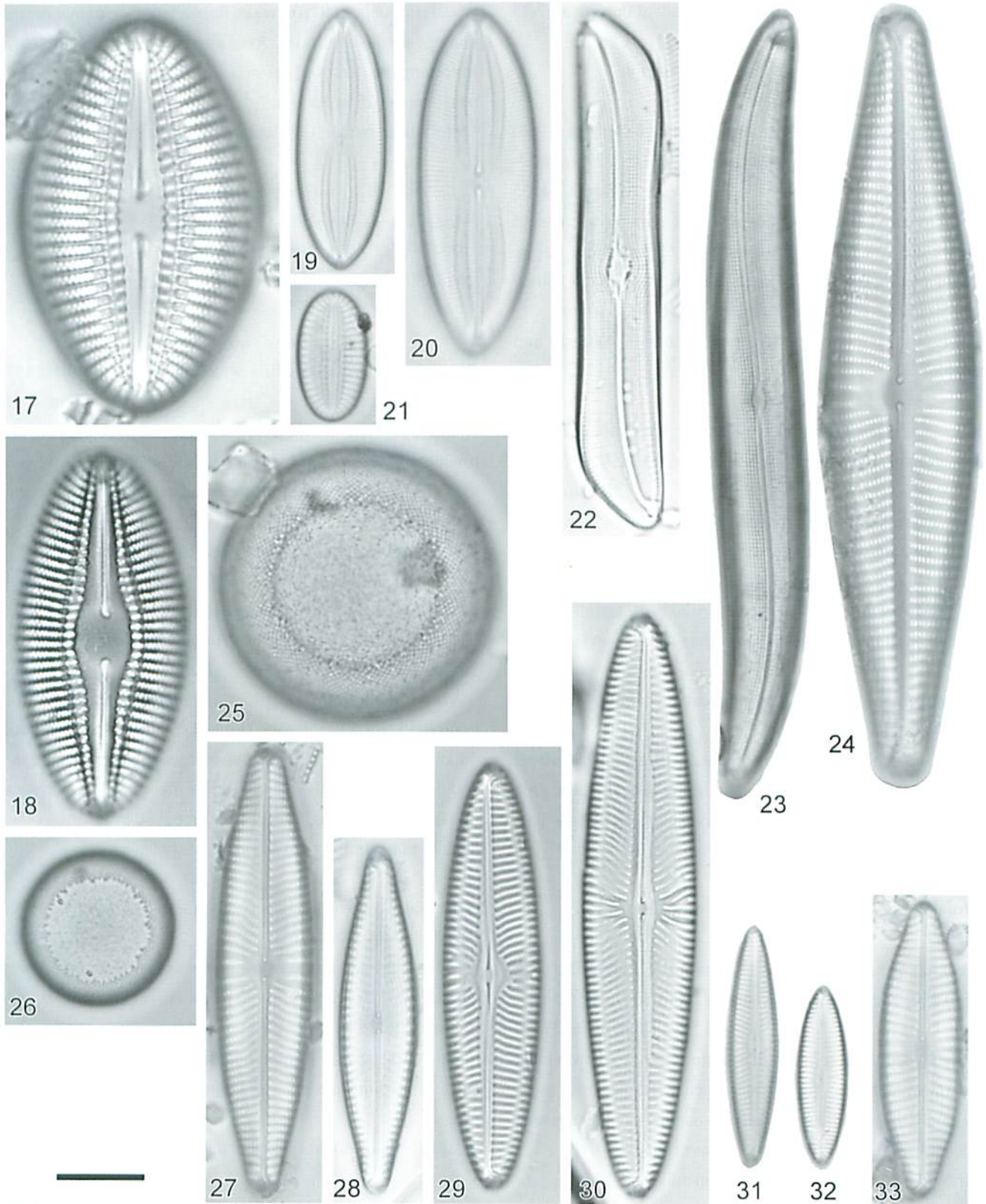


Plate 2.

17, 18. *Diploneis smithii* (Brébisson) Cleve, 19, 20. *Fallacia pygmaea* (Kützing) Stickle & D.G. Mann, 21. *Diploneis decipiens* var. *parallela* Cleve, 22. *Gyrosigma eximium* (Thwaites) Boyer, 23. *Gyrosigma scalproides* (Rabenhorst) Cleve, 24. *Navicula peregrina* (Ehrenberg) Kützing, 25, 26. *Hyalodiscus* sp. cf. *scoticus* (Kützing) Grunow, 27, 28. *Navicula rhynchocephala* Kützing, 29, 30. *Navicula digitoradiata* (Gregory) Ralfs, 31, 32. *Navicula cryptotenella* Lange-Bertalot, 33. *Navicula slesvicensis* Grunow. Black scale bar = 10  $\mu$ m for Figs. 17-33.



striae radiate, parallel to slightly convergent at the apices, 7-13 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

*Navicula gregaria* Donkin; Krammer & Lange-Bertalot (1986) 116, 38:10-15, Witkowski *et al.* (2000) 124:8-25, 129:9, 142:4-5, Cox (1994) **Plate 3. 34, 35**

Valves lanceolate to elliptic-lanceolate with protracted and subcapitate apices, 15-35  $\mu\text{m}$  long, 5-12  $\mu\text{m}$  wide. Raphe straight, axial area narrowly linear, central area variable. Striae weakly radiate, 14-18 in 10  $\mu\text{m}$ , lineolae 25-30 in 10  $\mu\text{m}$ .

Distribution: common on low marsh both in Akkeshi and Onnetoh

*Navicula peregrina* (Ehrenberg) Kützing; Krammer & Lange-Bertalot (1986) 100, 30:1, Witkowski *et al.* (2000) 297, 111:1-4

**Plate 2. 24**

Valve lanceolate with rounded apices, 60-190  $\mu\text{m}$  long, 17-30  $\mu\text{m}$  wide. Raphe lateral, external area narrow, central area moderately large. Transapical striae radiate, convergent at the ends, 5-8 in 10  $\mu\text{m}$ , lineolae coarse, 18-20 in 10  $\mu\text{m}$ .

Distribution: limited in high marsh both in Akkeshi and Onnetoh

*Navicula rhynchocephala* Kützing; Lange-Bertalot (2001) 64, 9:6-10 **Plate 2. 27, 28**

Valve lanceolate with protracted and rostrate apices, 40-60  $\mu\text{m}$  long, 8.5-10  $\mu\text{m}$  wide. Raphe slightly lateral. Axial area narrow, central area large, transversely rectangular. Striae parallel at the central, convergent at the apices, 10-12 in 10  $\mu\text{m}$ , lineolae coarse, about 25 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Akkeshi

*Navicula salinarum* Grunow; Krammer & Lange-Bertalot (1986) 110, 35:5-8, Witkowski *et al.* (2000) 304, 123:1-6

**Plate 3. 38, 39, 40**

Valve broadly lanceolate with rostrate apices, 15-50  $\mu\text{m}$  long, 6-14  $\mu\text{m}$  wide. Raphe slightly lateral, axial area narrow, central area small. Striae radiate and curved, parallel to convergent at the apices, 12-13 in 10  $\mu\text{m}$ , lineolae invisible in LM.

Distribution: common on low marsh in Akkeshi

*Navicula slesvicensis* Grunow; Krammer & Lange-Bertalot (1986) 102, 31:3-5, Witkowski *et al.* (2000) 306, 118:4-5

**Plate 2. 33**

Valve lanceolate or slightly elliptical with rounded apices,

25-50  $\mu\text{m}$  long, 8-10  $\mu\text{m}$  wide. Raphe lateral, external central endings slightly expanded. Axial area narrow, central area close to rectangular. Transapical striae relatively radiate, 8-11 in 10  $\mu\text{m}$ , lineolae 25 in 10  $\mu\text{m}$ .

Distribution: rare on high and low marshes in Akkeshi

#### *Frustulia* Rabenhorst

*Frustulia lange-bertalotii* Metzeltin, in Lange-Bertalot & Genkal (1999) 51, 38:1-8, Lange-Bertalot (2001) 169, 134:8-11

Distribution: common in salt pond in Onnetoh

#### *Pleuostigma* W. Smith

*Pleuostigma pulchrum* Grunow; Peragallo (1897-1908) 157, XXXI:1 **Plate 4. 50**

Valve sigmoid-rhombic, apices sigmoidally cuneate, 70-110  $\mu\text{m}$  long, 15-20  $\mu\text{m}$  wide. Raphe slightly sigmoid. Central nodule very small, elliptic. Striae fine, punctuate, oblique and transverse, about 25-30 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Akkeshi

#### *Gyrosigma* Hassall

*Gyrosigma eximium* (Thwaites) Boyer, in Boyer (1927) 462, Strenburg (1989), Sims (1996) 242, 2 **Plate 2. 22**

Valves sigmoid-linear, apices sigmoidally cuneate, 50-70  $\mu\text{m}$  long, 8-12  $\mu\text{m}$  wide. Raphe slightly sigmoid, central in the middle, not approximate to valve margin at the apices. Central nodule rounded, relatively large. Striae fine, punctuate, arranged in transverse and longitudinal lines, about 30 in 10  $\mu\text{m}$ .

Distribution: common on low marshes in Onnetoh

*Gyrosigma scalproides* (Rabenhorst) Cleve; Krammer & Lange-Bertalot (1986) 299, 116:5 **Plate 2. 23**

Valve sigmoid, narrower toward the apices, apices sigmoidally cuneate, 75-120  $\mu\text{m}$  long, 10-13  $\mu\text{m}$  wide. Raphe sigmoid, central in the middle, slightly eccentric approximate to the valve margin at the apices. Central nodule small. Striae fine, punctuate, arranged in transverse and longitudinal lines, 23-30 in 10  $\mu\text{m}$ .

Distribution: common on low marshes in Akkeshi

#### THALASSIOPHYSALES

##### *Amphora* Ehrenberg ex Kützing

*Amphora arenicola* (Grunow) Cleve; Hendeby (1964) 262, XXXVIII:10

Distribution: rare on low marsh in Onnetoh

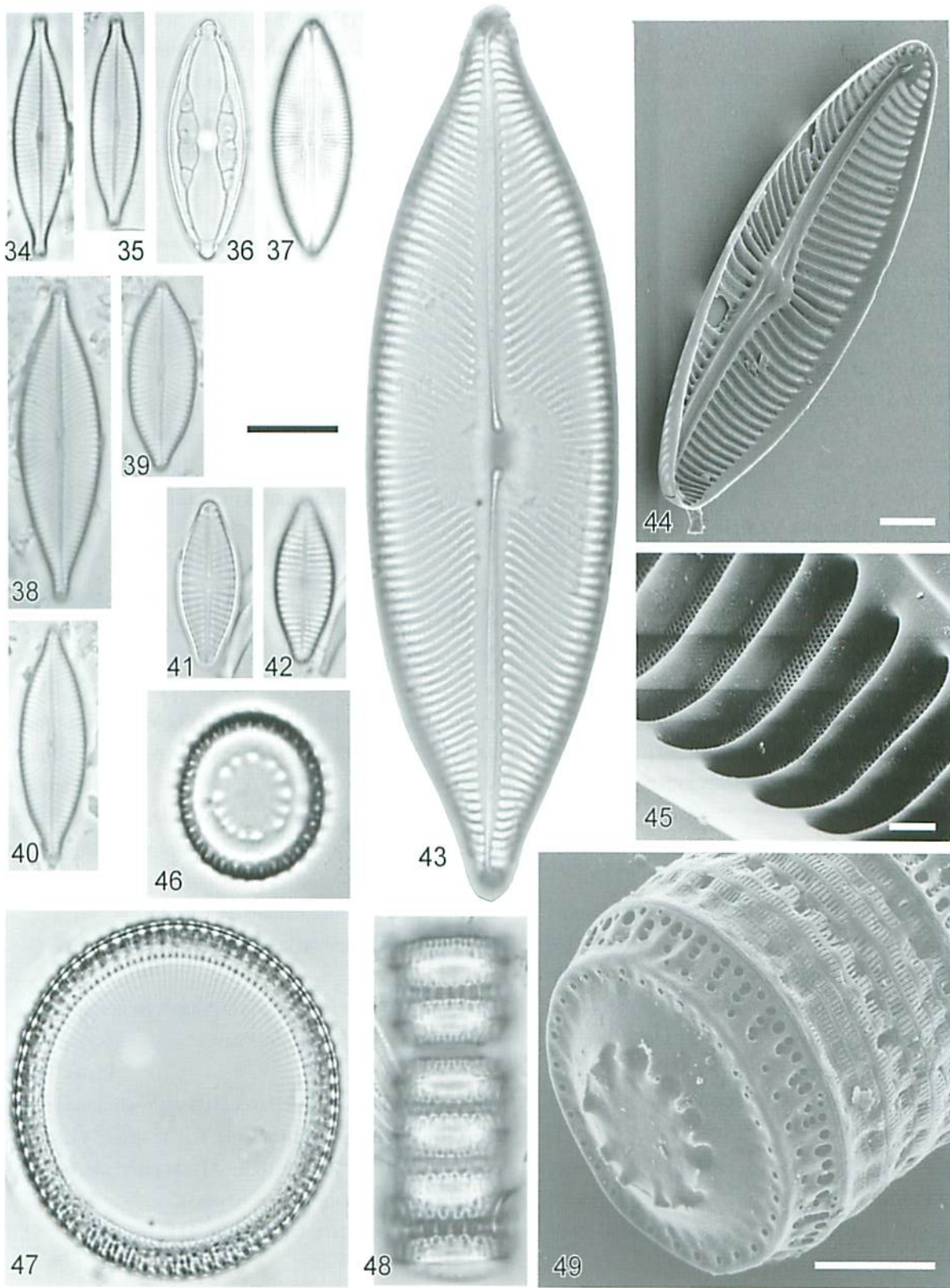


Plate 3.

34, 35. *Navicula gregaria* Donkin, 36, 37. *Mastogloia smithii* Thwaites, 38, 39, 40. *Navicula salinarum* Grunow, 41, 42. *Planothidium delicatulum* (Kützing) Round & Bukhtiyarova, 43. *Pinnunavis elegans* (W. Smith) Okuno, 44, 45. *Pinnunavis yarrens* (Grunow) Okuno, 46, 47, 48, 49. *Paralia sulcata* (Ehrenberg) Cleve. Black scale bar = 10  $\mu\text{m}$  for Figs. 34-44, 46-48. Scale bar in Fig. 45 = 2  $\mu\text{m}$ . Scale bar in Fig. 49 = 5  $\mu\text{m}$ .

*Amphora helenensis* Giffen (1973) 33, 7-9, Archibald (1983) 48, 115-119 **Plate 1. 1**

Valves semi-circular with rounded apices, ventral margin straight or slightly inflated in the middle, 15-20  $\mu\text{m}$  long, 3-5  $\mu\text{m}$  wide. Raphe strongly eccentric. Striae slightly radiate, punctate, about 15 in 10  $\mu\text{m}$ .

Distribution: rare on low marsh in Onnetoh

*Amphora holsatica* Hustedt (1925) 115, 4; Nagumo & Kobayasi (1990) 150, 1:1-6, 2:7-12 **Plate 1. 3**

Valves semi-circular with capitate ends, ventral margin straight or slightly inflated in the middle, 25-50  $\mu\text{m}$  long, 7-10  $\mu\text{m}$  wide. Raphe straight. Transapical striae, radiate, coarse punctate, 11-18 in 10  $\mu\text{m}$ .

Distribution: common on low marsh in Onnetoh

*Amphora marina* (W. Smith) Van Heurck; Schoeman & Archibald (1986) 426, 1-7

Distribution: rare on low marsh in Onnetoh

*Amphora salina* W. Smith; Schoeman & Archibald (1987) 385, 42-44 **Plate 1. 2**

Valves semi-circular with capitate ends, ventral margin straight or slightly inflated in the middle, 15-30  $\mu\text{m}$  long, 4-5  $\mu\text{m}$  wide. Raphe straight. Transapical striae, radiate, fine punctate, about 15 in 10  $\mu\text{m}$ .

Distribution: common on tidal flat in Onnetoh

*Amphora spectabilis* Gregory (1857) 516, XIII:80a, 80c; Hende (1964) 268, XXXVIII:8-9 **Plate 1. 7**

Valve broadly linear with bluntly rounded apices, arcuate margin, slightly flattened in the middle, undulate in the apices, 70-130  $\mu\text{m}$  long. Raphe biarcuate, central nodule near the ventral margin. Striae fine on the ventral side.

Distribution: very rare on low marsh in Onnetoh

*Amphora ventricosa* Gregory (1857) 511, XII:68-68b; Hende (1964) 269, XXXVIII:12 **Plate 1. 8**

Valve elongated, semi-lanceolate with acute apices, 30-80  $\mu\text{m}$  long, 5-15  $\mu\text{m}$  wide. Raphe straight, approximate to ventral margin. Striae fine, indistinct, 14-18 in 10  $\mu\text{m}$ .

Distribution: rare on low marsh in Onnetoh

*Amphora pusilla* Gregory (1857) 525, XIV:95-95b

**Plate 1. 5, 6**

Valve semi-circular with rounded apices, ventral margin inflated in the middle, 13-20  $\mu\text{m}$  long, 4-6  $\mu\text{m}$  wide. Raphe slightly eccentric, close to dorsal margin at the ends. Striae radiate in the middle, parallel at the apices, 15-24 in 10  $\mu\text{m}$ .

Distribution: rare on low marsh in Onnetoh

*Amphora* sp.-1:

**Plate 1. 9**

Valve semi-circular with capitate apices, ventral margin inflated in the middle, 35-50  $\mu\text{m}$  long, 7-10  $\mu\text{m}$  wide. Raphe slightly eccentric. Striae radiate, punctate, 15 in 10  $\mu\text{m}$ .

Distribution: rare on low marsh in Onnetoh

## BACILLARIALES

### *Bacillaria* J. F. Gmelin

*Bacillaria paxilifer* (Müller) Hende (1951) 71, 74

Distribution: rare on low marsh in Akkeshi

### *Tryblionella* W. Smith

*Tryblionella acuminata* W. Smith; Krammer & Lange-Bertalot (1988) 44, 34:4-6 (as *Nitzschia acuminata*)

Distribution: rare on tidal flat in Akkeshi

*Tryblionella coarctata* (Grunow) D.G. Mann, Krammer & Lange-Bertalot (1988) 50, 38:13-15A, (as *Nitzschia coarctata*), Snoeij & Balashova (1998) 108 **Plate 5. 61**

Valves linear panduriform with cuneate, sub-apiculate apices, 25-100  $\mu\text{m}$  long, 11-18  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae as many as striae in 10  $\mu\text{m}$ . Striae punctate, 8-10 in 10  $\mu\text{m}$ , puncta arranged in transverse rows.

Distribution: common on tidal flat in Akkeshi

*Tryblionella compressa* (Bailey) D.G. Mann; Krammer & Lange-Bertalot (1988) 46, 37:1-3 (as *Nitzschia compressa*)

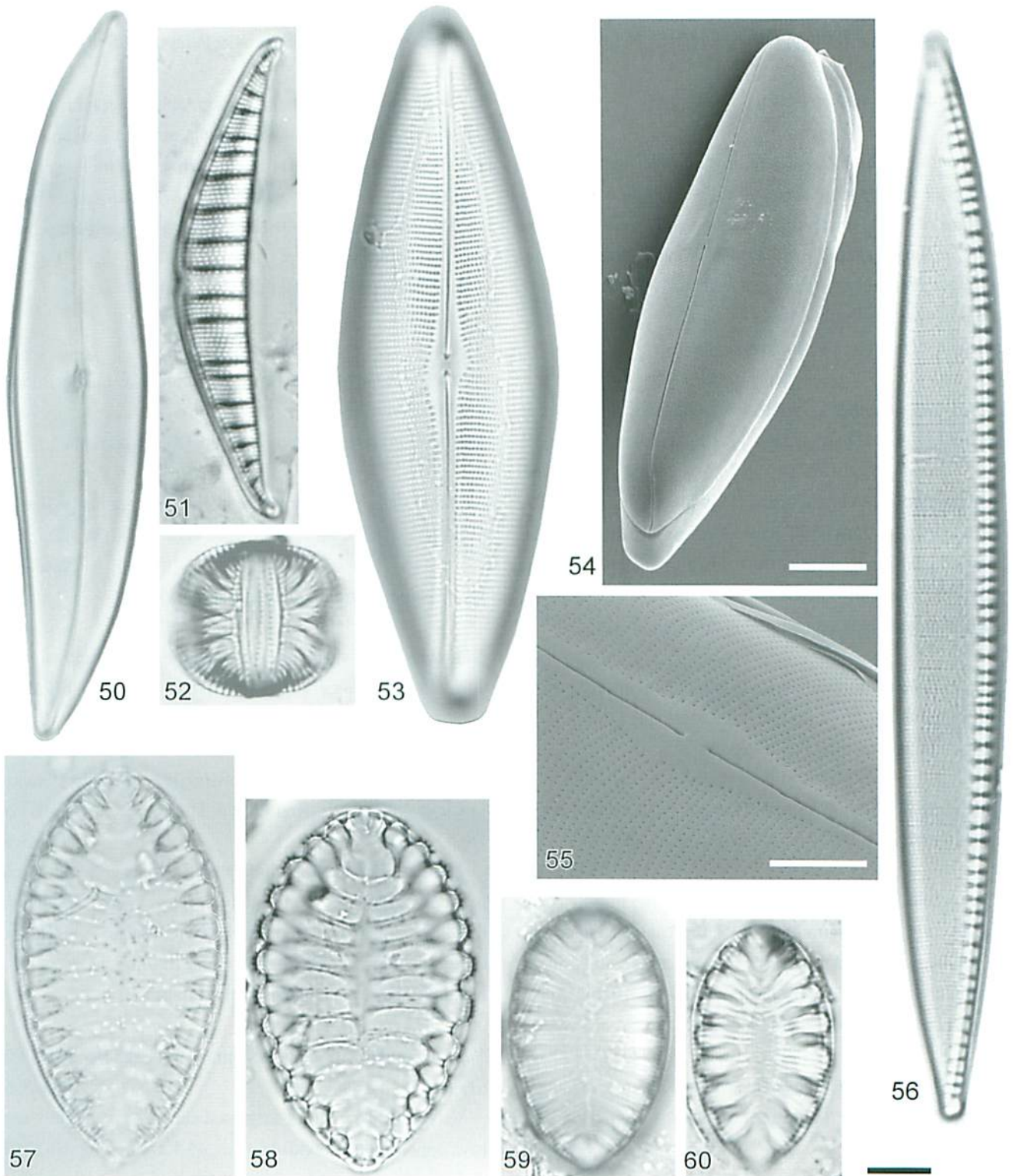
**Plate 5. 62, 68**

Valves elliptic or elliptic-lanceolate with sub-apiculate apices, 20-60  $\mu\text{m}$  long, 5-15  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae as many as striae in 10  $\mu\text{m}$ . Transapical striae, 5-20 in 10  $\mu\text{m}$ , striae punctate, 7-20 in 10  $\mu\text{m}$ .

Distribution: common on tidal flat in Akkeshi

*Tryblionella compressa* var. *balatonis* (Grunow) D.G. Mann; Krammer & Lange-Bertalot (1988) 46, 38:1-4 (as *Nitzschia compressa* var. *balatonis*)

Distribution: common on tidal flat in Akkeshi



## Plate 4.

50. *Pleოსigma pulchrum* Grunow, 51. *Rhopalodia gibberula* (Ehrenberg) O.Möller, 52. *Rhopalodia iriomotensis* Kobayasi *et al.*, 53, 54, 55. *Scolioneis tumida* (Brébisson ex Kützing) D.G.Mann, 56. *Nitzschia sigma* (Kützing) W.Smith, 57, 58. *Surirella striatula* Turpin, 59, 60. *Surirella litoralis* Hustedt. Black scale bar = 10  $\mu$ m for Figs. 50-54, 56-60. Scale bar in Fig. 55 = 5  $\mu$ m.

*Tryblionella compressa* var. *elongata* (Grunow) D.G.Mann; Krammer & Lange-Bertalot (1988) 46, 37:9-10 (as *Nitzschia compressa* var. *elongata*)

Distribution: common on tidal flat in Akkeshi

*Tryblionella debilis* Arnott; Krammer & Lange-Bertalot (1988) 39, 27:9-11 (as *Nitzschia debilis*) **Plate 5. 69, 70, 71**

Valves elliptic to linear-elliptic with broadly rounded apices, 13-40  $\mu\text{m}$  long, 7-20  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae broad. Transapical striae resolvable in LM, valve surface with a marked longitudinal fold.

Distribution: rare on tidal flat in Akkeshi

*Tryblionella granulata* (Grunow) D.G.Mann; Krammer & Lange-Bertalot (1988) 45, 35:9-13 (as *Nitzschia granulata*)

**Plate 5. 64**

Valves elliptic or elliptic-lanceolate with cuneate apices, 25-45  $\mu\text{m}$  long, 12-18  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae 6-7 in 10  $\mu\text{m}$ . Transapical striae coarsely punctate 5-7 in 10  $\mu\text{m}$ , puncta irregularly spaced.

Distribution: common on tidal flat in Akkeshi

*Tryblionella lanceola* (Grunow) D.G.Mann; Krammer & Lange-Bertalot (1988) 38:11-12 (as *Nitzschia lanceola*)

Distribution: rare on tidal flat in Akkeshi

*Tryblionella levidensis* (W.Smith) Grunow; Krammer & Lange-Bertalot (1988) 37, 27:1-4 (as *Nitzschia levidensis*)

**Plate 5. 67**

Valve linear-elliptic, slightly concave in the middle, with rounded apices, 15-50  $\mu\text{m}$  long, 8-15  $\mu\text{m}$  wide. Raphe eccentric, fibulae 6-12 in 10  $\mu\text{m}$ . Striae transapical, about 35 in 10  $\mu\text{m}$ , obscured by coarse transapical ribs, 5-10 in 10  $\mu\text{m}$ .

Distribution: rare on tidal flat in Akkeshi

*Tryblionella littoralis* (Grunow) D.G.Mann; Krammer & Lange-Bertalot (1988) 41, 30:6-10 (as *Nitzschia littoralis*), Snoeijs & Balashova (1994) 111 **Plate 5. 72, 73**

Valves broadly elliptic-lanceolate with cuneate or rounded apices, 30-160  $\mu\text{m}$  long, 12-25  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae 6-9 in 10  $\mu\text{m}$ . Transapical striae, 30-38 in 10  $\mu\text{m}$ , weakly developed transapical ribs.

Distribution: rare on tidal flat in Akkeshi

*Tryblionella salinarum* (Grunow in Cleve & Grunow) Pelletan;

Krammer & Lange-Bertalot (1988) 38, 28:5-10 (as *Nitzschia levidensis* 'salinarum'), Snoeijs & Potapova (1995) 111

**Plate 5. 63**

Valve broadly linear-elliptic with obtusely rounded apices, 18-45  $\mu\text{m}$  long, 8-18  $\mu\text{m}$  wide. Raphe strongly eccentric, fibulae about 35 in 10  $\mu\text{m}$ . Transapical striae discernible in LM, 5-12 in 10  $\mu\text{m}$ . This species differs from *T. levidensis* by having narrow transapical ribs, 10-13 in 10  $\mu\text{m}$  and zigzag-shaped contact line between the ribs.

Distribution: rare on tidal flat in Akkeshi

#### *Nitzschia* Hassall

*Nitzschia inconspicua* Grunow; Krammer & Lange-Bertalot (1988) 95, 69:1-13

Distribution: rare or common on tidal flat in Akkeshi

*Nitzschia sigma* (Kützing) W.Smith; Krammer & Lange-Bertalot (1988) 32, 23:1-9, 24:1, Witkowski *et al.* (2000) 404, 206:1-10

**Plate 4. 56**

Distribution: common on tidal flat in Akkeshi

*Nitzschia sigma* var. *intercedens* Grunow, in Grunow (1878) 118, 119, Grunow in Van Heurck (1880-1885) 178-179, 66:1

Distribution: rare on tidal flat in Akkeshi

*Nitzschia scalpelliformis* (Grunow in Cleve & Möller) Grunow in Cleve & Grunow; Krammer & Lange-Bertalot (1988) 26, 18:2-5, 7:11-12 **Plate 5. 66**

Valves linear in the middle slightly concave with oblique rounded apices, 20-100  $\mu\text{m}$  long, 5-8  $\mu\text{m}$  wide. Raphe in the middle central, towards apices eccentric, fibulae 7-9 in 10  $\mu\text{m}$ , central nodule present, striae 27-35 in 10  $\mu\text{m}$ .

Distribution: rare on high and low marshes

*Nitzschia bilobata* W. Smith, Krammer & Lange-Bertalot (1988) 61, 46:1-2 **Plate 5. 65**

Valves bilobate with constricted keel margin, slightly concave opposite one, rounded apices, 45-120  $\mu\text{m}$  long, 10-20  $\mu\text{m}$  wide. Raphe moderately eccentric, fibulae 5-8.5 in 10  $\mu\text{m}$ , striae 15-25 in 10  $\mu\text{m}$ .

Distribution: rare on tidal flat in Akkeshi

#### RHOPALODIALES

##### *Rhopalodia* O.Möller

*Rhopalodia gibberula* (Ehrenberg) O.Möller; Krammer &

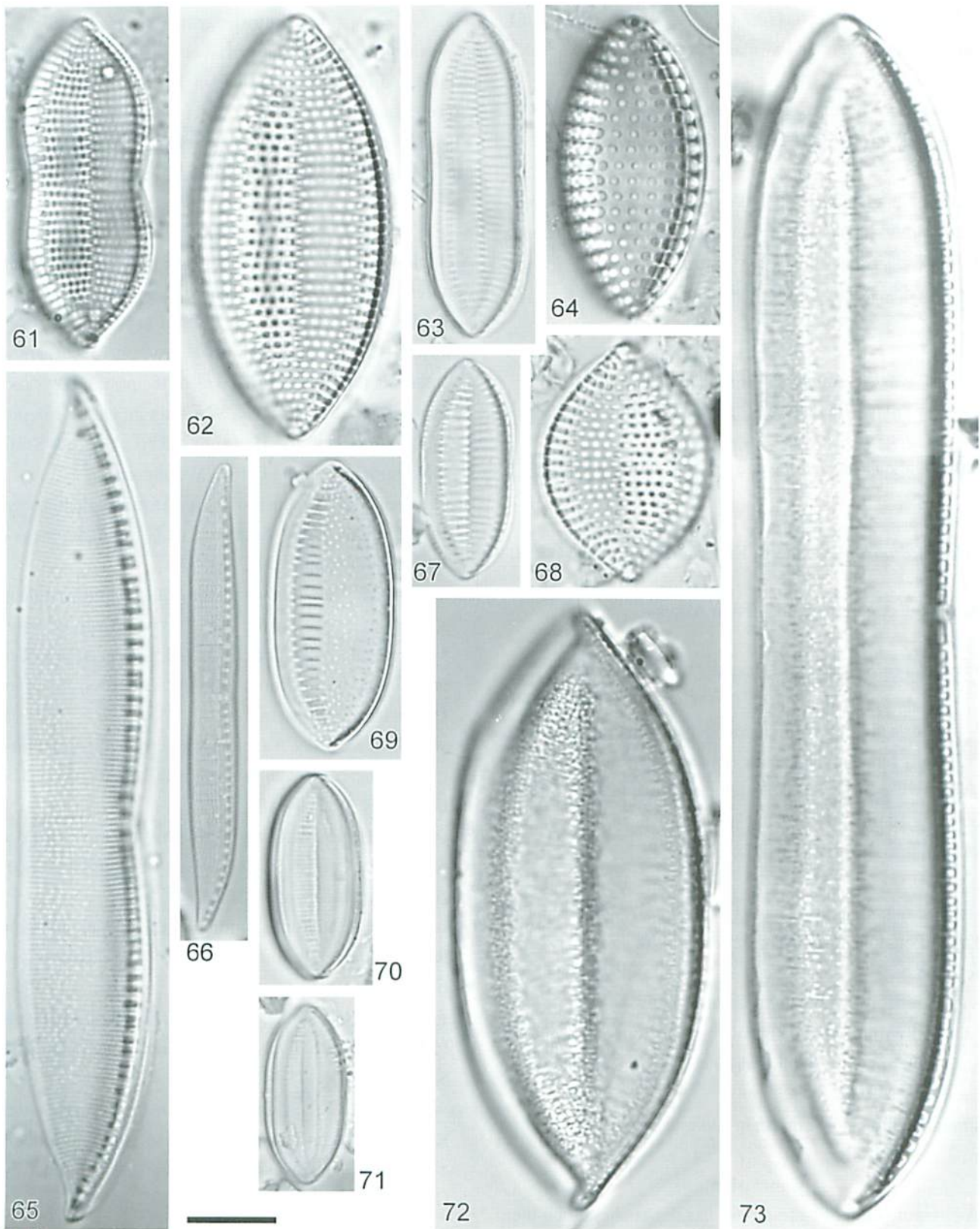


Plate 5.

61. *Tryblionella coarctata* (Grunow) D.G.Mann, 62. *Tryblionella compressa* (Bailey) D.G.Mann, 63. *Tryblionella salinarum* (Grunow in Cleve & Grunow) Pelletan, 64. *Tryblionella granulata* (Grunow) D.G. Mann, 65. *Nitzschia bilobata* W. Smith, 66. *Nitzschia scalpelliformis* (Grunow in Cleve & M'ller) Grunow in Cleve & Grunow, 67. *Tryblionella levidensis* (W.Smith) Grunow, 68. *Tryblionella compressa* (Bailey) D.G.Mann, 69. *Tryblionella* sp. cf. *debilis* Arnott, 70, 71. *Tryblionella debilis* Arnott, 72, 73. *Tryblionella littoralis* (Grunow) D.G.Mann. Scale bar = 10  $\mu$ m for Figs. 61-73.

Lange-Bertalot (1988) 60, 112:1-6

**Plate 4. 51**

Distribution: very rare on low marsh in Onnetoh

*Rhopalodia iriomotensis* Kobayasi *et al.*, in Kobayasi *et al.* (1993), Nagumo & Hara (1990) 337, 2:25-28 (as *Rhopalodia* sp.)

**Plate 4: 52**

Valves strongly dorsiventral, dorsal margin strongly convex, ventral margin slightly concave, apices rounded, 10-20  $\mu\text{m}$  long, 6-10  $\mu\text{m}$  wide. Striae about 12 in 10  $\mu\text{m}$ .

Distribution: very rare on low marsh in Onnetoh

#### SURIPELLALES

##### *Entomoneis* Ehrenberg

*Entomoneis alata* (Ehrenberg) Ehrenberg; Krammer & Lange-Bertalot (1986) 438, 203:1-4, 2:19-21

Distribution: rare on tidal flat and low marsh in Akkeshi

##### *Surirella* P.J.F.Turpin

*Surirella fastuosa* (Ehrenberg) Kützing; Hendeby (1964) 288, XL:4

Distribution: common on tidal flat in Akkeshi

*Surirella litoralis* Hustedt, in Hustedt (1955) 48, 24-25

**Plate 4. 59, 60**

Valves broadly ovate with moderately convex margins, one apex broadly rounded and cuneate opposite one, 25-40  $\mu\text{m}$  long, 12-20  $\mu\text{m}$  wide. Raphe indistinct, fibulae 3.5-10 in 10  $\mu\text{m}$ . Striae, about 23 in 10  $\mu\text{m}$ .

Distribution: common on tidal flat in Akkeshi

*Surirella striatula* Turpin; Hendeby (1964) 288, XL:2-3, Krammer & Lange-Bertalot (1988) 190, 140:4-5, Witkowski *et al.* (2000) 416, 216:5

**Plate 4. 57, 58**

Valves broadly ovate with moderately convex margins, one apex broadly rounded and cuneate opposite one, 30-150  $\mu\text{m}$  long, 20-130  $\mu\text{m}$  wide. Raphe indistinct, fibulae 4-10 in 10  $\mu\text{m}$ . Striae 14-18 in 10  $\mu\text{m}$ .

Distribution: rare on low marsh in Akkeshi

#### Conclusion

An investigation of diatom flora in salt marshes along the Pacific coasts of eastern Hokkaido, northern Japan revealed sixty-seven brackish diatom taxa. This data will contribute to the future ecological and paleoecological studies in salt marsh environments.

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