

Morphometric comparison of the neotype of *Asterionella formosa* Hassall (Heterokontophyta, Bacillariophyceae) with *Asterionella edlundii* sp. nov. from Lake Hovsgol, Mongolia

Janice L. Pappas and Eugene F. Stoermer

Abstract

We conducted a morphometric study to compare *Asterionella* specimens from Lake Hovsgol, Mongolia with the neotype specimens of *A. formosa* Hassall from the Glienicke See, Berlin, Germany. Specimens were digitized and measured for valve length, mid-valve width, head pole width, and foot pole width, and length to mid-valve ratio was calculated. Plots of morphometric measures revealed that specimens from Lake Hovsgol are not in the same size class as those from the Glienicke See. Size change series for each population revealed different rates of size diminution. For Lake Hovsgol specimens valve length change to mid-valve width change had a value of 0.217. For the neotype specimens of *A. formosa*, valve length change with respect to mid-valve width change was 0.41. A related rate, as a proxy for the relation between size diminution between each lake's population, had a value of -1.25 which indicates that each population vegetatively reproduces at a different rate. Cluster analysis using all morphometric measures resulted in Lake Hovsgol specimens aggregating in a group separate from the neotype *A. formosa*. With evidence of endemism being more prevalent in diatoms than what was once thought, genetic evidence of possible species differences among *Asterionella* in other lakes, and different environmental conditions between the two locales of *Asterionella* in this study, we propose that the *Asterionella* specimens from Lake Hovsgol are different from the neotypes of *A. formosa* and should be treated as *A. edlundii* Stoermer & Pappas sp. nov.

Key index words: *Asterionella*, diatom taxonomy, Lake Hovsgol, morphometry, neotype

Introduction

Asterionella is one of the most recognizable of all diatom genera. It may be a dominant form in plankton, usually found in the spring and often in the winter in temperate lakes such as the Great Lakes. The taxa in this genus are heteropolar, having a mostly narrow, long valve face with head and foot poles that differ in size (Patrick & Reimer 1966). The striae are usually fine and parallel throughout most of the valve. Spines are may be present on the valve margin. On the advalvar side of the frustule, several copulae with rows of pores may be present (Round *et al.* 1990). Septa or intercalary bands are absent (Patrick & Reimer 1966), areolae are uniseriate, vela are indistinct, and a narrow sternum is pre-

sent (Round *et al.* 1990).

Apices are capitate but variable in shape (Patrick & Reimer 1966). Apical pore fields may be present at either end of both valves (Round *et al.* 1990). During mitotic division, these fields may be lost (Round *et al.* 1990, Mann 1999). When present, rimoportulae openings at either end of both valves are parallel to the transapical axis (Round *et al.* 1990), and the external opening of this process does not have an external extension.

Recently, a review of the taxonomic history (Pappas & Stoermer 2001a) and quantitative shape analysis (Pappas & Stoermer 2001b) of *Asterionella* has shown that species identifications are in need of careful scrutiny. The taxonomic history is scant and sketchy, no consensus exists for the number of species identified within the genus, and type material does not exist for *Aste-*

rionella formosa Hassall (Lund 1962, Körner 1970, Pappas & Stoermer 2001a) that is the type species for the genus (Hassall 1850a,b, Patrick & Reimer 1966).

Valve shape of *Asterionella* is very distinct, and a cursory look at specimens from the genus make it instantly recognizable. However identifications of *Asterionella* species were made without careful, extensive morphological study (e.g., Smith 1856), even during the advent of diatom studies (Pappas 2000, Pappas & Stoermer 2001a). Instead, diatomists relied on others, assuming that the necessary morphological studies would be carried out at some later time (Pappas 2000). Some species designations were based on specimens in girdle view (e.g., Hassall 1850b, Patrick & Reimer 1966) or very poor drawings with no detail (e.g., Van Heurck 1880-1885, 1886, Peragallo & Peragallo 1897-1908, Cleve-Euler 1953). The result has been to assign freshwater taxa of *Asterionella* to *A. formosa*, and uncertainty exists about appropriate application of other species names to attempt to sort taxa within the genus. This has led to recent studies using quantitative methods as an aid in sorting taxa in *Asterionella* (Pappas 2000, Pappas & Stoermer 2001b).

From quantitative shape analysis of *Asterionella* specimens from the Great Lakes, seven shape groups were found. Some valve shape variation was evident in that some of the shape groups overlapped. However, the seven shape groups, each within a range of variation, represent distinctly identifiable different morphologies (Pappas 2000, Pappas & Stoermer 2001b). These seven shape groups may represent separate species in relation to water circulation patterns in the largest of the Great Lakes. *Asterionella* were found to occur as distinct valve shape distributions from northern Lake Superior, Lake Huron, and Green Bay to northern Lake Michigan to southern Lake Michigan. Valve shape difference may be grossly mapped to seasonal circulation patterns as approximate boundaries representing possible reproductively isolated populations of *Asterionella* (Pappas 2000).

In his monographic study of the genus, Körner (1970) neotypified *Asterionella formosa* based on specimens from the Glienicke See, Berlin, Germany. As such, this is the only authoritative material for specimen comparison purposes. Kör-

ner (1970) used field collections, light and scanning electron microscopy, and cultures in his study. He recognized two freshwater taxa, *A. formosa* and *A. ralfsii* W.Sm. *Asterionella gracillima* Heib., *A. bleakeleyi* W.Sm., and *A. formosa* var. *acaroides* Lemmerm. were included as three of a number of synonyms with *A. formosa*. Körner (1970) cultured specimens only from the Glienicke See. These specimens had valve shapes unlike those from natural populations, especially taxa that were not from the Glienicke See. Körner (1970) did not validate subsuming all *Asterionella* taxa under *A. formosa* as a result of culturing or microscopic studies.

Often, *Asterionella formosa* is said to be a cosmopolitan species (Beaver 1981, Lowe 1974). However, some evidence exists that microhabitat separation occurs (Pappas 2000, Pappas & Stoermer 2001b). In addition, reproductive isolation (Soudek & Robinson 1983) by water currents in the Great Lakes (Pappas 2000) may explain the existence of different valve shape as possible species differences. Therefore, not all specimens identified in the past as *A. formosa* are necessarily that taxon. Many specimens from the Great Lakes do not resemble the neotype of *A. formosa* (Pappas & Stoermer 2001a,b). The view that diatoms are widespread in distribution has come under question recently, and endemism has been found to be a more prevalent than once believed (Kocielek & Spaulding 2000).

Most endemics are associated with ancient lakes. However, there are cases in which Holocene lakes exhibit speciation (Theriot 1992). In Yellowstone Lake, valve morphology of a new species, *Stephanodiscus yellowstonensis*, was determined to be distinct from ancestral stock of *S. niagarae*. In Lake Superior, a new species, *Stephanodiscus superiorensis*, was also found to be distinct from the ancestral stock of *S. niagarae*. Evolution of species in these lakes occurred over a 1000 to 10000 year time frame (Theriot & Stoermer 1984, Theriot 1987). Rapid speciation of *Asterionella formosa* has been documented in lakes in England and other lakes in the United States (Soudek & Robinson 1983).

Character dependence on size has been reported for *Stephanodiscus* (Theriot 1987). Within that genus, measurements of characters such as areolae, spine and rimoportulae widths are de-

pendent on diameter which prevents complete morphological separation of species groups. *Stephanodiscus niagarae* overlaps with *S. yellowstonensis* and *S. superiorenensis* to some degree, although the latter two taxa are endemics in Yellowstone Lake and Lake Superior, respectively (Theriot & Stoermer 1984, Theriot 1987). Measurements from specimens of *Asterionella* have been reported to be within a narrow range (e.g., Patrick & Reimer 1966), and pennate diatom asexual development has been reported to be dependent on cell size (Hostetter & Hoshaw 1972).

Soudek & Robinson (1983) found that electrophoretic banding patterns of many isolates of *Asterionella formosa* from the same population had undetectable differences, while populations from different bodies of water exhibited different banding patterns. They concluded that there are significant genetic differences among populations that inhabit different bodies of water.

In a recent study of Lake Hovsgol, Mongolia, we found *Asterionella* specimens that appear to be significantly different from those of other populations of the genus. We present a morphometric study to compare the specimens from Lake Hovsgol with the neotypes of *A. formosa*. Our results show that the specimens from Lake Hovsgol are not the same as the neotypes of *A. formosa*. We propose a new species name, *Asterionella edlundii* Stoermer & Pappas sp. nov., for the taxon from Lake Hovsgol.

Methods

From strewn microscope slides mounted in Hyrax, *Asterionella* specimens from two sources were digitized for use in our study. Our source was slides in the E. F. Stoermer collection, Herbarium, University of Michigan, Ann Arbor, MI 48109-2228, USA:

M234D: Lake Hovsgol, Mongolia, 50° 54' 968" N, 100° 32' 112" E, 1570 m (total depth), 180 μ S (conductivity), 8.7 (pH), 11.1°C (water temperature), 150 m plankton (net collection), 63 μ m (net base filtration), 0-50 m (collecting depth), Station D, secchi 20 m, Hovsgol National Park, collected by M. B. Edlund, 18 July 1998;

M238D: Lake Hovsgol, Mongolia, 50° 55' 001" N,

100° 35' 115" E, 1604 m, 180 μ S, 8.7, 10.6°C, 100 m plankton, 63 μ m, 0-25 m, Station B, secchi 17.1 m, Hovsgol National Park, collected by M. B. Edlund, 18 July 1998.

The other source was the H. Körner collection, Botanischer Garten und Botanisches Museum Berlin-Dahlem, Berlin, Germany:

25634a: Glienicker See, Berlin, Germany, neotype A-19, *Asterionella formosa*, collected by H. Körner, 26. 3. 1966.

25634b: Glienicker See, Berlin, Germany, neotype A-19, *Asterionella formosa*, collected by H. Körner, 26. 3. 1966.

044: Glienicker See, Berlin, Germany, plankton, (25634) neotype A-19, original material, *Asterionella formosa*, collected by H. Körner, 26. 3. 1966.

045: Glienicker See, Berlin, Germany, plankton, (25634) neotype A-19, original material, *Asterionella formosa*, collected by H. Körner, 26. 3. 1966.

Digital images were obtained by using a Leitz Dialux 20 compound light microscope (with oil immersion objective, 1.3 numerical aperture, and \times 1300 magnification) with a Sony 3CCD digital camera. Images were digitized, captured and transmitted to a computer using NIH Image software (version 1.62; Wayne Rasband at the US National Institutes of Health, <http://rsb.info.nih.gov/nih-image/>). A more detailed description of the microscope and software used for digital imaging is given in Stoermer (1996). Specimens used in analyses were those found in valve view.

Valve length, mid-valve width, head pole width, and foot pole width were measured and length to mid-valve width ratio calculated. Plots of morphometric measures were made to compare populations. From plots of valve length versus length to mid-valve width ratio, valve length to mid-valve width change for each population's specimens was calculated as the slope or $\frac{\Delta y}{\Delta x}$.

We wanted to calculate the change in valve length versus valve length to mid-valve width ratio change for each population, and we wanted to compare these values with respect to time.

This change represents a proxy for comparing the rate at which size diminution occurs in each population and is determined using the Pythagorean Theorem. To do this, we rotate the plots of Figs 14 and 27 so that x =valve length to mid-valve width ratio, y =valve length (μm), and

$$x^2 + y^2 = z^2 \quad z = \sqrt{x^2 + y^2}$$

where z is the hypotenuse of a right triangle. That is, the x -axis is used to form the base, and the y -axis is used to form the height of the right triangles. Each population's rotated slope from Figs 14 and 27 becomes the hypotenuses for two right triangles by superimposing one population's hypotenuse on the other population's hypotenuse such that each hypotenuse intersects each other and the x and y axes. The point at which the hypotenuses cross indicates the differences in angles between right triangles. This procedure is known as a related rate (Thomas 1979), and more details on how to apply the related rate will be given using the results from this study and reported in the next section.

We wanted to know, how fast would the hypotenuse for lake Hovsgol specimens need to be slid downward on the y -axis so that the y and x values become the same as those for Glienickee See specimens? That is, what value that would make it so that the slope for one population's specimens would be equal to the slope for the other population's specimens? This value is the related rate which is calculated by differentiating implicitly the equation for the Pythagorean Theorem with respect to t , where t is any instant in time.

Cluster analysis was accomplished to cross-validate morphometric differences between populations. Measurements of valve length, mid-valve width, head pole width, and foot pole width were used to obtain a dendrogram of specimen groupings.

Results

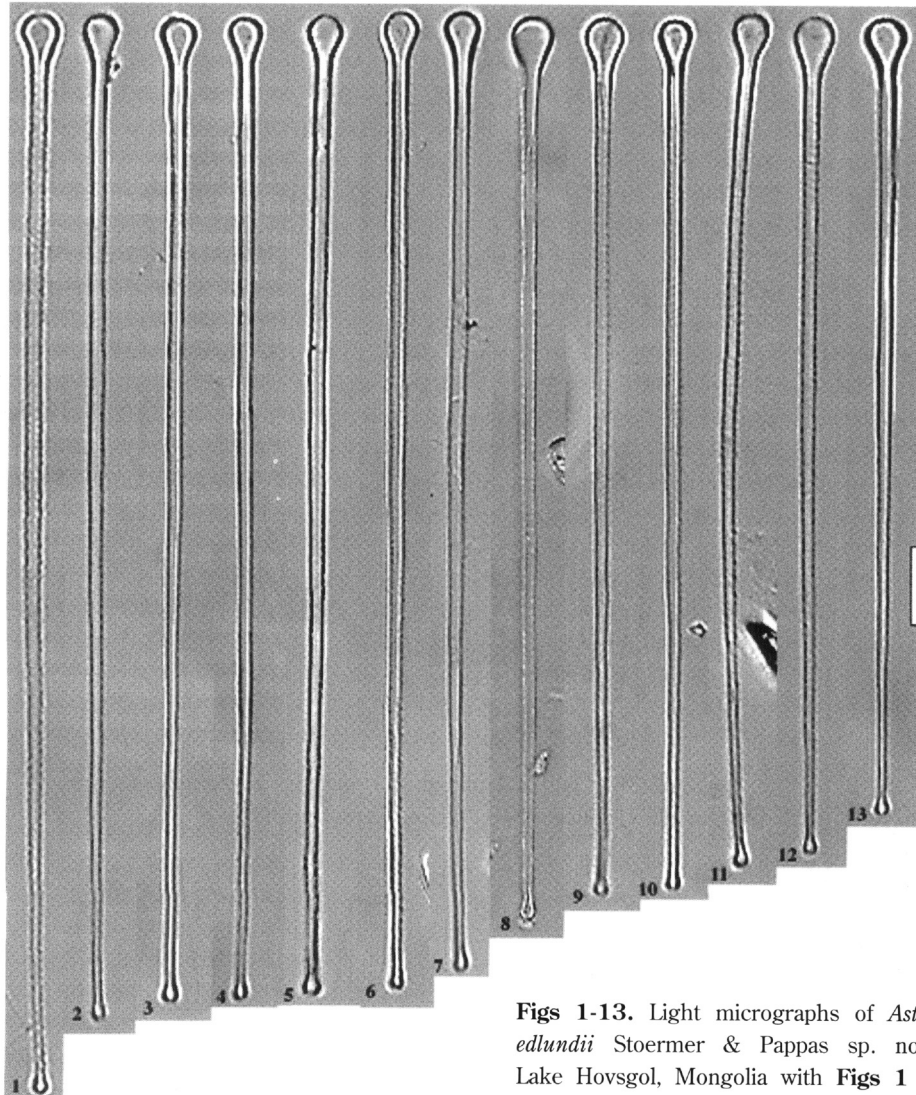
From Lake Hovsgol slides, 85 of over 200 specimens of *Asterionella edlundii* viewed were used in analyses. The valve length ranged from 112 to 146 μm with the average at 129 μm . Most commonly observed valve length was 140 μm . The mid-valve width of specimens ranged from 1.4 to 2.2 μm with the average mid-valve width at 1.7 μm , and the most commonly meas-

ured mid-valve width was at 1.66 μm . *Asterionella edlundii* from Lake Hovsgol have long, narrow valves (Figs 1-13). With some of the larger specimens, there is a bend or bowed-shape to the valve (e.g., Figs 1 and 11). Valve length to mid-valve width ratio change over the entire range of valve lengths indicated that as specimens became smaller, they became wider. A slope of 0.217 was calculated for this data (Fig. 14).

The head pole ranged from 4.5 to 5.5 μm at its widest, with the average at 4.8 μm and 4.4 μm was the most commonly measured width. The foot pole ranged from 1.4 to 1.7 μm at its widest point, averaged 1.58 μm , and 1.66 μm was the most common measurement made. Head and foot poles are capitate with the foot poles almost indistinct. Stria density in 10 μm ranged from 20 to 24.

Specimens of the neotype of *Asterionella formosa* from the Körner collection were not in the best condition. Slides had many damaged specimens and specimens obscured by debris. After careful inspection of all available slides, we chose 57 of over 200 specimens viewed to be adequate for use in analyses. Specimens had an average valve length of 49 μm , with a valve length of 54 μm most often found. They ranged in length from 30 to 82 μm . Mid-valve width ranged from 2 to 4.5 μm for most specimens with an average of 2.4 μm and the most often observed mid-valve width was 2.2 μm . Two specimens were narrower (1.7 and 1.9 μm), and one specimen was wider (5 μm) than the range given. The neotypes of *A. formosa* are generally robust (Figs 15-26). Mid-valve width increased as valve length diminished, and a slope of 0.41 for this population's data was calculated (Fig. 27).

The head pole width averaged 3.9 μm with 3.7 μm usually observed. The range in width was 3.3 to 4.5 μm with one specimen measured at 5.2 μm . The foot pole width mirrored mid-valve width and averaged 2.4 μm with 2.2 μm most often observed. Foot pole width ranged from 1.9 to 3.0 μm with one specimen at 1.5 μm . Both the head and foot poles are rounded to subcapitate in shape with the foot poles being quite prominent. Striae are 24 to 28 in 10 μm (Körner 1970). Stria density for *Asterionella formosa* are widely reported to be in this range (Patrick &



Figs 1-13. Light micrographs of *Asterionella edlundii* Stoermer & Pappas sp. nov. from Lake Hovsgol, Mongolia with **Figs 1** and **11** showing bow-shaped valves. Bar = 10 μ m.

Reimer 1966, Krammer & Lange-Bertalot 1991).

A proxy for the relation between size diminution for each lake's populations was calculated as a related rate. We created a diagram using right triangles to find values for each population by superimposing x and y axes from plots of valve length versus valve length to mid-valve width ratio (Fig. 28). Values for x and y are the intercepts where the hypotenuse intersects with the x and y axes. For Lake Hovsgol specimens, $x=25$, $y=160$ (Fig. 28) and z was calculated to be 161.94. For Glienicker See specimens, $x=33$, $y=118$ (Fig. 28).

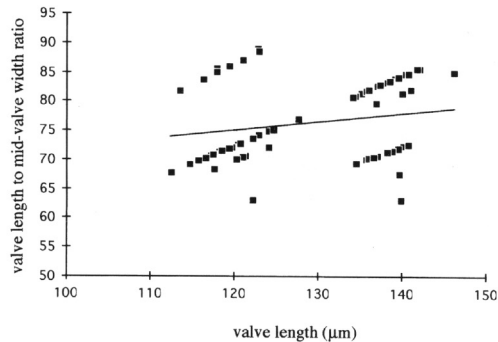
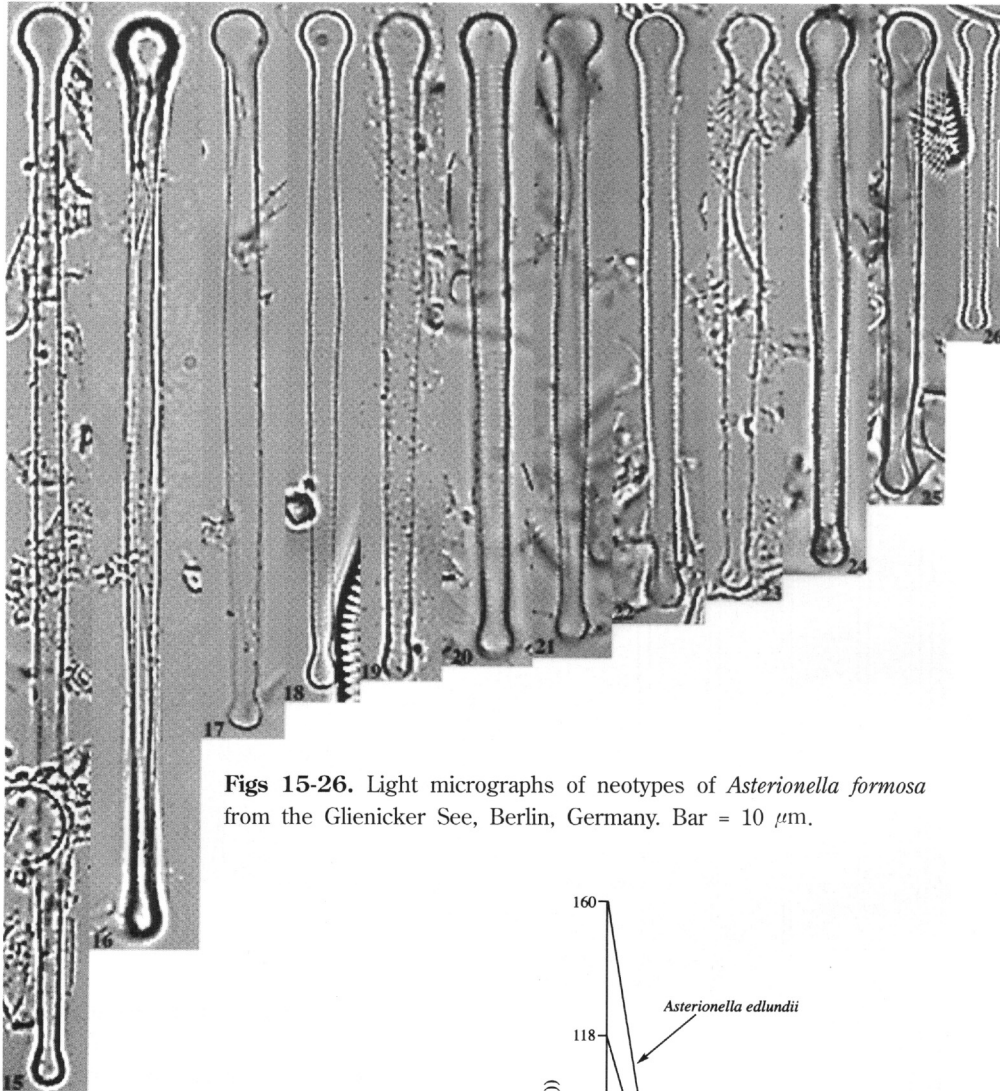


Fig. 14. Valve length versus valve length to mid-valve width ratio for *Asterionella edlundii* Stoermer & Pappas sp. nov. from Lake Hovsgol, Mongolia. Slope = 0.217.



Figs 15-26. Light micrographs of neotypes of *Asterionella formosa* from the Glienicker See, Berlin, Germany. Bar = 10 μm .

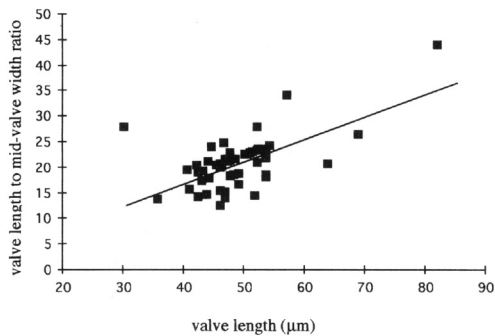


Fig. 27. Valve length versus valve length to mid-valve width ratio for neotypes of *Asterionella formosa* from the Glienicker See, Berlin, Germany. Slope = 0.41.

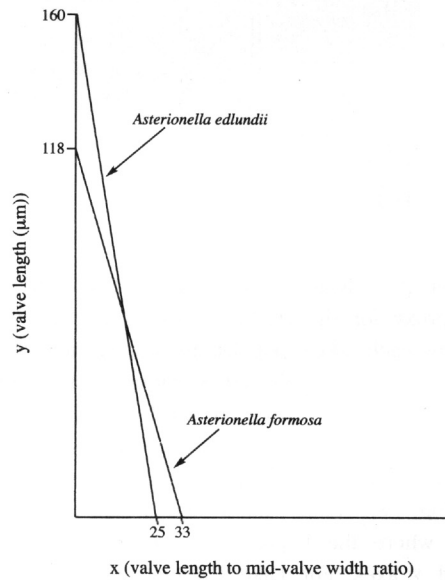


Fig. 28. Diagram used to calculate the related rate based on the change in the hypotenuse from Lake Hovsgol specimens (*A. edlundii*) to Glienicker See specimens (*A. formosa*).

We know that $\frac{dx}{dt}=8$ from the difference between the x -intercepts for each population and $\sqrt{x^2+y^2}=z=161.94$. We wanted to solve for $\frac{dy}{dt}$ by differentiating implicitly the equation for the Pythagorean Theorem with respect to t as

$$\begin{aligned}\frac{d(x^2)}{dt} + \frac{d(y^2)}{dt} &= \frac{d(z^2)}{dt} \\ 2x \frac{dx}{dt} + 2y \frac{dy}{dt} &= 0 \\ \frac{dy}{dt} &= -\frac{x}{y} \frac{dx}{dt} = -\frac{25}{160} \bullet 8 = -1.25\end{aligned}$$

Lake Hovsgol specimens would have to slow down their rate of size reduction by 1.25 in order to be identical to Glienicker See specimens. That is, for specimens from Lake Hovsgol to exhibit the same rate of size diminution as those from the Glienicker See, the related rate would have to equal zero.

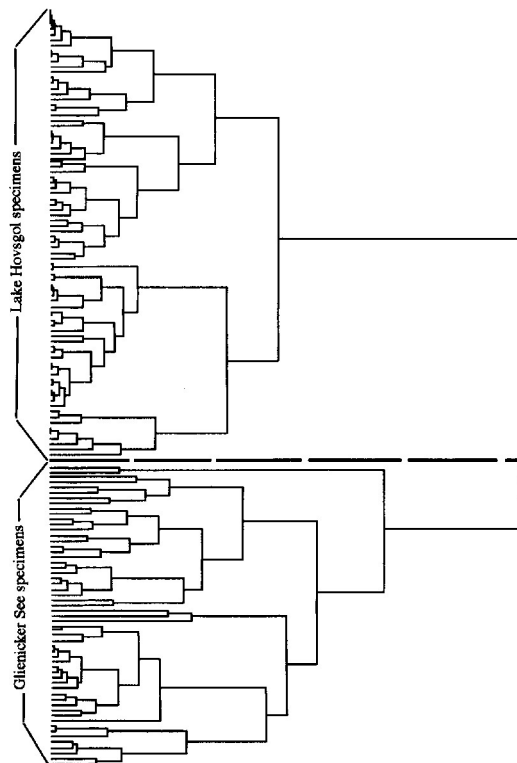


Fig. 29. Euclidean distance complete linkage cluster of all morphometric measures for all *Asterionella* specimens. The dashed line separates *A. edlundii* from Lake Hovsgol, Mongolia (top group) from the neotypes of *A. formosa* from the Glienicker See, Berlin, Germany.

Cross-validation of results was accomplished using a multivariate statistical technique. Valve length, mid-valve width, head pole width, and footpole width for all specimens was used in a cluster analysis with Euclidean distance and complete linkage methods (Johnson & Wichern 1992). Two groups were partitioned, and complete linkage clusters are depicted in the dendrogram in Fig. 29. The same result was produced using Euclidean distance metric and single linkage methods (Johnson & Wichern 1992).

Discussion

Results of our study support the conclusion that the taxon from Lake Hovsgol is distinguishable as a new species, *Asterionella edlundii* sp. nov. Morphometric and multivariate statistical analyses confirm that *A. formosa* population from the Glienicker See does not overlap with *A. edlundii* population from Lake Hovsgol in several characters. Cluster analyses cross-validated the plots of morphometric measures indicating that the two *Asterionella* populations are distinct.

From the slopes as rates of valve length with respect to mid-valve width changes and a related rate of -1.25 , we can infer that vegetative reproduction is implicitly different for each population. That is, the rate at which *A. edlundii* specimens from Lake Hovsgol change in valve length with respect to mid-valve width during vegetative reproduction is slower, 0.217 , than the rate for the neotype specimens of *A. formosa*, 0.41 . The slopes from plots of valve length versus valve length to mid-valve width ratio for each population would have to be equal in order that *A. edlundii* would be conspecific with *A. formosa*. With regard to size diminution, change in valve length to mid-valve width for *A. edlundii* specimens from Lake Hovsgol occurs more slowly than it does for *A. formosa* specimens from the Glienicker See.

Valve shape variation occurs as a result of vegetative reproduction (Geitler 1932). Shape variation within a species occurs during cell division as valve shape change is slight and gradual and convergence to a more ovoid form occurs (Mann 1994, 1999). Valve ontogeny is constrained by the internal form of the mother cell, the external form of the daughter cell, and the internal cytoskeleton in relation to the silica

deposition vesicle (Mann 1984). Valve shape is directly inherited in that the shape of the mother cell determines the shape of the daughter cell (Mann 1994).

Environmental factors can produce variation in valve shape. Cell wall flexibility (Mann 1994), growth rate and size reduction may be influenced by degree of silicification, which thereby affects valve shape (Mann 1999). Variation in silicification is related to cell size. Larger cells may be more heavily silicified than smaller ones, regardless of the silica concentration in the environment (Theriot 1987). Valve shape variation may occur by salinity affects on turgor pressure (Mann 1999). Changes in silica concentrations and availability, other nutrients, and turgor pressure may produce gradual shape changes during valve ontogeny (Mann 1994, 1999). Cell shape restoration occurs via vegetative reproduction (Mann 1994, 1999).

Size range restrictions may occur as a result of temperature (Stoermer & Ladewski 1976). Cold water forms of *Asterionella* in the northern Great Lakes tend to be longer than warm water forms from southern Lake Michigan, which tend to be shorter and exhibit a wider range of sizes (Pappas 2000). *Asterionella* growth rates during the life cycle are slow and long, perhaps on the order of years (Mann 1988). Cyclical change in frustule length can vary up to 60 μm between ecotypes (Soudek & Robinson 1983). In a recent study of *A. formosa* from the Great Lakes, the valve length was not found to exceed 100 μm (Pappas 2000), unlike *A. edlundii* specimens which are much longer. The range in valve length of *A. edlundii* specimens from 112 to 146 μm versus 30 to 82 μm for neotype specimens of *A. formosa* does not overlap.

Asterionella has been considered to be widespread in its geographic distribution (Patrick & Reimer 1966). Often, the identity of specimens from the genus is reduced to the taxon *A. formosa*, thereby confounding what may be a more limited distribution for particular taxa of the genus. Endemism is more common in diatom populations than was once recognized (Kociolek & Spaulding 2000). Diatom dispersal has not been found to occur on via eolian material or on avian vectors (Kociolek & Spaulding 2000). *Asterionella* does not survive desiccation (Jaworski &

Lund 1970) or passage through the gut of waterfowl (Atkinson 1972). Diatom endemism is especially evident in ancient lakes (Mann 1999). The neotype of *A. formosa* and *A. edlundii* from an ancient lake, Lake Hovsgol, are found in widely separated locations on different continents. The disparate geographic location of the Glienicker See from Lake Hovsgol would lend credence to the argument that *A. edlundii* cannot be conspecific with *A. formosa*.

Gene exchange is practically nonexistent in diatoms with different morphologies from geographically distant locations (Kociolek & Spaulding 2000). *Asterionella formosa* was found to exhibit different electrophoretic banding patterns between North America and European lakes. Moreover, patterns were highly divergent between Holocene lakes and the only ancient lake sampled, Lake Ohrid (Soudek & Robinson 1983). This evidence suggests that different *Asterionella* species, rather than merely *A. formosa*, exist in different lakes.

Asterionella formosa has been considered to be tolerant of a wide variety of environmental conditions, including different degrees of nutrient enrichment and temperature extremes (Stoermer & Yang 1970, Stoermer & Ladewski 1976). Neotype material of *A. formosa* was collected by H. Körner on March 26, 1966 (Körner 1970) from the Glienicker See, which is a stratified, eutrophic to hypertrophic lake. Originally, Hassall (1850a,b) named *Asterionella formosa* from specimens found in the Thames at Brentford in the drinking water of Grand Junction Company (Patrick & Reimer 1966), where nutrient enriched conditions prevailed.

For the most part, *Asterionella formosa* is considered to be an indicator of eutrophy to mesotrophy (Lowe 1974, Beaver 1981). For example, it has been found in nutrient enriched waters of southern Lake Michigan (Stoermer & Ladewski 1976) and Blelham Tarn (Lund 1962, Lund & Reynolds 1982). *Asterionella formosa* has been found in surface sediments of relatively recently eutrophied lakes, indicating that the taxon is representative of enriched conditions (Soudek & Robinson 1983). In experimental enclosures known as Lund tubes, *A. formosa* did not grow in Buttermere, a very oligotrophic lake in the English Lake District (Lund & Reynolds 1982).

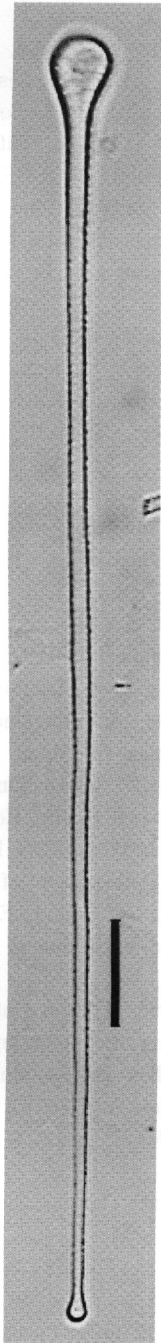


Fig. 30. Light micrograph of the holotype (CAS M234C, California Academy of Sciences) of *Asterionella edlundii* Stoermer & Pappas sp. nov. Bar = 10 μm .

Similarly, Lake Hovsgol is a pristine lake, which is further evidence that *Asterionella* in this lake is not the same as neotype *A. formosa*.

Asterionella has been recognized by researchers as a genus necessitating taxonomic inquiry for some time (e.g., Smith 1856, Lund 1962, Stoermer & Yang 1970, Körner 1970). Few morphologically informative drawings and images exist throughout the historical documentation of *Asterionella*. Hassall's (1850b) original drawings showed *A. formosa* in girdle view only (Lund 1962). Lack of images and rigorous analysis has perpetuated complacency about the status of the taxonomy of the genus. Recently, the taxonomy of the genus has been called into question as a result of sketchy historical documentation and assumptions about the genus (Pappas & Stoermer 2001a,b). Revising the genus is especially important, since *Asterionella* are used as ecological indicators of nutrient enrichment or acidic lake conditions (e.g., Stoermer & Yang 1970, Körner 1970, Soudek & Robinson 1983).

***Asterionella edlundii* Stoermer & Pappas
sp. nov. Fig. 30**

Valvae heteropolaris, apicibus capitatis, 112-146 μm longae, 1.4-2.2 μm latae in centro. Capitipolus spatulatus, 4.5-5.5 μm latae. Fundipolus vegrandis et capitatus, 1.4-1.7 μm latae. Coloniae instar stellarum. Striae 20-24 in 10 μm , parallelae. Rimoportula praesens ad capitipolum. Spinae praesens in ambitu valvae.

Valves heteropolar with capitate apices, 112-146 μm long, 1.4-2.2 μm broad at center. Head pole spatulate, 4.5-5.5 μm broad. Foot pole small, capitate, 1.4-1.7 μm broad. Stellate colonies formed. Striae 20-24 in 10 μm , parallel. Rimoportula present at head pole. Spines present around edges of valves.

Etymology: Named after Dr. M. B. Edlund who collected the material.

Type Locality: Lake Hovsgol (50° 54' 968"N, 100° 32' 112"E), Mongolia - in plankton.

Holotype: CAS M234C (California Academy of Sciences) is here designated (Fig. 30).

Isotype: M234D (the Herbarium, University of Michigan, Ann Arbor, MI); MDH M234B (the Mongolian Diatom Herbarium, Mongolia State University, Ulaanbaatar, Mongolia); MBE M234A (personal collection of M. B. Edlund, Minnesota).

Distribution: The species is known only from Lake Hovsgol, Mongolia.

This species is distinguished from *A. formosa* by the size of the frustules, the extreme unequal size and shape of the apices, and coarser striae.

Acknowledgement

We thank Dr. Regine Jahn, Botanischer Garten und Botanisches Museum Berlin-Dahlem, Germany for access to the H. Körner collection. This research was supported by National Science Foundation Grant DEB-9870218.

References

- Atkinson, K. M. 1972. Birds as transporters of algae. *British Phycological Journal* 7: 319-321.
- Beaver, J. 1981. Apparent Ecological Characteristics of Some Common Freshwater Diatoms. Plankton Taxonomy Unit, Ontario Ministry of the Environment, Rexdale, Ontario.
- Cleve-Euler, A. 1953. Die Diatomeen von Schweden und Finnland. Teil II: Araphideae, Brachyraphideae. *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 4: 1-158. figs 292-483.
- Geitler, L. 1932. Der Formwechsel der pennaten Diatomeen. *Archiv für Protistenkunde* 78: 1-226.
- Hassall, A. H. 1850a. Memoir on the organic analysis of microscopic examination of water supplied to the inhabitants of London and the suburban districts. *The Lancet* 1: 230-235.
- Hassall, A. H. 1850b. Microscopic examination of the water supplied to the inhabitants of London and the suburban districts. p. 10, pl. 2 (2), fig. 5.
- Hostetter, H. P. & Hoshaw, R. W. 1972. Asexual developmental patterns of the diatom *Stauroneis anceps* in culture. *Journal of Phycology* 8: 289-296.
- Jaworski, G. H. M. & Lund, J. W. G. 1970. Drought resistance and dispersal of *Asterionella formosa* Hass. *Nova Hedwigia* 31: 37-48.
- Johnson, R. A. & Wichern, D. W. 1992. Applied Multivariate Statistical Analysis, 3rd edition. 642 pp. Prentice Hall, Englewood Cliffs, NJ.
- Kocielek, J. P. & Spaulding, S. A. 2000. Freshwater diatom biogeography. *Nova Hedwigia* 71: 223-241.
- Körner, H. 1970. Morphologie und taxonomie der diatomeengattung *Asterionella*. *Nova Hedwigia* 20: 557-724.
- Krammer, K. & Lange-Bertalot, H. 1991. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. *In*: Ettl, H., Gerloff, J., Heynig, H. & Mollenhauer, D. (eds). Süßwasserflora von Mitteleuropa, Band 2/3. 576 pp. Gustav Fischer Verlag, Stuttgart, Jena.
- Lowe, R. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. EPA-670/4-74-005, U. S. Environmental Protection Agency, Cincinnati, Ohio.
- Lund, J. W. G. 1962. Phytoplankton from some lakes in northern Saskatchewan and from Great Slave Lake. *Canadian Journal of Botany* 40: 1499-1514.
- Lund, J. W. G. & Reynolds, C. S. 1982. The development and operation of large limnetic enclosures in Blelham Tarn, English Lake District, and their contribution to phytoplankton. *In*: Round, F. E. & Chapman, B. V. (eds), *Progress in Phycological Research* 1: 1-65. Elsevier Biomedical Press B. V., London.
- Mann, D. G. 1984. An ontogenetic approach to diatom systematics. *In*: Mann, D. G. (ed.) *Proceedings of the 7th International Diatom Symposium*. pp. 113-144. Koeltz, Koenigstein.
- Mann, D. G. 1988. Why didn't Lund see sex in *Asterionella*? A discussion of the diatom life cycle in nature. *In*: Round, F. E. (ed.) *Algae and the aquatic environment*. pp.384-412. Biopress, Bristol.
- Mann, D. G. 1994. The origins of shape and form in diatoms: the interplay between morphogenetic studies and systematics. *In*: Ingram, D. S. & Hudson, A. J. (eds) *Shape and form in plants and fungi*. pp.17-38. Academic Press, London.
- Mann, D. G. 1999. The species concept in diatoms. *Phycologia* 38: 437-495.
- Pappas, J. L. 2000. Fourier shape analysis and shape group determination by principal component analysis and fuzzy measure theory of *Asterionella* Hassall (Heterokontophyta, Bacillariophyceae) from the Great lakes. Doctoral Dissertation. 170 pp. University of Michigan, Ann Arbor.
- Pappas, J. L. & Stoermer, E. F. 2001a. *Asterionella* Hassall (Heterokontophyta, Bacillariophyceae): taxonomic history and quantitative methods as an aid to valve shape differentiation.

- Diatom 17 : 47-58.
- Pappas, J. L. & Stoermer, E. F. 2001b. Fourier shape analysis and fuzzy measure shape group differentiation of Great Lakes *Asterionella* Hassall (Heterokontophyta, Bacillariophyceae). In : Economou-Amilli, A. (ed.) Proceedings of the 16th International Diatom Symposium. pp. 485-501. Amvrosiou Press, Athens.
- Patrick, R. & Reimer, C. W. 1966. The Diatoms of the United States, Exclusive of Alaska and Hawaii, Volume 1. The Academy of Natural Sciences of Philadelphia, Monograph Number 13 : 1-688.
- Peragallo, H. & Peragallo, M. 1897-1908. Diatomées marines de France et des districts maritimes voisins. Asher and Co., Amsterdam.
- Round, F. E., Crawford, R. M. & Mann, D. G. 1990. The Diatoms : Biology and Morphology of the Genera. 747 pp. Cambridge University Press, Cambridge.
- Smith, W. 1856. A Synopsis of the British Diatomaceae, volume 2. xxxiii+89 pp. John van Voorst, London.
- Soudek, Jr., D. & Robinson, G. G. C. 1983. Electrophoretic analysis of the species and population structure of the diatom *Asterionella formosa*. Canadian Journal of Botany 61 : 418-433.
- Stoermer, E. F. 1996. A simple, but useful, application of image analysis. Journal of Paleolimnology 15 : 111-113.
- Stoermer, E. F. & Yang, J. J. 1970. Distribution and relative abundance of dominant plankton diatoms in Lake Michigan. Great Lakes Research Division Publication No.16. pp.1-64. University of Michigan, Ann Arbor.
- Stoermer, E. F. & Ladewski, T. B. 1976. Apparent optimal temperature for the occurrence of some common phytoplankton species in southern Lake Michigan. Great Lakes Research Division Publication No. 18. pp.1-49. University of Michigan, Ann Arbor.
- Theriot, E. 1987. Principal component analysis and taxonomic interpretation of environmentally related variation in silicification in *Stephanodiscus* (Bacillariophyceae). British Phycological Journal 22 : 359-373.
- Theriot, E. 1992. Clusters, species concepts, and morphological evolution of diatoms. Systematic Biology 41 : 141-157.
- Theriot, E. & Stoermer, E. F. 1984. Principal component analysis of *Stephanodiscus* : observations on two new species from the *Stephanodiscus niagarae* complex. Bacillaria 7 : 37-58.
- Thomas, G. B. 1979. Calculus and Analytic Geometry, Alternate Edition. 1034 pp. Addison-Wesley, Reading, Massachusetts.
- Van Heurck, H. 1880-1885. Synopsis des Diatomées de Belgique, Texte et Atlas. 235 pp., 135 plates. Anvers.
- Van Heurck, H. 1896. A treatise on the Diatomaceae. xxxv+558 pp. W, Wesley and Son, London.

Janice L. Pappas : Museum of Zoology, University of Michigan, 1109 Geddes Ave., Ann Arbor, MI 48109-1079, USA

Eugene F. Stoermer : School of Natural Resources, 430 East University, University of Michigan, Ann Arbor, MI 48109-1115, USA