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Teratological forms of diatoms (Bacillariophyceae) as indicators of water pollution in the western part of Puck Bay (southern Baltic Sea)

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Abstract

Studies of benthic diatom communities in the surface sediments of the Swarzewo area of Puck Bay were carried out during 1998 and 1999 in order to assess water quality, and in particular the organic load. Among the 192 taxa identified, teratological forms of diatoms were recorded in 17 diatom species, primarily in the species *Opephora mutabilis*, *Planothidium delicatulum* and *Fragilaria fasciculata*. The number of teratological forms was significantly higher in sediments rich in organic matter, which had concurrent high concentrations of phosphorus and nitrite nitrogen compounds. The highest teratological diatom abundances were recorded in α-mesosaprobic conditions, especially during spring and summer. It is postulated that teratological diatom valves are indicative of poor water quality.

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INTRODUCTION

Diatom growth depends on several environmental factors. Numerous species of diatom exhibit narrow tolerances to environmental variability (Battarbee 1988, Denys 1991/2, Anderson & Vos 1992, Vos & de Wolf 1993, Hoffman 1994, Van Dam et al. 1994). This intolerance means that they are frequently and successfully used as indicators in water quality assessments (e.g. Lange-Bertalot 1979, Kobayasi & Mayama 1989, Prygiel & Coste 1996, Dokulil et al. 1997, Lobo 1997, Kwandrans et al. 1998, Kawecka et al. 1999, Bogaczewicz-Adamczak et al. 2001, Rakowska 2001). Unfavourable environmental conditions impact the life cycle of diatoms, and the resultant valve morphologies that develop under such circumstances differ from those inhabiting undisturbed environments. Valves that differ from those that are morphologically typical for a given species, which have aberrant valve outline or striation deformations, are called teratological forms. An increase in the percentage content of teratological forms of diatoms in marine environments may be connected with increased organic matter concentration in sediments (Witkowski 1991). Other factors that are teratogenic, and may be pathogenic, include high temperatures and salinities (Estes, Dute 1994; Håkansson 1999), low current velocity (typical of summer drought conditions), and subsequent increased light intensity and raised water temperatures (Antoine, Benson-Evans 1984), high UV radiation (Cabrol et al. 2004), increase in nutrient concentrations (Kling 1993; Estes, Dute 1994) and high concentrations of heavy metals, e.g. copper (Dickman 1998; Ruggiu et al. 1998; Cattaneo et al. 2002; Fore, Grafe 2002; Cooper et al. 2003), and cadmium, nickel, zinc, chromium and lead (Dickman 1998). Previous reports attempting to utilise teratological diatoms in assessing water pollutant loading have been undertaken by Lai, Chen (1998), Ruggiu et al. (1998) and Cattaneo et al. (2002).

Teratological forms of diatoms occur in bottom sediments of aquatic systems including Puck Bay, the Gulf of Gdańsk and some streams discharging into the Gulf of Gdańsk. Benthic diatom communities of the shallow water of the Swarzewo area of Puck Bay were studied in 1998-1999 (Bogaczewicz-Adamczak, Dziengo 2003). The ecological groups of the diatoms, and the diatom indices, were determined and serve as a basis for assessing the environmental conditions of Puck Bay littoral zone.

The primary aim of this paper is to investigate the abundance of teratological forms of the diatom species and to ascertain any correlation with certain environmental parameters in the surface sediments of the western part of the Gulf of Gdańsk i.e. Puck Bay. The timing of the study period is of particular relevance to the assessment of the local environmental health following the closure in 1997 of the major discharge of the sewage treatment plant in Swarzewo.

RESEARCH AREA

Puck Bay is located in the western part of the Gulf of Gdańsk. The interior part of Puck Bay, called Puck Lagoon, which has a surface area of 102.7 km^2 and average depth of ca 3.1 m, is classified as an estuary (Majewski 1990). Wave processes in this area depend on the local wind system, which are mainly from western directions. Because of the shallow depths, the water column does not show thermal stratification and the water temperature follows that of air temperature, from 0-2°C in winter and early spring, up to 17-21°C in the summer (Nowacki 1993). Water salinity in Puck Bay is relatively low, averaging 7.3 PSU (Majewski 1990). In general sediments in the western part of the Gulf of Gdańsk have an organic matter content from 1 to 5%, while in eastern areas it increases with the degree of sediment dispersion (Jankowska, Łęczyński 1993).

The former sewage treatment plant in Swarzewo is situated on the west coast of the bay, halfway between Puck and Władysławowo (Fig. 1). Before 1997 a drainage ditch served as a sewage treatment plant outlet, and purified waters were discharged into Puck Bay littoral zone. The extent of discharge impacts was dependent on the direction of the wind and water currents (Wołowicz 1993).

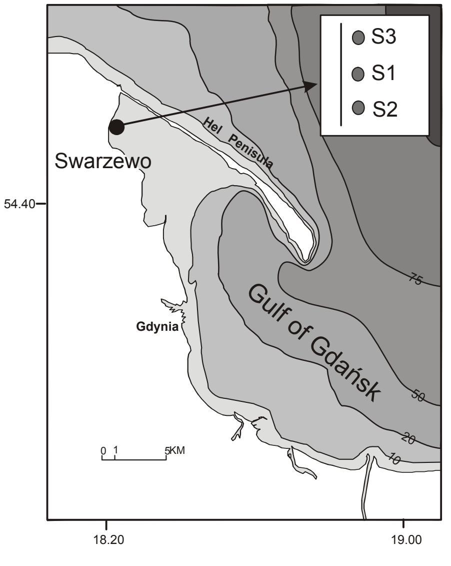

Fig.1. Location of sampling stations in Puck Bay.

MATERIAL AND METHODS

Samples of surface sediments were collected once a month between June 1998 and May 1999 from the shallow water zone of Puck Bay, in the area of the sewage treatment plant at Swarzewo. Sampling stations were situated at three profiles (Fig. 1).

The samples for diatom analyses were boiled in 30% H_2O_2 at temperatures between 60 and 90°C in a water bath for three days and washed twice in distilled water. To prepare permanent diatom slides Naphrax was used as a mounting medium. The diatoms were identified using a Nikon microscope at 1200× magnification. At least 500 diatoms valves were counted from each slide and a percentage content of each taxon was calculated. The number of teratological forms of diatoms was counted and calculated as a percentage of total numbers of diatom taxa recorded at the each site. The chemical parameters of the sampling sites have been previously reported (see Bogaczewicz-Adamczak & Dziengo 2003).

RESULTS

A total of 192 diatom taxa were identified in the surface sediments of Puck Bay, comprising 181 pennate and 11 centric taxa. The following genera had the highest number of representatives: *Navicula* (46 taxa), *Fragilaria* (18), *Nitzschia* (16), *Amphora* (10) and *Achnanthes* (10) (Bogaczewicz-Adamczak & Dziengo 2003). 17 taxa were identified as showing various kinds of teratology (Table 1). Their valves showed varying degrees of aberration including deformation of the valve apical axis (sternum, raphe sternum) and of the valve surface structure (striation). Teratological forms were observed most frequently in *Planothidium delicatulum, Opephora mutabilis* (benthic, eutraphentic and β-mesosaprobic taxa) and *Fragilaria fasciculata* (benthic, eutraphentic and α-mesosaprobic taxa). Deformation of the valve outline was typical for *P. delicatulum* while aberrant valve surface was typical for *O. mutabilis* and *F. fasciculata.*

The number of teratological forms of diatom showed seasonal variability (Fig. 2). Teratological forms of *F. fasciculata* were most abundant in summer 1998, of *P. delicatulum* in autumn 1998, and of *O. mutabilis* in spring 1999. The maximum number of teratological forms of diatom was observed in spring 1999.

Analyses of the diatom data showed that organic–pollution-tolerant diatoms (β-mesosaprobic) were dominant, and organic–pollution-resistant diatoms (α-mesosaprobic) were seasonally variable. The numbers of teratological forms

Table 1

The frequency of teratological forms of diatoms in shallow water sediment samples from Puck Bay.

Taxa	**%**
Opephora olsenii Möller	23.7
Achnanthes delicatula (Kütz.) Grunow	21.02
Fragilaria fasciculata (Ag.) Lange - Betralot	20.38
Cocconeis peltoides Hustedt	7.01
Fragilaria virescens var. *subsalina* (Ralfs) Grunow	5.73
Navicula gregaria Donkin	3.82
Diatoma moniliformis Kützing	3.18
Cocconeis placentula Ehrenberg	2.55
Fragilaria schulzii Brockmann	2.55
Achnanthes lemmermannii Hustedt	1.91
Fallacia cassubiae Witkowski	1.91
Fragilaria construens var. *venter* (Ehr.) Grunow	1.27
Navicula detenta Hustedt	1.27
Navicula protracta (Grun.) Cleve	1.27
Melosira nummuloides (Dillwyn) Agardh	1.27
Achnanthes dispar Cleve	0.64
Fragilaria pulchella (Ralfs) Lange-Bertalot	0.64

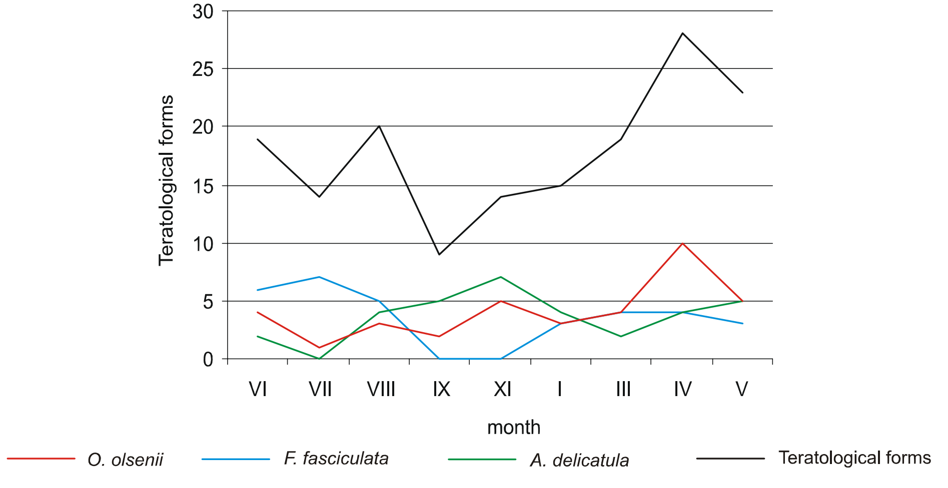

Fig. 2. Seasonal variability of teratological forms of predominant diatoms in shallow water sediment samples from Puck Bay.

were variable, but generally increased in spring and summer, notably at profile 1 (Fig. 3).

In summer 1998 tolerant diatoms dominated the saprobic spectrum, with average numbers ranging from 50% of profile 3 sample stations, to 57% of stations at profile 1 (Fig 3). These were accompanied by the resistant diatoms occurring with frequencies ranging from 33% at stations along profile 2, to 37% along profile 3. In autumn 1998 tolerant diatoms were dominant, averaging 61% (profile 2) to 67% (profile 1, Fig. 3). These were accompanied by resistant diatoms, averaging from 28% (profile 1) to 31% (profiles 3 and 2). In winter 1999 tolerant diatoms were dominant, with average numbers ranging from 59% (profile 1) to 67% (profile 2, Fig. 3). The accompanying resistant diatom numbers ranged from 25% (profile 2) to 32% (profile 1). In spring 1999 tolerant forms dominated the saprobic spectrum of the diatom flora, with average numbers ranging from 68% (profile 2) to 72% (profile 3, Fig. 3). These were accompanied by resistant diatom taxa at numbers ranging from 20% (profile 3) to 22% (profile 1, Fig. 3).

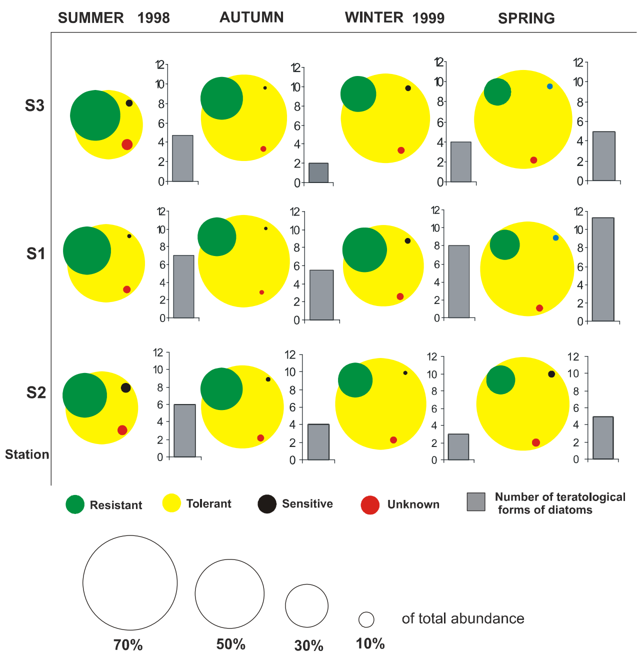

Fig. 3. Seasonal variability of percentage share of resistant, tolerant and sensitive diatoms to the organic pollution, and number of teratological forms of diatoms in shallow water sediment samples from Puck Bay.

Increases in the number of teratological forms of diatoms show close relationships with rises in organic matter content (Fig. 4A), ranging from 0.7% (profile 2) to 2.0% (profile 3), concurrent with increases in phosphate (Fig. 4C) and nitrite (Fig. 4E) concentrations in the sediments. Increased concentrations of oxygen (Fig. 4B), ammonia (Fig. 4D) and nitrates (Fig. 4F) were not clearly correlated with the number of teratological forms of diatoms.

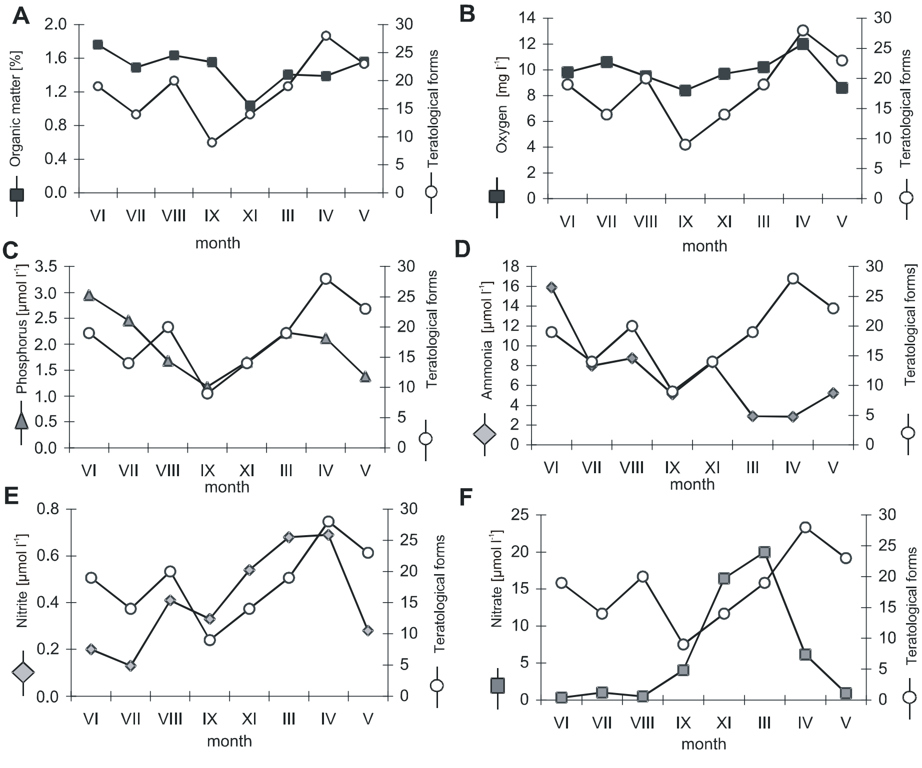

Fig. 4. The correlation between water chemistry and number of teratological forms of diatoms in shallow water sediment samples from Puck Bay.

Increases in the number of teratological forms of diatom correlated with increases in chlorophyll *a* concentrations in the sediments, associated with blue-green algal blooms (Fig. 5, Fig. 6).

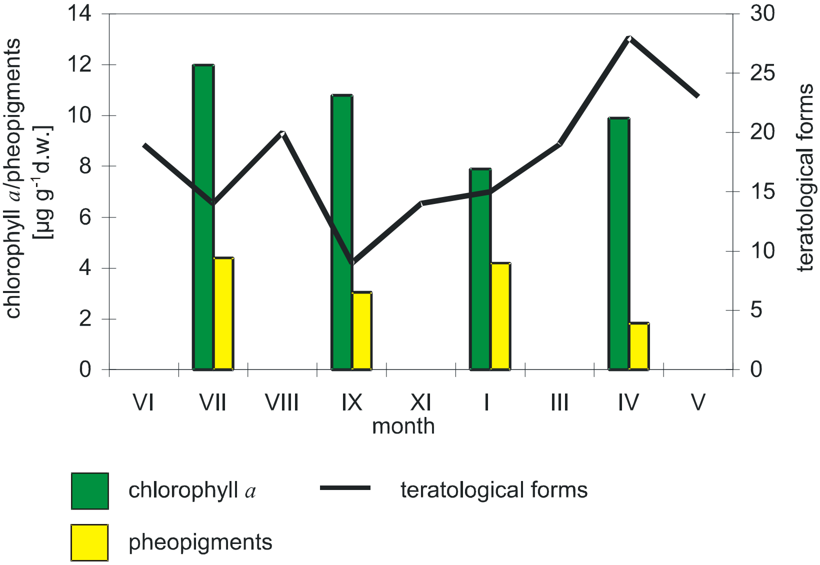

Fig. 5. The correlation between concentrations of chlorophyll *a* and phaeopigments and number of teratological forms of diatoms in shallow water sediment samples from Puck Bay.

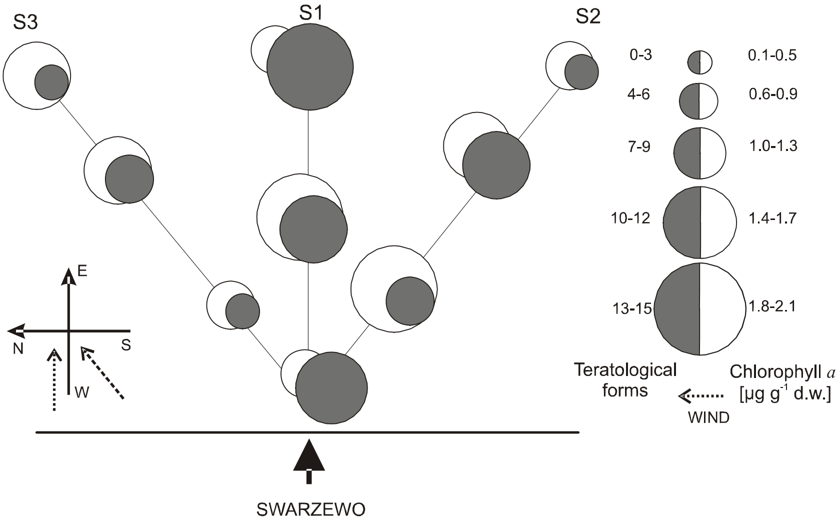

Fig. 6. The spatial distribution of teratological forms of diatoms and concentration of chlorophyll *a* in surface sediments of Puck Bay.

SUMMARY AND DISCUSSION

The presence of teratological forms of diatoms in the surface sediments of Puck Bay, in the historic discharge area of the sewage treatment plant at Swarzewo, may indicate unfavourable environmental conditions in this region. Increases in the number of diatom species and teratological forms in spring might result from low oxygen concentrations in the water after winter (after ice melt) and/or the effect of the spring diatom bloom. The summer peak in teratological forms of diatoms is connected with high concentrations of organic matter (following cyanobacterial blooms) and with the presence of hydrogen sulphide in the sediments. The quantity of teratological forms increases with increases in biogenic compound concentrations, especially phosphates and nitrites, in the sediments.

The relationship between biogenic concentration and the occurrence of teratological forms has previously been observed in different types of environments. During water quality assessments of Karlikowski Stream, around its outlet into the Gulf of Gdansk, numerous teratological forms of *Fragilaria fasciculata* were observed in samples with high concentrations of ammonium nitrogen and nitrites (Stefaniak 1998).

Laboratory experiments have shown that shape aberrations in clonal cultures of *Nitzschia palea* were caused by nutrient deficiency (Estes & Dute 1994). Kling (1993) discusses rapid cell size reduction of *Asterionella formosa* in relation to low Si, increased P and/or increased temperature. According to that author cell size reduction may be a response of the diatom frustule to environmental stress. High concentrations of chlorophyll *a* indicate that surface sediments in the Swarzewo area of Puck Bay were characterised by eutrophication and high productivity.

Dominance of eutraphentic species belonging to the α/β-mesosaprobic group in the diatom flora confirms a high degree of water fertility and considerable pollution resulting from the decay of organic matter. On the basis of Lange-Bertalot's (1979) classification, it was estimated that in the summer of 1998 the waters in the study area were assessed to water quality class III (IV), whilst in the spring of 1999 the water quality was slightly improved. The worst saprobic conditions were observed in profile 1, corrolating with the high number of teratological forms in those samples.

In the surface sediments of Puck Bay coastal shallows we observed teratological forms of *Cocconeis placentula, Fragilaria construens* var. *venter, F. virescens* var. *subsalina, Opephora mutabilis* and *Planothidium delicatulum*. These co-occurred with increased organic matter content (in summer), whereas teratological forms of *Synedra tabulata* (=*Fragilaria fasciculata*) were present in samples with both high and low organic matter content (Witkowski 1991).

The occurrence of deformed diatom valves (of *Cocconeis placentula, Fragilaria construens, F. fasciculata, F. subsalina*, *Opephora mutabilis* and *Planothidium delicatulum*) was also reported in samples with high organic content in sediments from Karlikowski Stream (Szpejewska 1999, Bogaczewicz–Adamczak et al. 2001). The increases in number and distribution of the teratological forms of diatoms indicate a connection with the prevailing westerly winds, which are responsible for the translocation of biogenic substances and organic matter in a south-easterly direction and the accumulation at the depth of 0.5 – 0.7 m.

CONCLUSIONS

Our results indicate that teratological forms constitute an adequate indicator of environmental quality. Despite a noticeable correlation between the number of teratological of diatoms and physico-chemical parameters, however, they cannot be the sole source of water quality monitoring. The information resulting from their occurrence can be a useful complement to other biological and chemical analyses.

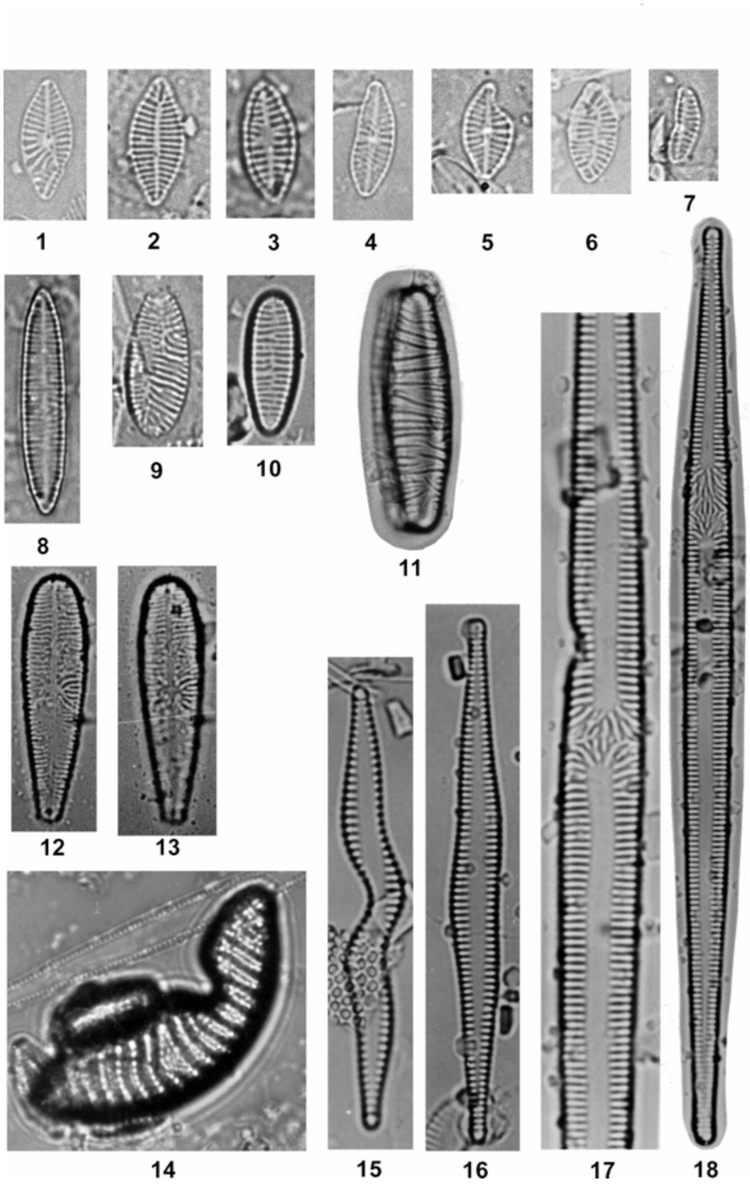

Plate 1: 1-7. *Planothidium delicatulum* (Kützing) Round & Bukhtiyarova; 8-9. *Fragilaria virescens* var. *subsalina* (Ralfs) Grunow; 10. *Fragilaria schulzii* Brockmann; 11. *Diatoma vulgaris* Bory; 12-13. *Gomphonema olivaceum* (Hornemann) Brèbisson; 14. *Epithemia* sp.; 15-18. *Fragilaria fasciculata* (Agardh) Lange – Betralot.

Magnification = 1500× (1-17); 1000× (18).

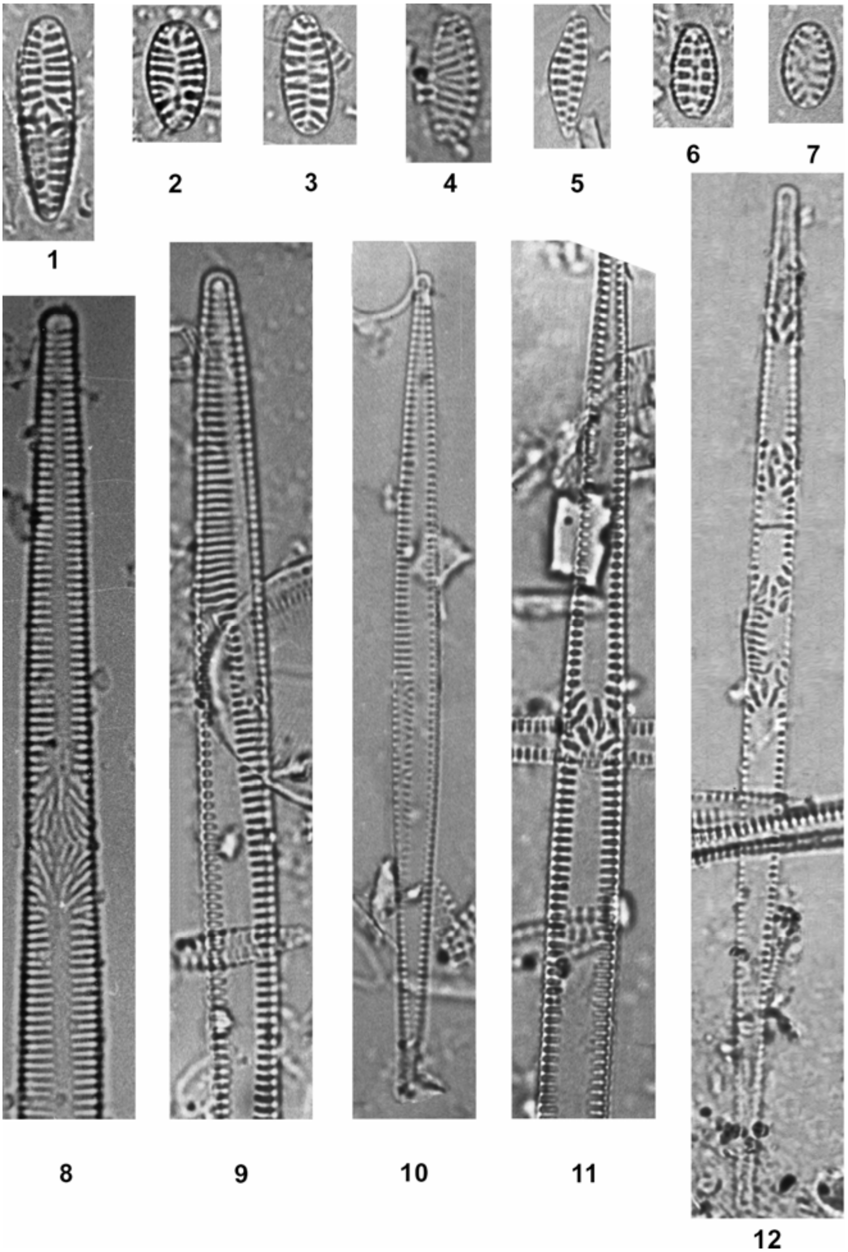

Plate 2: 1-7. *Opephora olsenii* Möller; 8-12. *Fragilaria fasciculata* (Agardh) Lange – Betralot.

Magnification = 1500× (1-12).

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