

## On the taxonomic status of the genera *Belonastrum* and *Synedrella* proposed by Round and Maidana (2001)

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**Abstract** – Two new genera, *Belonastrum* and *Synedrella*, were erected by Round and Maidana (2001) to accommodate *Synedra berolinensis* and *Synedra parasitica*, respectively. Neither genus was characterized by scanning electron microscopy data (SEM), with both of the transfers based primarily on the ecology of the taxa, namely, the planktonic habit of *S. berolinensis* and the epiphytic nature of *S. parasitica*. Based on both SEM and detailed comparative analyses of specimens found in North American samples, the two transfers above are refuted. The combination *Staurosirella berolinensis*, proposed by Buktiyarova (1995), is recommended for *Synedra berolinensis*. *Synedra parasitica* and its variety *subconstricta* are transferred to the genus *Pseudostaurosira* sensu Williams & Round (1987).

**diatoms / taxonomy / Fragilarioid diatoms**

**Résumé** – Sur le statut taxonomique des genres *Belonastrum* et *Synedrella* proposé par Round & Maidana (2001). Deux nouveaux genres, *Belonastrum* et *Synedrella*, ont récemment été créés par Round & Maidana (2001) pour accommoder respectivement *Synedra berolinensis* et *Synedra parasitica*. Même si les auteurs incluent dans leur publication des images prises au microscope électronique à balayage (MEB), les deux transferts ont été basés sur l'écologie des taxa, notamment sur l'habitat planctonique de *S. berolinensis* et la nature épiphytique de *S. parasitica*. Basés sur des analyses au MEB et sur des analyses comparatives de spécimens trouvés dans des échantillons nord-américains, les deux transferts mentionnés plus haut sont réfutés. Ici, le transfert de *S. berolinensis* vers *Staurosirella berolinensis* proposé par Buktiyarova (1995) est recommandé et *S. parasitica* et sa variété *subconstricta* sont transférés au genre *Pseudostaurosira* sensu Williams & Round (1987).

**diatomées / taxonomie / diatomées fragilarioides**

### INTRODUCTION

Two genera, *Belonastrum* and *Synedrella*, were proposed recently to accommodate, respectively, *Synedra* (*Fragilaria*) *berolinensis* and *Synedra* (*Fragilaria*) *parasitica* (Round & Maidana, 2001). Both transfers were based primarily on the ecological habitats that the species occupy.

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*Synedra berolinensis* forms star-shaped colonies that float in the plankton of lakes and rivers. The attachment of cells within the colony is accomplished by secretion of mucilaginous material from the basal end of the frustules. Until the articles of Lange-Bertalot (1989) and Round & Maidana (2001), the ultrastructure of this diatom was poorly known, and its taxonomy was confused. Lemmermann (1900) described the species for the first time and placed it in *Synedra*, within a subgenus that he called *Belonastrum*. Although Lemmermann did not present a drawing to accompany his protologue of *S. berolinensis*, later authors were able to find and illustrate the taxon (e.g., Hustedt in Schmidt *et al.*, 1874-1959; Krammer & Lange-Bertalot, 1991; and others). It is now known that *S. berolinensis* produces short spines, and that although they may not entirely accomplish the functions of similar structures in other fragilarioids (see later), this feature alone is sufficient to warrant its separation from *Synedra sensu stricto*. Krammer & Lange-Bertalot (1991) assigned *S. berolinensis* to the genus *Fragilaria*, as they did with most other taxa traditionally placed in *Synedra*. Their merging of *Fragilaria* and *Synedra* is based on a continuum of forms between the two genera, an idea refuted by Round *et al.* (1990), Williams (1986) and Williams & Round (1986; 1987), who split both taxa into several other genera based on electron microscopy analyses.

*Synedra parasitica* is an epiphyte living on other diatoms, especially those with a canal raphe (*Nitzschia*, *Campylodiscus*, etc.). The reasons for this epiphytism are not known (Round & Maidana, 2001), but the occurrence of *S. parasitica* on other habitats such as rocks, macrophytes, or mud cannot be completely ruled out due to the lack of detailed LM and SEM information. *Synedra parasitica* was originally described by Smith (1856) as *Odontidium parasiticum*, but was later transferred by Grunow (in Van Heurck, 1881) to the genus *Fragilaria*. Hustedt (1930) rejected this move because he recognized a distinction (at the LM level) between *Synedra* and *Fragilaria*, particularly with regard to the type of colony formed by species in each of these genera (ribbon-like versus fan-shaped). Thus, since *O. parasiticum* did not form ribbon-like colonies it was transferred to *Synedra*.

*Synedra parasitica* was subsequently transferred to *Fragilaria* by Krammer & Lange-Bertalot (1991), again based on a purported morphological similarity between the species previously allocated to *Fragilaria* and *Synedra*.

Although Round & Maidana (2001) presented some SEM information, the analysis of this information was not exhaustive and lacked a comparative perspective. Specifically, the type of areolae and the closing plates in both taxa, combined with the features of the spines and apical pore fields do resemble those of other taxa placed in the genus *Pseudostaurosira sensu Williams & Round* (1987).

Analyses of North American material provided an opportunity for detailed studies of the morphology of these two taxa. Results of these studies are presented herein, along with an analysis of the taxonomy of the two taxa in light of the classification system proposed by Williams & Round (1987). These results suggest that the combination *Staurosirella berolinensis* proposed by Bukhtiyarova (1995) is the most appropriate taxonomic position for *S. berolinensis*. Also, the transfer of *S. parasitica* to the genus *Pseudostaurosira* is proposed. A third taxon, *S. parasitica* var. *constricta* (also included in *Synedrella* by Round & Maidana [2001]), is transferred to *Pseudostaurosira*.

## MATERIALS AND METHODS

Twelve samples were analyzed for this work (Table 1), all containing well-developed populations of fragilarioid diatoms. The sample from Lake o' Pines, Wisconsin (USA) was taken from a depth of 7.5 m along a core collected in 1995. Surface sediments were collected from all Connecticut, USA, localities following methods described in detail by Morales *et al.* (2001) and Morales (2001). Material from the Michipicoten Island (Ontario, Canada) sample was collected in 1968 from a sandy bottom in ca. 45 cm water depth. The rest of the samples corresponded to periphytic material collected as part of a Cooperative Agreement between the Academy of Natural Science's Patrick Center for Environmental Research and NAWQA (National Water Quality Assessment Program of the United States Geological Survey). Methodology used in the collection of NAWQA samples is explained in detail in Moulton *et al.* (2002).

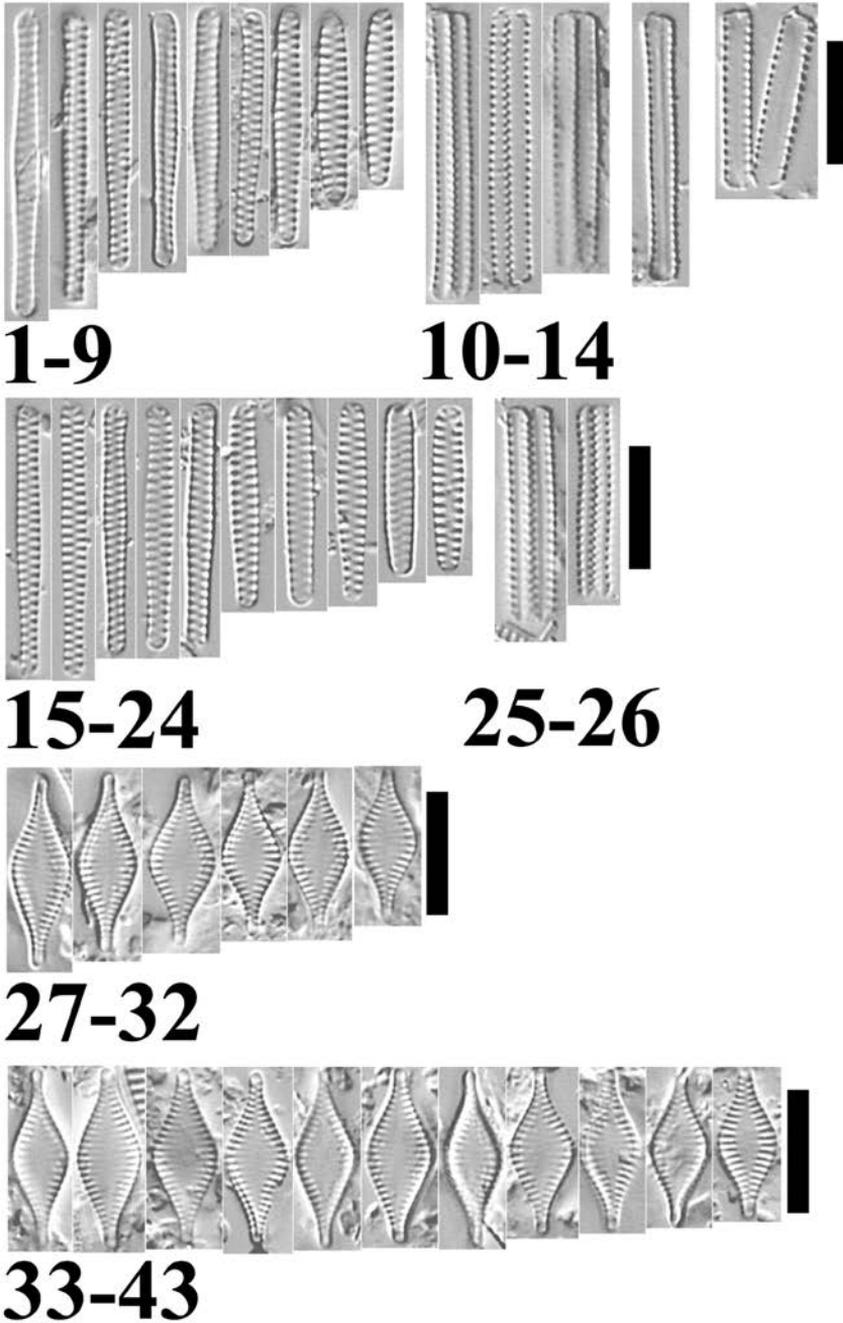
Tab. 1. List of samples used during the present study with a reference to the collection where the samples can be found.

<i>Locality</i>	<i>Collection</i>	<i>Study Unit (if NAWQA)</i>
Lake o' Pines, Wisconsin, USA	Author's personal	
Avery Pond, Connecticut, USA	Dr. P. Siver, CT Coll.	
Lake of Isles, Connecticut, USA	Dr. P. Siver, CT Coll.	
Shaker Pond, Connecticut, USA	Dr. P. Siver, CT Coll.	
Wyassup Lake, Connecticut, USA	Dr. P. Siver, CT Coll.	
Michipicoten Island, Ontario, Canada	UMICH EFS # 1788	
Stariski Creek NR Anchor Point, Alaska, USA	ANSP G.C. 105490	Cook Inlet
Turtle River, Grand Folks County, North Dakota, USA	ANSP G.C. 101603	Red River of the North
Turtle River, Grand Folks County, North Dakota, USA	ANSP G.C. 101610	Red River of the North
Caloosahatchee River, Lee County, Florida	ANSP G.C. 103590	Southern Florida Basins
Peace River, DeSoto County, Florida, USA	ANSP G.C. 103603	Southern Florida Basins
Peace River, DeSoto County, Florida, USA	ANSP G.C. 103612	Southern Florida Basins

Only permanent slides from the NAWQA samples were used for LM. These slides were prepared following methodology presented in Charles *et al.* (2002). A Nikon Microphot-FXA equipped with a Panasonic WV-BD400 video camera was used for LM analyses.

For SEM studies, aliquots of clean material were air dried onto 15 × 15 cm pieces of aluminum foil. Smaller pieces were trimmed and mounted on aluminum stubs with the aid of double-sided tape. The stubs were then coated with Gold-Palladium using a Polaron Sputter Coater for ca. 30 sec. at 1.8 kV. A Leo-Zeiss 982-DSM electron microscope was used for SEM analyses.

Plates were mounted using Photoshop v. 6.0. Morphological terminology follows Anonymous (1975) and Ross *et al.* (1979).



Figs 1-43. LM images of taxa treated in this work. **1-14.** *Staurosirella berolinensis*. Peace River, De Soto County, Florida. ANSP G.C. 103603. **15-26.** *Staurosirella berolinensis*. Peace River, De Soto County, Florida. ANSP G.C. 103612. **27-32.** *Pseudostaurosira parasitica*. Turtle River, Grand Folks County, North Dakota. ANSP G.C. 101610 **33-43.** *Pseudostaurosira parasitica*. Turtle River, Grand Folks County, North Dakota. ANSP G.C. 101603 All scale bars: 10  $\mu$ m.

## RESULTS AND DISCUSSION

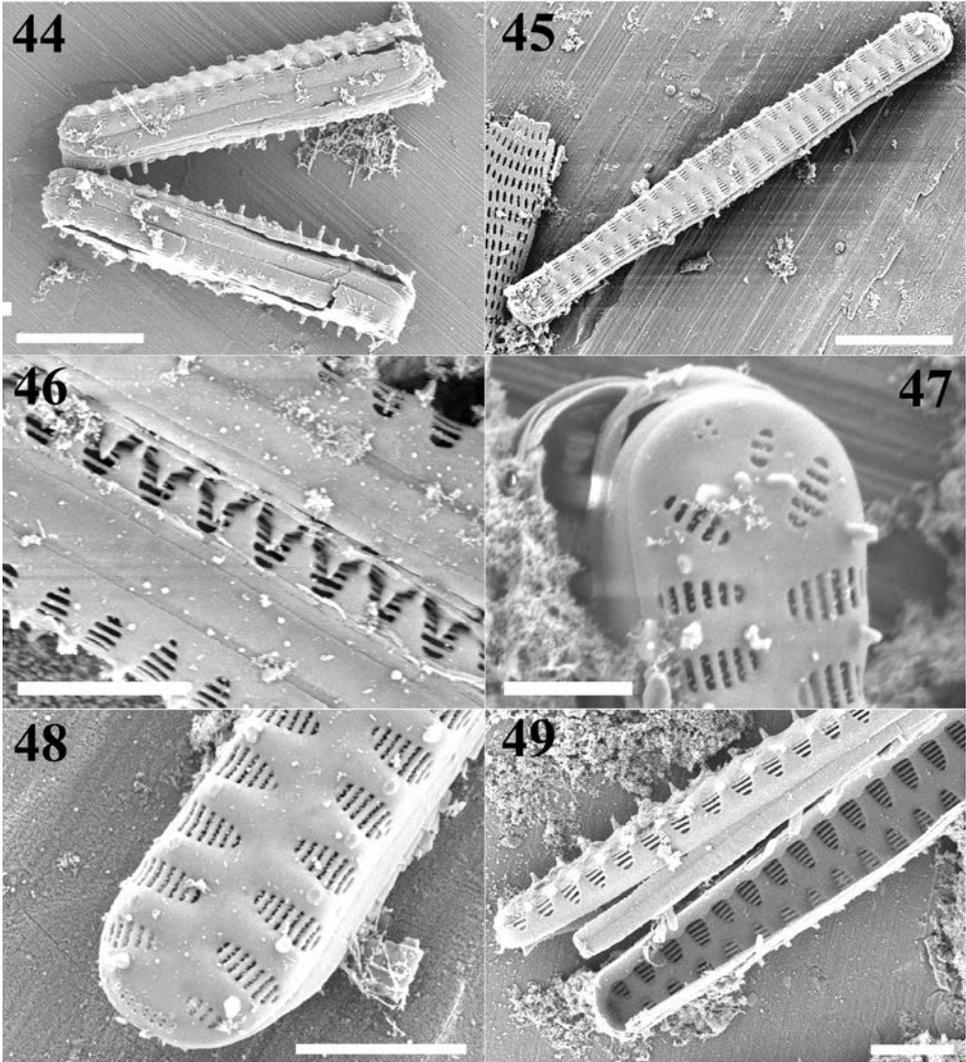
Electron microscopy analyses of *S. berolinensis* show that this taxon has multiple features shared with species currently placed in the genus *Staurosirella*. These observations support the combination *Staurosirella berolinensis* proposed by Bukhtiyarova (1995).

The colonial pattern in *S. berolinensis* is produced by secretion of mucilaginous material, which is probably later impregnated with inorganic particles. Both LM and SEM clean material contained remnants of such colonies, suggesting a partial resistance of the mix to acid digestion (Figs 14 and 44). This is corroborated by the observation of inorganic particles at the foot pole of several valves as shown in Fig. 45. In spite of the formation of mucilage-linked colonies, the valves still produce spines, which are located on the costae. While these spines are not as elaborated as those in other species of *Staurosirella* (e.g. *S. lapponica*, *S. pinnata*, etc.), they seem to also accomplish the function of adjoining contiguous valves (Figs 10-12, 25-26, and 46). It is possible that spines play the role of linking daughter cells soon after vegetative division to ensure the eventual formation of the star-shaped colony. Otherwise (and in the absence of a means of bonding) the products of mitotic division would soon disaggregate due to water disturbance. The existence of a ribbon-like stage prior to the formation of a star-shaped colony suggests that the stellate colony is an adaptation to a planktonic habit (Krammer & Lange-Bertalot, 1991) and that the ancestor was an organism that formed ribbon-like colonies. From this perspective, it is possible that the same ancestor gave rise to other fragilarioids including the species currently allocated to *Staurosirella*.

Another adaptation that favors the formation of a star-shaped colony in *S. berolinensis* is the polarity of the frustules, which is betrayed by a difference in width between the head (wider) and the foot (narrower) poles (Figs 1-9, 15-24, 45, and 50). In addition, the apical pore fields present at both poles differ from one another (compare, Figs 47 and 48). These structures are much more reduced at the head pole and are composed of a few scattered poroids. At the foot pole, the poroids are more numerous and neatly arranged in two or three rows. This type of poroid arrangement is also present in other species in *Staurosirella* (Morales, 2001; Round *et al.*, 1990). Valve polarity is also a characteristic of other species of *Staurosirella*. Many morphs of *S. pinnata*, for example, express this polarity, often in mixtures with non-polar morphologies from the same locality (see Morales, 2001, fig. 3h-i, p. 110). Therefore, valve polarity is yet another feature shared by *S. berolinensis* and species of *Staurosirella*.

The striae in *S. berolinensis* are also of the *Staurosirella* type (compare Figs 50 and 52 with Figs 51 and 53). As described by Morales (2001), the striae in the latter genus resemble holes carved onto the surface of the valves, and these holes are then crossed by bridges (cross members) delimiting very elongated areolae. This pattern can be observed in the specimens depicted in Figs 50 and 51, which also show a similar construction of the central sternum, the alternate arrangement of the striae, and the positioning of the spines on the costae.

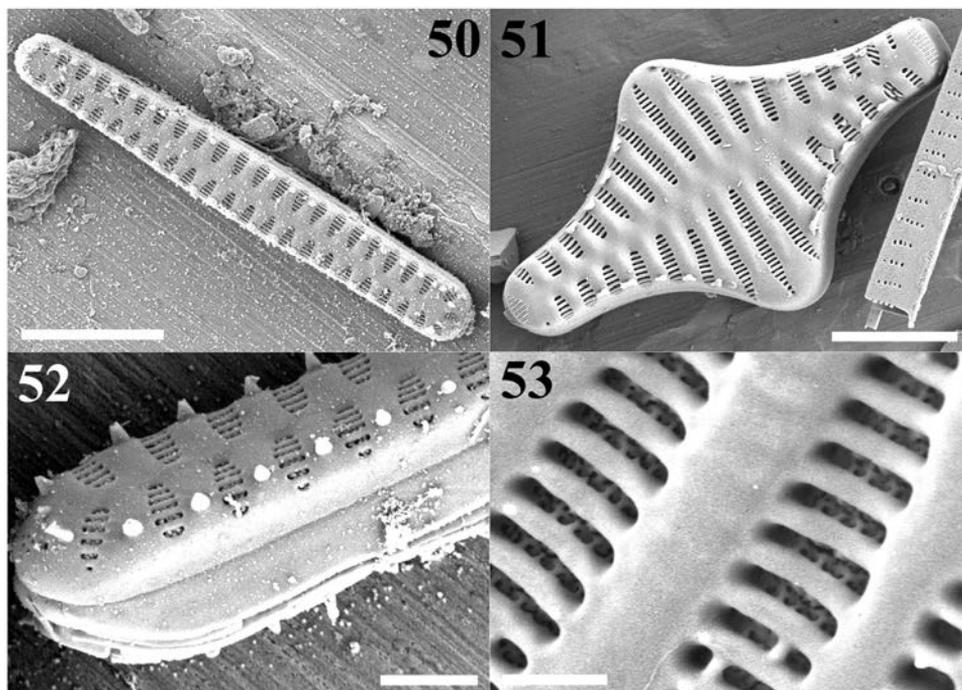
Very little is known about the type of closing plates in *Staurosirella*, but representatives in North American material have allowed a close observation of these structures. Comparing Figs 52 and 53, it can be hypothesized that the closing plates of *S. berolinensis* and *S. leptostauron* resemble each other, again, suggesting a close relationship between the two taxa. In both cases, the closing plates originate from the longer walls of the cross members and project toward the inte-



Figs 44-49. *Staurosirella berlinensis* SEM images. Peace River, De Soto County, Florida. ANSP G.C. 103612. **44.** Detail of the frustules belonging to the same colony. Cementing material has been digested by acid action. **45.** Outer view of the valve surface. **46.** Girdle view showing attachment of two neighboring cells presumably soon after mitotic cell division. **47.** Detail of the head pole with a reduced apical pore field. **48.** Detail of foot pole showing more developed apical pores. No rimoportulae openings can be seen. **49.** Internal view of foot pole showing lack of a rimoportula. Scale bars: Figs 44 and 45: 5  $\mu\text{m}$ , Fig. 47: 1  $\mu\text{m}$ , Figs 46, 48 and 49: 2  $\mu\text{m}$ .

rior of the wall, further branching in a dichotomous fashion and intertwining with neighboring closing plates.

Finally, the girdle band features and the absence of rimoportulae in *S. berlinensis* further support its transfer to the genus *Staurosirella*. Girdle bands in *S. berlinensis* are open, vary in number between 3 and 6, and lack perforations

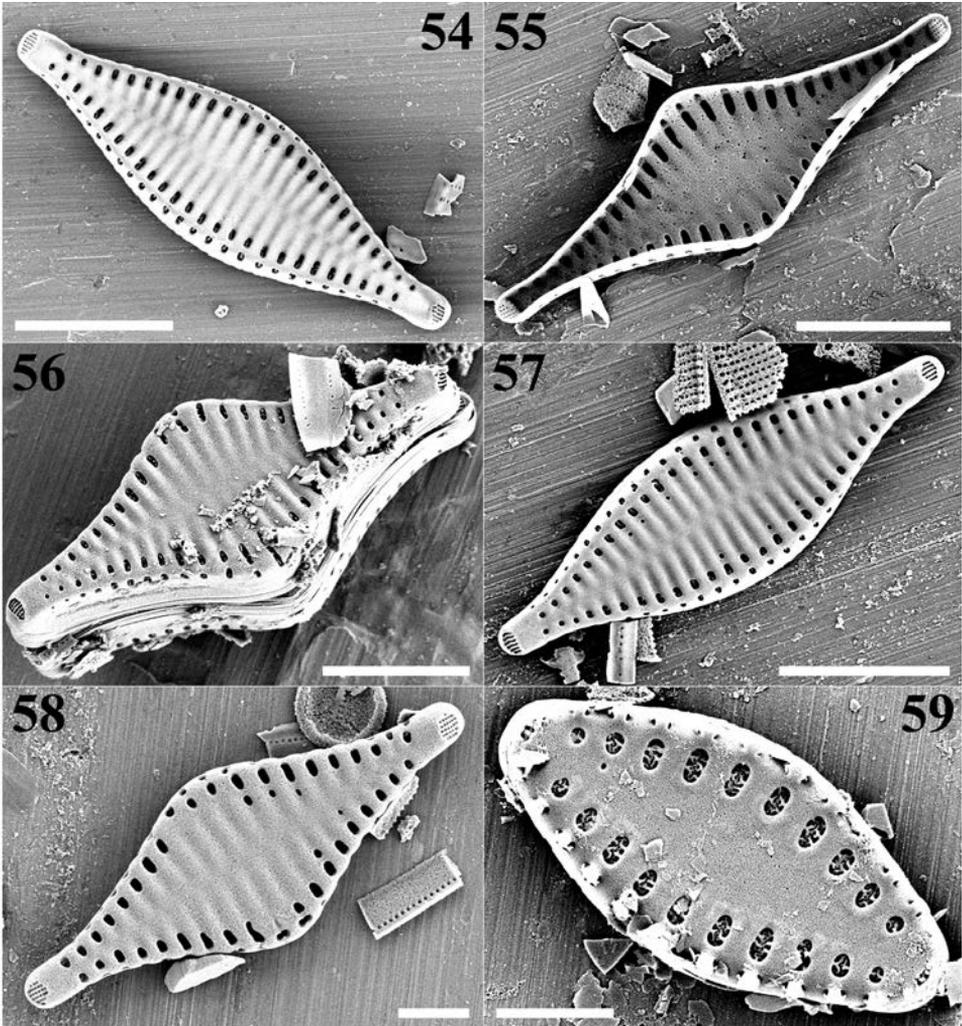


Figs 50-53. Comparison between *Staurosirella berolinensis* and *Staurosirella leptostauron* SEM images. **50.** *S. berolinensis*, detail of the outer surface. Peace River, De Soto County, Florida. ANSP G.C. 103612. **51.** *S. leptostauron*, detail of the outer surface. Stariski Creek NR Anchor Point, Alaska. ANSP G.C. 105490. **52.** *S. berolinensis*, detail of the closing plates. Same locality as Fig. 50. **53.** *S. leptostauron*, detail of the closing plates. Michipicoten Island, Ontario, Canada. UMICHS EFS # 1788. Scale bars: Figs 50 and 51: 5  $\mu\text{m}$ , Fig. 52: 1  $\mu\text{m}$ , Fig. 53: 500 nm.

(Figs 44, 49, and 52). The valvocopula is larger than the rest of the girdle bands as in other *Staurosirella* species (Fig. 52).

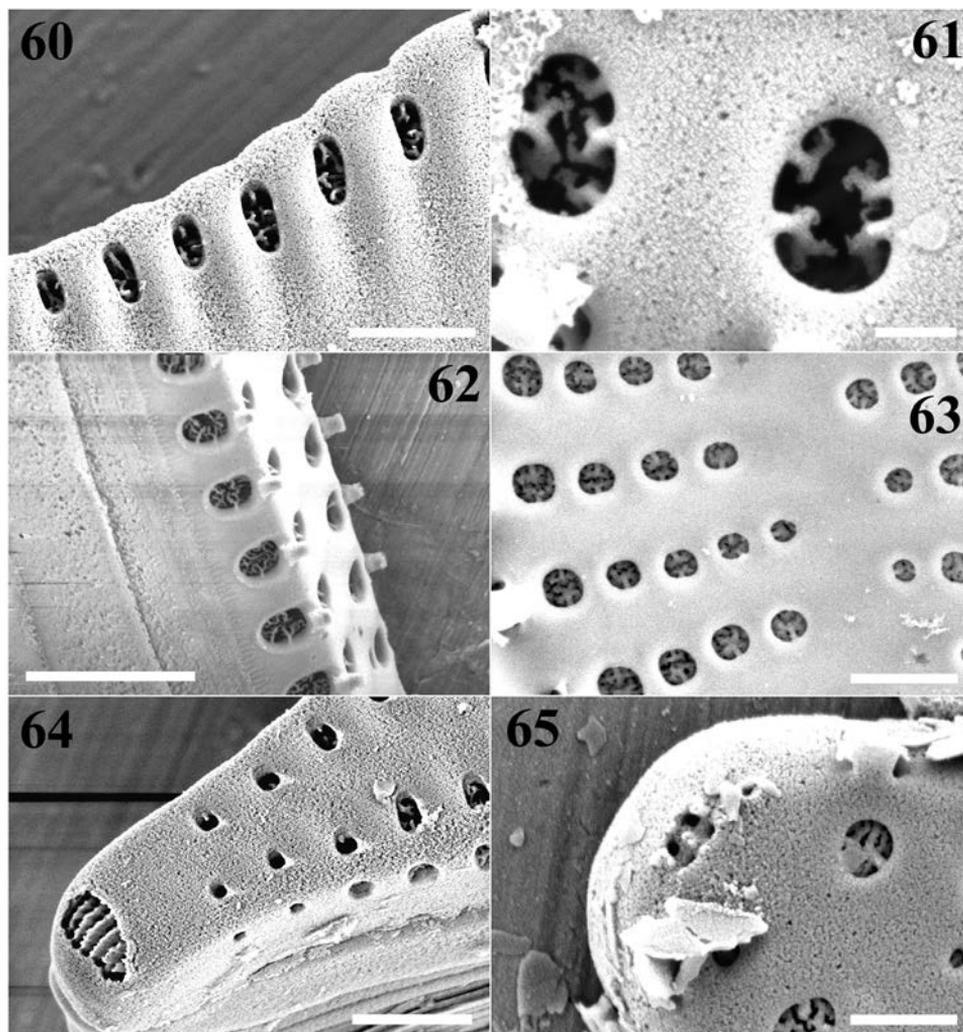
*Synedra parasitica* has always been a taxonomically problematic species. Although it shares many features with species in *Fragilaria* sensu lato, it also does with *Synedra* sensu lato. Examples of its relationship with the latter are its lack of spines and the type of apical pore fields (ocellulimbus). Many changes have occurred in the taxonomy of the genus *Synedra* in recent years (Williams & Round, 1986) and none of the newly created genera accommodate *S. parasitica*. Likewise, many new genera have been created to accommodate the formerly broadly circumscribed *Fragilaria* (Flower *et al.*, 1995; Morales, 2001; Williams & Round, 1987), but the possibility of a close relationship of *S. parasitica* with species in any of these genera has not been discussed in the literature.

The type of striae in *S. parasitica* clearly indicates a similarity with the genus *Pseudostaurosira* (Figs 27-43, 54-59, and 60-65), although species in the latter do possess spines, which are located interrupting the striae at the valve face-mantle junction. Whether the production of spines can be suppressed under changing environmental circumstances in species of the genus *Pseudostaurosira* (or any other fragilarioid genus) has not been studied and the field is open for this type of analysis. There is no doubt that to uncover the relationship between spiny



Figs 54-59. *Pseudostaurosira parasitica* and *P. brevistriata* SEM images. **54, 57, and 58.** *P. parasitica*: details of the valve surface. **54, 57.** Avery Pond, Connecticut. Dr. P. Siver, CT Coll. **58.** Lake of Isles, Connecticut. Dr. P. Siver, CT Coll. **55.** *P. parasitica*: valve interior showing the absence of rimoportulae. Lake of Isles, Connecticut. P. Siver, CT Coll. **56.** *P. parasitica*: outer surface showing some details of the girdle bands. Lake o' Pines, Wisconsin, USA **59.** *P. brevistriata*: details of the outer surface. Wyassup Lake, Connecticut, USA. Dr. P. Siver, CT Coll. Scale bars: Figs 54-57: 5  $\mu$ m, Figs 58 and 59: 2  $\mu$ m.

and spineless forms, detailed and controlled experimentation is required. Nevertheless, the hypothesis that both forms may occur during the life cycle of a single species can be suggested. Likewise, the hypothesis that some species within a given genus, which also includes spiny species, may have lost the ability to produce spines due to adaptation to a newly invaded habitat can also be drawn. Therefore, *Pseudostaurosira* could accommodate *S. parasitica*.



Figs 60-65. Comparison of *Pseudostaurosira parasitica* with other *Pseudostaurosira* species (SEM images). **60.** Detail of the closing plates in *P. parasitica*. Lake o' Pines, Wisconsin, USA. **61.** Detail of the closing plates in *P. brevistriata*. Wyassup Lake, Connecticut, USA. Dr. P. Siver, CT Coll. **62.** Detail of the closing plates in *P. clavatum*. Caloosahatchee River, Lee County, Florida. ANSP G.C. 103590. **63.** Detail of the closing plates in *P. trainorii*. Shaker Pond, Connecticut, USA. Dr. P. Siver, CT Coll. **64.** Apical pore field of *P. parasitica*. Lake o' Pines, Wisconsin, USA. **65.** Apical pore field of *P. brevistriata*. Wyassup Lake, Connecticut, USA. Dr. P. Siver, CT Coll. Scale bars: Figs 60 and 64: 1  $\mu\text{m}$ , Fig. 61: 200 nm, Figs 62 and 65: 500 nm. Source of images: Figs 60 and 64: Morales et al. (2001), Fig. 62. Morales (2002), Fig. 63: Morales (2001).

The strongest support for the placement of *S. parasitica* in *Pseudostaurosira* comes from a detailed analysis of the areolae and the closing plates. Furthermore, the apical pore fields, the girdle band characteristics, and the lack of rimoportulae provide additional support.

The areolae in *S. parasitica* are wide and vary in shape from round to transapically elongated, sometimes along the same striae. The number of areolae varies from one to two or four per striae, and always one of the areolae is located on the valve mantle (Figs 54-58). These features are also characteristic of *Pseudostaurosira brevistriata*, *P. pseudoconstruens* and other genera reported in recent literature that should be transferred to *Pseudostaurosira* (Rumrich *et al.*, 2000).

The closing plates in *S. parasitica* originate mostly from the areolar walls that are parallel to the transapical axis of the valve (Figs 54, 56, 57, and 60). The branching of the closing plates is dichotomous, as happens in several other species of *Pseudostaurosira*: *P. brevistriata* (Fig. 61), *P. clavatum* (Fig. 62), *P. trainorii* (Fig. 63), and others. A comparison of Figs 60-63 suggests that the closing plates in *S. parasitica* are synapomorphic with those in *Pseudostaurosira*. From this point of view, a single common ancestor might have given rise to *S. parasitica*, which adapted to become an epiphyte (although the exclusive epiphytism of this taxon still remains to be proven), and to the rest of the species in *Pseudostaurosira* (for which the ecology is not entirely known).

The apical pore fields in *S. parasitica* are of the ocellulimbus type, that is, a polar plate with densely packed poroids (Williams, 1986). This structure resembles those in other *Pseudostaurosira* species such as *P. clavatum* (Morales, 2002) and *P. brevistriata* (Compare Figs 64 and 65) in that the polar plate is sunken onto the valve face-mantle junction and in that the poroids are arranged in discernible rows. The sunken feature of the apical pore field is more conspicuous in *S. parasitica* than in the other species of the genus *Pseudostaurosira*.

Very little is known about the girdle band characteristics in *S. parasitica*. My observations (somewhat illustrated in Fig. 56) suggest that they are open and that they lack perforations, thus, resembling those in other species in *Pseudostaurosira*. Finally, the absence of rimoportulae (in combination with the characters cited above) suggests a close relationship with the genus *Pseudostaurosira*.

The occurrence of a taxon in a different ecological setting does not automatically imply that this taxon is more distantly related to other species than are species encountered within a single habitat. If speciation is made possible through a process by which an organism adapts to the exploitation of resources within the habitat of the «mother» species, or in any other potentially favorable site, then it is reasonable for a single genus to contain species that are adapted to different ecological situations. If a given species is relatively young in evolutionary terms, then the relationship with other species within its genus is still close and any differences between them would not warrant creating a new genus. This seems to be the case for both of the taxa analyzed here. The morphological similarities with previously described genera suggest that the adaptation to the planktonic or epiphytic habitats is relatively recent.

The practice of deciding the taxonomic position of an entity based solely on an ecological perspective is not sound. Allocating species to genera defined by the habitat in which they occur confers classification systems a rigidity that does not allow for any evolutionary considerations. As commented by Kocielek (1998), the taxonomy of any taxon must incorporate an evolutionary perspective, for species and genera are dynamic systems in which the interplay between genes and the environment constantly provides for more opportunities for survival.

## CONCLUSIONS

Utilizing the above discussion, the following taxonomic proposals are made:

*Staurosirella berolinensis* (Lemmermann) Bukhtiyarova (Bukhtiyarova, 1995).

**Basionym:** *Synedra berolinensis* Lemmermann (Lemmermann, 1900).

**Synonym:** *Fragilaria berolinensis* (Lemmermann) Lange-Bertalot (Lange-Bertalot, 1993; Krammer & Lange-Bertalot, 1991).

Note: Lange-Bertalot first attempted to place *Synedra berolinensis* in *Fragilaria* (Lange-Bertalot, 1989). However, this was done only as a short note in the legends of two plates, and no formal reference to the basionym was made. What is more he incorrectly attributed the name to Hustedt instead of Lemmermann (Lange-Bertalot, 1989, legend to Plate1, p. 82).

*Pseudostaurosira parasitica* (W. Smith) Morales **comb. nov.** (Figs 27-43, 54-58, 60, and 64).

**Basionym:** *Odontidium parasiticum* W. Smith (Smith, 1856, *A Synopsis of the British Diatomaceae*, 2: 19, plate LX, fig. 375).

**Synonyms:** *Fragilaria parasitica* (W. Smith) Grunow (Van Heurck, 1881). *Synedra parasitica* (W. Smith) Hustedt (Hustedt, 1930). *Synedrella parasitica* (W. Smith) Round et Maidana (Round & Maidana, 2001).

*Pseudostaurosira parasitica* var. *subconstricta* (Grunow) Morales **comb. nov.**

**Basionym:** *Fragilaria parasitica* var. *subconstricta* Grunow (in Van Heurck, 1881, *Synopsis des Diatomées de Belgique*, Fasc. 3, plate 45, fig. 29).

**Synonyms:** *Synedra parasitica* var. *subconstricta* (Grunow) Hustedt (Hustedt, 1930). *Fragilaria parasitica* var. *subconstricta* Grunow (Van Heurck, 1881). *Synedrella subconstricta* (Grunow) Round et Maidana (Round & Maidana, 2001).

The latter taxon has not been discussed in this paper, but based on the SEM photograph presented by Round & Maidana (2001), it is evident that this taxon is closely related to *Pseudostaurosira parasitica*, hence, it is closely related to *Pseudostaurosira* for the reasons presented above.

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