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A further contribution to the diatom flora of sewage enriched waters in southern Africa

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The systematics and autecology of the diatoms observed in an algal sample from a maturation pond of the Walvis Bay (South West African coast) sewage works are discussed. Fourteen diatom species are recorded. A new species, *Amphora subacutiuscula,* is described. The diatom association was subjected to a statistical analysis to determine the relative abundance of the different species in the association. Since the structure of the diatom association is the result of environmental conditions, it is possible to employ the association to determine the ecological conditions prevailing in the water.

The chemical results of the maturation pond water suggest eutrophic, alkaline water with a high concentration of dissolved solids. Therefore, species favouring these conditions are expected to occur in this water. Except for the new species, *Amphora subacutiuscula,* whose autecology is still unknown, all the other species recorded in this sample are alkaline water inhabitants. Many of these are brackish species or are able to tolerate certain fluctuations in osmotic pressure. The dominant species, *Amphora tenerrima,* suggests brackish conditions. *Cyclotella meneghiniana,* a sub-dominant species, is known to be nitrogen heterotrophic and, therefore, grew well in the pond.

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Introduction

The algal sample was collected on November 17, 1971 in a maturation pond at Walvis Bay sewage works. This sample was taken from the sandy bottom of the pond, near its margin and about 40mm beneath the water surface. Walvis Bay is a South African port on the barren South West African coast (23°0'S, 14°28'E). The sewage works receives mainly domestic sewage and consists of primary sedimentation tanks, biological filters, humus settlement tanks, and maturation ponds. The latter are situated within the coastal dune zone and are responsible for the secondary treatment of sewage mainly due to the photosynthetic activities of algae. The maturation ponds are shallow, usually about 1 metre in depth, and receive biologically treated effluent from the humus settlement tanks after the raw sewage has passed through the primary sedimentation tanks and biological filters. It is important to note that these ponds end blindly in the dunes with no outflow and water loss is due to seepage and evaporation. Because of the relatively large volume of these ponds, chemical conditions may be considered to remain reasonably stable.

The relative abundance of each species was calculated by using a modified "Thomasson Analysis" (Cholnoky, 1968, p. 53–55; *cf.* Schoeman, 1972*a*) and is given as a percentage of the total number of individuals counted (Table 1). Since the structure of the diatom association is the result of environmental conditions, it is possible to employ the association to determine the general ecological conditions prevailing in the water. Unfortunately only one algal sample was available for examination but, nevertheless, it should serve to give some picture of general environmental conditions. An important aspect of this paper is that it is the first contribution to our knowledge of the diatom flora of this region.

Only a few chemical analyses are available for the water sample that was collected, together with the diatom sample, on November 17, 1971 (Table 2, column *C*). For these results I wish to thank Mr. P. F. Hamman of the South West African Department of Water Affairs. For comparative purposes, two further sets of chemical analyses (Table 2, columns *A* and *B*), of samples previously collected on April 20, 1967, are also given. These results suggest that species favouring eutrophic, alkaline water with a high concentration of dissolved solids can be expected to occur in the maturation ponds.

Systematics and Autecology of the Species Recorded

A list of the diatoms found in the sample is given below in alphabetical order together with some taxonomic and ecological comments.

AMPHORA Ehrenberg 1840

Amphora subacutiuscula n. sp. Fig. 1–5

In general appearance the Walvis Bay specimens closely resemble a number of other species, *e.g. Amphora acutiuscula* Kützing (*cf.* Grunow *in* van Heurck, 1880-1885, Pl. 1, fig. 18), *A. exigua* Gregory (*cf.* Cleve, 1895, p. 123), *A. sydowii* Cholnoky (1963, p. 237, Pl. 8, figs. 3–6), and *A. tumida* Hustedt (1956, p. 120, figs. 51–54). They differ from *A. acutiuscula* in that their dimensions are often smaller. The number of ventral striae (where visible) is also greater than that of *A. acutiuscula*. *A. exigua* has less striae in 10μm along the dorsal margin. In shape, some of the larger Walvis Bay specimens resemble Cholnoky's (*l.c.*) figured specimens of *A. sydowii*. However, this species possesses undulating longitudinal costae, of which one or two near the dorsal margin are very well developed. *A. sydowii* also displays less ventral striae in 10 μm, these being very short. Hustedt's (*l.c.*) description of *A. tumida* states that it has short protracted ends. The Walvis Bay specimens tend to have longer protracted ends that are especially noticeable on the larger specimens. The ventral striae of *A. tumida* are very short and difficult to observe. They are also difficult to observe on the Walvis Bay specimens, but, where visible, they are longer than those illustrated by Hustedt. Therefore, the Walvis Bay specimens differ sufficiently to warrant the description of a new species.

The valves are semi-elliptical to semi-lanceolate with convex dorsal margins that may tend to become slightly flattened in the middle, and straight ventral margins that may be slightly convex or concave in the middle, 13–34.5μm long and 3.5–5.5μm wide. The ends of the valve are well protracted, may be slightly capitate, and are usually directed ventrally. The raphe branches are usually straight and filiform though occasionally they may be slightly curved. The terminal fissures were not observed and the central pores are small and close together. Along the dorsal side the axial area is linear and narrow. Along the ventral

TABLE 1

Species composition of sample expressed as percentages of total diatoms

Amphora subacutiuscula	17.7
Amphora tenerrima	53.2
Anomoeoneis sphaerophora	5.9
Cyclotella meneghiniana	15.1
Cymbella pusilla	1.5
Fragilaria pinnata	0.7
Navicula pseudohalophila	1.1
Nitzschia apiculata	0.7
Nitzschia fonticola	3.0
Nitzschia thermalis	0.4
Synedra tabulata	0.7

TABLE 2

Chemical analyses of water from Walvis Bay sewage ponds (All results, except pH, in mg/1)

Sampling point	A	B	C
Oxygen absorbed (4 hour)	21	13	13
Biochemical oxygen demand (5 days)	37	7	—
Chemical oxygen demand	226	125	123
NH_3 (as N)	28	5	3.1
NO_3 (as N)	0.7	0.2	—
Organic N	—	—	2.5
pH	8.8	8.8	alkaline
Total dissolved solids (at 180C)	2694	3208	—
Total hardness (as $CaCO_3$)	600	660	—
Total alkalinity (as $CaCO_3$)	450	450	—
Sodium (as Na)	740	860	—
Chloride (as Cl)	1180	1420	—
Sulphate (as SO_4)	216	206	—

A. Sample taken near the end of the first section of the maturation pond system. 20.4.1967.
B. The furthest point of the maturation pond system where it branches between the dunes. 20.4.1967.
C. Sample taken from one of the pond branches nearest Walvis Bay. 17.11.1971.

side it may be fairly wide in smaller specimens where ventral striae are invisible, but in larger specimens, which possess ventral striae, it is narrow and linear. The dorsal transapical striae are radial and finely punctate, 18–20(22) in 10μm in the middle and slightly more concentrated at the poles. The ventral striae are short and radial becoming invisible near the ends, 27–30 in 10μm. In the middle they are interrupted, thereby forming a small central area that reaches the ventral margin. Ventral striae are not visible on the smaller specimens.

In the maturation pond this species represented 17.7% of the diatom association, indicating that conditions were suitable for its growth, although not optimal.

Valvae semi-ellipticae vel semi-lanceolatae marginibus dorsalibus convexis, fortasse complanescentes in parte mediana, marginibus ventralibus directis fortasse levissime convexis sive concavis in mediana parte, 13–34.5μm longae, 3.5–5.5μm latae. Apici valvarum bene protracti, fortasse levissime capitati, plerumque crescenti ventraliter. Rami raphis recti et filiformes, aliquando levissime curvati. Fissurae terminales non observatae, pori centrali parvi, approximati. Secus laterem dorsale area axialis linearis, angusta. Secus laterem ventrale fortasse satis lata in specimenibus parvioribus ubi striae ventrales invisibiles sed in specimenibus majoribus striis ventralis angusta, linearis. Striae dorsales transapicae radiales, punctatae subtiliter, 18–20(22) in 10μm in mediana parte, leviter concentratae apicibus. Striae ventrales breves, radiales, invisibiles prope extremos, 27–30 in 10μm. In mediana parte interruptae, facientes aream centralem parvam extensam margine ventrale. Striae ventrales non visibiles specimenibus parvioribus.
Habitat in lacunis cloacalis in thiniis in Balaenarum Sino (Walvis Bay), ad oras Africae austro-occidentali.
TYPUS: praeparatum no. Walvis Bay 1 in collectione C.S.I.R., Pretoria.

ICONOTYPUS: figurae nostrae no. 1–5.

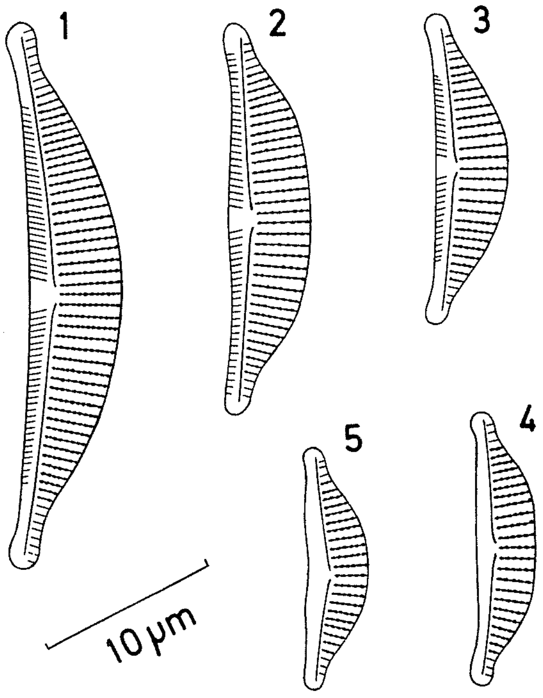

FIG. 1–5. *Amphora subacutiuscula* n.sp.

Amphora tenerrima Aleem et Hustedt (1951, p. 16, figs. 3*a-f*; *cf*. Cholnoky, 1959, p. 13, fig. 80; 1960, p. 26, fig. 68; 1966*c*, p. 162). Fig. 8–10.

The autecology of this species is still poorly known. It is a brackish water species (Cholnoky, 1968, p. 222) and has also been found in sulphate-rich waters of South West Africa (S.W.A.). In a sample from the Swakop River in S.W.A., it represented 10% of the diatom association (Cholnoky, 1963, p. 252). The chemical analyses of this sample (Cholnoky, 1963, p. 236) are as follows: total dissolved solids 3060 mg/1, sulphate as SO_4 275 mg/1, chloride as Cl 1405 mg/1 and pH 7.7 (measured in the laboratory). Conditions in the alkaline water of the Walvis Bay maturation pond must be suitable for its growth since it represented 53.2% of the diatom association. Its presence here also suggests brackish water conditions.

Dimensions: 9.3–16μm long, 2.2–2.8μm wide and 22–23.5 dorsal transapical striae in 10μm (up to 29 in 10μm at the poles).

ANOMOEONEIS Pfitzer 1871

Anomoeoneis sphaerophora (Kützing) Pfitzer (*cf*. Cleve, 1895, p. 6; Müller, 1899, p. 295, Pl. 12, figs. 1–15; Hustedt, 1927–1966, part 2, p. 270, figs. 1108*a,b* = *Navicula sphaerophora* Kützing, 1844, p. 95, Pl. 4, fig. 17; *cf*. Schmidt *in A*. Schmidt Atlas, Pl. 49, figs. 49–51; Grunow *in* van Heurck, 1880-1885, p. 101, Pl. 12, fig. 2).

Although very little is known of its autecology, it is believed to grow optimally in alkaline water (*cf*. Jörgensen, 1948, p. 49; Hustedt, 1957, p. 257). Its pH optimum probably lies above 8.5 (Cholnoky, 1968, p. 386).

Dimensions: 28–45μm long, 13.2–14μm wide and 16.5–18 transapical striae in 10μm.

CYCLOTELLA Kützing 1834

Cyclotella meneghiniana Kützing (1844, p. 50, Pl. 30, fig. 68; *cf.* Fricke *in* A. Schmidt Atlas, Pl. 222, figs. 25–31; van Heurck, 1880–1885, Pl. 94, figs. 11–14, 17–20; Hustedt, 1927–1966, part 1, p. 341, fig. 174; Cholnoky, 1970*b*, p. 11).

Swale (1969) observed this species to be one of the dominant algae of the phytoplankton in some English rivers. Hustedt (1927–1966, part 1, p. 342) lists it as a littoral form and "seltener auch im Plankton". It is a facultative nitrogen heterotrophic diatom with a pH optimum that lies above a value of 8 (Cholnoky, 1968; p. 389; 1970*b*, p. 11). The pH of the river waters from which Swale (1969, p. 3) recorded it (dominant) is approximately 8.0. However, Liebmann (1962, p. 331) states that its best growth occurs at a pH of 7.5 and 120 mg/1 Cl. Cholnoky (*l.c.*) remarks further that it tolerates mild changes in osmotic pressure as well as mild oxygen deficiencies. *C. meneghiniana* grew quite well in the eutrophic water of the maturation pond and represented 15.1% of the diatom association.

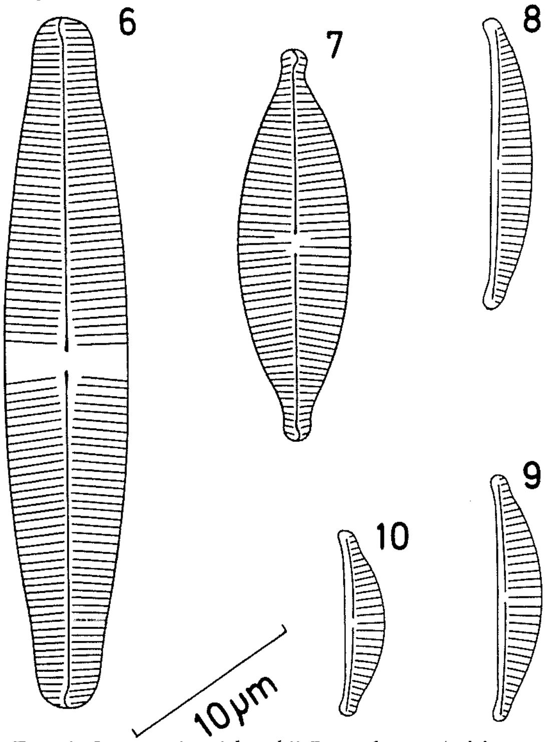

FIG. 6. *Stauroneis wislouchii* Poretzky et Anisimowa. FIG. 7. *Navicula pseudohalophila* Cholnoky. FIG. 8–10. *Amphora tenerrima* Aleem et Hustedt.

Dimensions: the valves are 24–30μm in diameter with 7.5–8 radial ribs in 10μm.

CYMBELLA Agardh 1830

Cymbella pusilla Grunow (*cf.* A. Schmidt Atlas, Pl. 9, figs. 36, 37; Hustedt, 1930, p. 354, fig. 646; 1949, p. 113, Pl. 11, figs. 5–7; *in* A. Schmidt Atlas, Pl. 380, figs. 33–36).

Both Hustedt (1930, p. 354) and Cholnoky (1968, p. 225) state that it is a brackish water species. Cholnoky (1968, p. 623) regards all species of the genus *Cymbella* to be autotrophic in their metabolism. Therefore, they are unable to compete with heterotrophic species in eutrophic water. This probably accounts for the small numbers (1.5%) of *C. pusilla* in the eutrophic maturation pond water.

Dimensions: 20–25μm long, 5–5.4μm wide, and about 15 transapical striae in 10μm (more concentrated at the poles).

FRAGILARIA Lyngbye 1819

Fragilaria pinnata Ehrenberg (*cf.* Hustedt *in* A. Schmidt Atlas, Pl. 297, figs. 47–72, Pl. 298, figs. 47–74, it being impossible to distinguish between the type and its varieties as given by Hustedt; 1927–1966, part 2, p.160, figs. 671*a-i* and *m-o,* on the same grounds as stated above; *cf.* Cholnoky, 1970*a,* p. 25).

This was another rare species in the Walvis Bay sample (0.7%). When present in large numbers it is a good indicator of oxygen-rich, alkaline, and oligotrophic water (Cholnoky, 1968, p. 397, 467). It is undoubtedly a freshwater species (Hustedt, *l.c.,* p.161; Patrick and Reimer, 1966, p. 127; Cholnoky, 1968, p. 227) but is able to survive slight fluctuations in osmotic pressure (Cholnoky, *l.c.*).

NAVICULA Bory 1824

Navicula pseudohalophila Cholnoky (1960, p. 74, figs. 231–235; *cf.* Giffen, 1963, p. 240, figs. 76, 77). Fig. 7.

N. pseudohalophila is probably a freshwater species which can tolerate moderate fluctuations in osmotic pressure (Cholnoky, 1968, p. 234). It has been observed by Giffen (*l.c.*) in some brackish waters of the Eastern Cape Province (South Africa). Cholnoky (1968, p. 408) maintains that its pH optimum lies between 7.5 and 8. Only a few specimens of this species occurred in the maturation pond sample.

Dimensions: 20–22 μm long, 5.8–6.6 μm wide, and 23–24 transapical striae in 10 μm (slightly more at the poles).

Navicula pygmaea Kützing (*cf.* Smith, 1853, p. 48, Pl. 31, fig. 274 as *Navicula minutula,* and 1856, p. 91; A. Schmidt Atlas, Pl. 70, fig. 7; Hustedt, 1930, p. 312, fig. 561; 1927–1966, part 3, p. 538, fig. 1574; Patrick and Reimer, 1966, p. 442, Pl. 39, fig. 4).

Cholnoky (1968), p.235; 1970*b,* p.23) states that it is a freshwater diatom which can only survive in brackish waters if the fluctuations in osmotic pressure are slight. Most other authors mention that it favours brackish water. Scheele (1956, p. 445) lists it as a mesohalobe but Hustedt (1957, p.305) remarks that, judging from his observations, it is probably only a beta-mesohalobe. Patrick and Reimer (1966, p. 442) mention that its ecological distribution is in fresh water of high mineral content as well as in brackish water. They also state that it sometimes occurs in polluted water. This agrees with Hustedt's (*l.c.*) observation "häufig an verschmutzten Standorten". Only two specimens were seen in the Walvis Bay material.

Dimensions: 20–25μm long, 8.5–9μm wide, 27 transapical striae in 10μm in the centre and up to 30 in 10μm at the poles.

Navicula seminulum Grunow (*cf.* Hustedt *in* A. Schmidt Atlas, Pl. 401, figs. 50–63; 1927–1966, part 3, p. 241, fig. 1367; Schoeman, 1972*b, in press,* figs. 18–20).

A single specimen of this species was observed. Notes on its ecological requirements have been given by Cholnoky (1968) and Schoeman (1972*a,* 1972*b*).

NITZSCHIA Hassall 1845

Nitzschia apiculata (Gregory) Grunow (*in* Cleve and Grunow, 1880, p. 73; *in* van Heurck 1880–1885, Pl. 58, figs. 26, 27; *cf.* Hustedt *in* A. Schmidt Atlas, Pl. 331, figs. 14, 15; 1930, p. 401, fig. 765).

This freshwater species can survive moderate fluctuations in osmotic pressure (Cholnoky, 1968, p. 236). Other authors consider it to be mesohalobous (Kolbe, 1927, p. 94; Scheele, 1956, p. 445; Hustedt, 1957, p. 341). It is an inhabitant of alkaline waters (Cholnoky, *l.c.*) and has been termed alkaliphilous by Scheele (1952, p. 366) and Hustedt (*l.c.*). A few valves were seen in the Walvis Bay sample.

Dimensions: 43–49μm long, about 8μm wide, and 16–17 transapical striae in 10μm.

Nitzschia fonticola Grunow (*in* van Heurck, 1880–1885, Pl. 69, figs. 15–20; *cf.* Hustedt *in* A. Schmidt Atlas, Pl. 348, figs. 60–72; 1930, p. 415, fig. 800; 1949, p. 142, Pl. 13, figs. 75–83, 91–93; Cholnoky, 1966*b,* p. 55, fig. 157; Archibald, 1966, p. 231, figs. 8–13).

N. fonticola is a freshwater species but can tolerate relatively large fluctuations in osmotic pressure (Cholnoky, 1968, p. 237). It grows optimally in alkaline water, probably at a pH value above 8.0 (*cf.* Jörgensen, 1948, p. 62; Cholnoky, 1968, p. 413; Schoeman, 1972*a, in press*). Experiments have shown that it is an obligate nitrogen heterotrophic species (Cholnoky, 1968, p. 627). Notwithstanding the fact that conditions (trophic level and pH) in the maturation pond appear to be suitable for its growth, it represents only 3% of the diatom association.

Dimensions: 9–18μm long, about 3μm wide, 15–16 carinal pores in 10μm, and 27–29 transapical striae in 10μm.

Nitzschia thermalis (Ehrenberg) Auerswald (*cf.* Grunow *in* van Heurck, 1880–1885, Pl. 59, figs. 15–20, 24, on morphological grounds, it being impossible to distinguish between *N. thermalis,* the var. *intermedia* and *N. stagnorum, cf.* Cholnoky, 1962, p. 60 and 1966*a,* p. 206 (as *N. stagnorum*); on similar grounds also the following, Hustedt, 1930, p. 403 and 405, figs. 771, 773; *in* A. Schmidt Atlas, Pl. 346, figs. 12–16; 1949, p. 130–131, Pl. 11, figs. 62–64).

Notes on the autecology of this nitrogen heterotrophic species are given in a previous paper (Schoeman, 1972*b, in press*). It is extremely rare in the Walvis Bay sample.

Dimensions: 30–40μm long, about 6μm wide, 7–9 carinal pores in 10μm, and about 27 transapical striae in 10μm.

STAURONEIS Ehrenberg 1843

Stauroneis wislouchii Poretzky et Anisimowa (*cf.* Hustedt, 1927–1966, part 2, p. 792, fig. 1137; Cholnoky, 1963, p. 249, Pl. 8, figs. 3 35–~~6~~7). Fig. 6.

Cholnoky (*l.c.*) recorded a number of specimens from South West Africa that are 25–33 μm long and 6–10μm wide with up to 28 striae in 10μm at the poles, where they often become parallel and, therefore, do not remain radial throughout as stated by Hustedt (*l.c.*). Hustedt (*l.c.*) gives the following dimensions for this species: 23–36μm long, 5–9μm wide, 22–24 striae in 10μm and up to 28 in 10μm at the poles. Foged (1966, p. 71, Pl. 7, fig. 10) observed one very large specimen, 37.3 μm long and 8.7μm wide with 22–24 striae in 10μm. The single Walvis Bay specimen observed, although slightly larger, fits the description of this species rather well. It is 37.8 μm long and 6.8μm wide with 22 transapical striae (finely punctate) in 10μm in the central regions and up to 26 in 10μm at the poles. The striae of this specimen are radial, becoming slightly convergent at the poles.

According to Hustedt (*l.c.*) this species occurs in the saline, inland waters of Eastern Europe and Central Asia. Cholnoky (1968, p. 245) states that it is a brackish water species which is widely distributed in sulphate- and carbonate-rich waters.

SYNEDRA Ehrenberg 1830

Synedra tabulata (Agardh) Kützing (*cf.* Hustedt, 1927–1966, part 2, p. 218, fig. 710; the numerous varieties listed by Hustedt represent the species range of variation and cannot be separated from the type, *cf.* Cholnoky, 1970*b*, p. 36).

S. tabulata is widely distributed in the brackish waters of Southern Africa. Cholnoky (1968, p. 247; 1970*b*, p. 36) maintains that its optimal growth only occurs in waters characterised by strong fluctuations in osmotic pressure. Patrick and Reimer (1966, p. 141, as *Synedra fasciculata*) give its ecological distribution to be "in water of high conductivity, sometimes 5 slightly brackish". Hustedt (19~~6~~7, p.238) considers it to be a mesohalobic, pH-indifferent species. Jörgensen (1948, p.67), who found it in waters with a pH varying from 7.3 to above 9.0, terms it alkaliphilous. It is probably an inhabitant of obligotrophic waters Cholnoky, 1968, p.630; oligosaprobic according to Hustedt, *l.c.*). This possibly accounts for its sparse occurrence (0.7%) in the maturation pond where the water is definitely not oligotrophic.

Dimensions: 160–180μm long, 5.6–6.8μm wide, and 10–11 transapical striae in 10μm.

Discussion

The systematics and autecology of the various diatom species recorded are discussed in the text. As stated earlier in this paper, the chemical results suggest that species favouring eutrophic, alkaline water with a high concentration of dissolved solids can be expected to grow optimally in the maturation pond. The ecological requirements of *Amphora subacutiuscula,* one of the subdominant species, are unknown. The other species recorded are all alkaline water inhabitants.

Amphora tenerrima (53.2%), *Cymbella pusilla* (1.5%), and *Synedra tabulata* (0.7%) are considered to be brackish water species, whereas *Cyclotella meneghiniana* (15.1%), *Navicula pseudohalophila* (1.1%), *Nitzschia apiculata* (0.7%), and *N. fonticola* (3.0%) may occur in brackish water; and are able to tolerate mild to moderate fluctuations in osmotic pressure (Cholnoky, 1968). The species listed above account for 75.3% of the diatom association. This undoubtedly suggests that brackish conditions (fluctuations in osmotic pressure) do occur in the maturation pond. Freshwater species (*Nitzschia thermalis* and *Fragilaria pinnata*) represent only 1.1% of the diatom association, although *F. pinnata* is able to survive very slight changes in osmotic pressure. *Amphora subacutiuscula* represented 17.7% of the diatom association and, therefore, conditions in the alkaline pond may be considered suitable, though not optimal, for its growth. The remaining 5.9% of the association is represented by *Anomoeoneis sphaerophora,* an inhabitant of alkaline water which "reagieren auf plötzliche Drucksteigerungen mit inneren Schalenbildungen" (Cholnoky, 1968, p. 222). Thus it is also possible for this species to survive sudden changes in osmotic pressure.

Cyclotella meneghiniana, Nitzschia fonticola, and *N. thermalis* are known to be nitrogen heterotrophic species and represent 18.5% of the diatom association. *Cymbella pusilla,* *Fragilaria pinnata*, and *Synedra tabulata* are autotrophic species and grow optimally in oligotrophic water. Together they account for less than 3% of the association. Unfortunately, it is not known whether the dominant and subdominant species in the association (*Amphora tenerrima* and *A. subacutiuscula*) are autotrophic or heterotrophic in their metabolism. The need for physiological experiments and further field observations is clearly evident.

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