

## A NEW FRESHWATER *GYROSIGMA* (BACILLARIOPHYCEAE) SPECIES FROM HAWAII\*

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**Abstract.** We describe here a new freshwater species of *Gyrosigma* from Kauai, Hawaii. The new species is angular, with straight and parallel sides and apices bent in opposite directions, 32–46  $\mu\text{m}$  long and 5.5–7.0  $\mu\text{m}$  wide. *Gyrosigma krammeri* sp. nov. possesses prominent depressions on either side of the external central area. Frustules are isomorphic with regard to the deflection of the external proximal raphe ends, and otherwise possess the diagnostic features of the genus *Gyrosigma*. Taxa with similar morphology include an undescribed specimen from South America as well as *G. moresbyana* Reichardt from Papua New Guinea. The freshwater diatom flora of Hawaii appears to contain many undescribed taxa.

**Key words:** biogeography, diatoms, freshwater, *Gyrosigma*, Hawaii, taxonomy, ultrastructure

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### INTRODUCTION

The freshwater diatom flora of Hawaii is not well documented. Hustedt (1942) described several species in his classic paper on freshwater diatoms from several Pacific islands. More recently, floras published by Rushforth and his associates (Fungladda *et al.* 1983; Rushforth *et al.* 1984; McMillan & Rushforth 1985) recorded species that would be considered cosmopolitan. Reichardt (2005) described a new *Gomphonema* Ehrenberg from Hawaii, Massey (1978) a new *Stauroneis* species, and Main (2003) a new genus *Diprora* and several new species from unique habitats. Sherwood (2004) summarized the literature up to 2003. Most recently, Lowe *et al.* (2009) and Lowe and Sherwood (in press) described new species of *Achnanthes* and *Cosmioneis* from wetwall habitats on Oahu and Maui, respectively.

The diatom genus *Gyrosigma* Hassall has recently received significant attention (e.g., Stidolph 1988, 1992, 1993, 1994; Sterrenburg 1990, 1992, 1993; Reid & Williams 2003; Reid 2004). Though

these authors have not always seen eye-to-eye in their interpretation of features and taxa, they have enlightened us as to the variability and ultrastructure of classic and new species of the genus. None of these authors treated many freshwater species from the tropics.

In this paper we formally describe *Gyrosigma krammeri* Kociolek, Graeff & Lowe, sp. nov. as a species new to science from freshwater environments in Hawaii, and detail its valve ultrastructure. We discuss the systematic position of this species and its possible implications for our understanding of the origin of the Hawaiian freshwater diatom flora.

### MATERIALS AND METHODS

Material was collected from Lanai Stream, on the property of the McBryde Garden at the National Tropical Botanical Garden, South shore of Kauai, Hawaii, 29 July 2009 (21°53'8.67"N, 159°29'33.04"W).

Samples were cleaned by boiling in nitric acid. Cleaned valves were mounted on slides with Naphrax. Light microscope observations were made with an Olympus Bx-51 with the use of 63 $\times$  (NA 1.43) and 100 $\times$

\* Dedicated to Dr. Kurt Krammer on the occasion of his 85<sup>th</sup> birthday

(NA 1.40) objectives, and digital images were taken with an Olympus DP-71 digital camera. A JEOL JSM 6480 LV was used for scanning electron microscopy. Cleaned material was air-dried on glass coverslips attached to aluminum stubs. Stubs were coated with gold-palladium with a Cressington sputter coater operated at 8 Pa and 30 mA, providing *ca* 10 nm of coating.

The relative abundance of *G. krammeri* was determined by three random 100 valve counts from slides of the material and averaging the three counts.

## RESULTS

### *Gyrosigma krammeri* Kociolek, Graeff & Lowe, *sp. nov.* Figs 1–15

*Valvae angulator, lateribus parallelis rectis, angulator extremis a se adverso flexiss apicibus rotundatis. Longitudo 32–46 μm. Latitudo 5.5–7.0 μm. Area axialis angusta unornata ad apicem, faciens aream centram irregularem ad anguste ellipsoideam. Raphe marginata in uno latere costa longitudinali. Area centralis depressibus 1–2 circularibus ut plerumque autem non semper relative amplis. Rami raphis s-formi. Extrema proximalia externi raphis deeflecta opposita uno cetera. Extrema distalia externi raphis deflecta opposita congruentia extrema proximalia. Transapicales striae radiatae ad centro, parallelae fere longitudinem valvis, convergentae ad apicibus, 30–32/10 μm, longitudinaliter striae 40–42/10 μm. Frustulae isomorphicae.*

TYPE: HAWAII, Kauai, Lanai Stream at McBryde Campus, National Tropical Botanical Garden. 29 July 2009, *leg. J. P. Kociolek & C. L. Graeff* [HOLOTYPE (Fig. 4): Accession Number 744386, Herbarium of the Bishop Museum of Natural History (BISH), Honolulu; ISOTYPES: Accession #627381; slide #223003, Diatom Collection, California Academy of Sciences, (CAS), San Francisco].

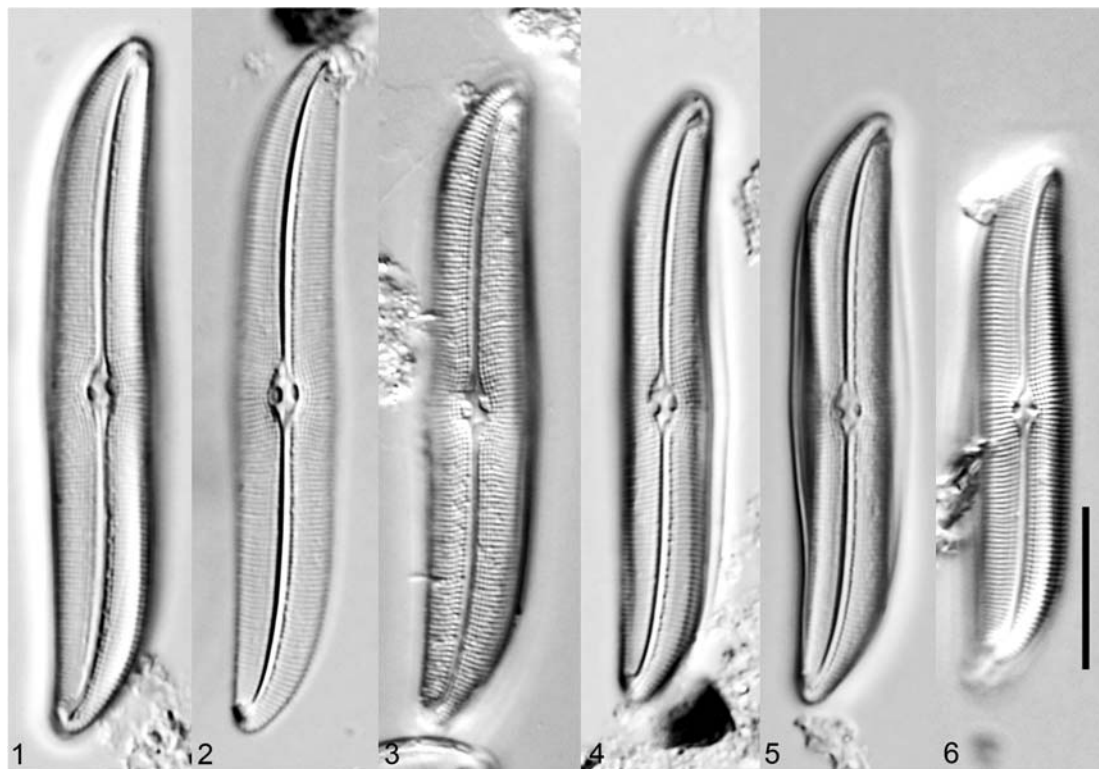
ETYMOLOGY: Named in honor of Kurt Krammer, for his many and varied contributions to diatom research, and on the occasion of his 85<sup>th</sup> birthday.

Valves angular, with parallel, straight sides, distal ends bent in opposite directions, and apices rounded. Length 32–46 μm. Breadth 5.5–7.0 μm. Axial area narrow, unornamented at the apices and forming an irregular to narrowly ellipsoidal central area. Raphe bordered on one side by a longitu-

dinal rib. Central area bears two circular depressed structures that are commonly but not always relatively large. Each branch of the raphe is S-shaped, with the external proximal ends deflected opposite one another. External distal raphe end deflected opposite its corresponding proximal end. Striae radiate about the center, parallel along most of the length of the valve, to converge at the ends. Transapical striae 30–32/10 μm; lengthwise striae 40–42/10 μm. Frustules isomorphic (having the same orientation of the raphe from one valve to the other (Sterrenburg 1993).

In SEM the valve exterior has two prominent depressions in the ovoid to elliptical central area (Figs 7–10). Central area bears proximal raphe ends deflected in opposite directions from one another (Figs 8–10). The raphe transitions from a simple slit to becoming lateral, and the axial area widens towards the central area and the apices (Figs 8–11). At the distal ends the raphe ends are deflected opposite one another, and opposite the corresponding proximal end (Fig. 11). The axial area is bordered on one side by a row of slit-like areolae that is more distant from the other striae (Figs 9–11). The two central round to ovoid openings may have a common chamber. Striae are composed of slit-like areolae externally, round to oval internally. Striae are radiate and curved around the center. Striae distant from the center become curved towards the center, then bend towards the apex (Figs 9–11). External distal ends deflected onto the valve mantle. A triangular unornamented area at the apex is bordered by striae, the raphe end and a row of slits on the mantle (Fig. 11). These have been termed ‘apical pores’ by Sterrenburg (1991).

Internally the elevated axial area is bordered by longitudinally oriented ribs, more prominent on the primary side of the axial area than on the secondary side (Fig. 12). The ribs do not extend all the way to the helictoglossae (Figs 12 & 13). The central nodule is ellipsoidal and contains the dilated proximal ends (Figs 14 & 15). The central nodule is bordered by arched thickenings, variously termed ‘central bars’ (e.g., Schrader 1973; Sterrenburg 1991; Reid 2002; Reid & Williams 2003) or ‘crescentic thickenings’ (Stidolph 1993)



**Figs 1–6.** *Gyrosigma krammeri* Kociolek, Graeff & Lowe, *sp. nov.* Valve views showing size range; all LM. Scale bar = 10  $\mu$ m. Figure 1 is of the holotype.

and ‘apical costae’ (Stidolph 1988), which are continuous with the longitudinal ribs (Figs 12, 14 & 15). The raphe terminates distally into helicoglossae (Fig. 13). Internal openings of the areolae appear rectangular (e.g., Fig. 14).

#### DISCUSSION

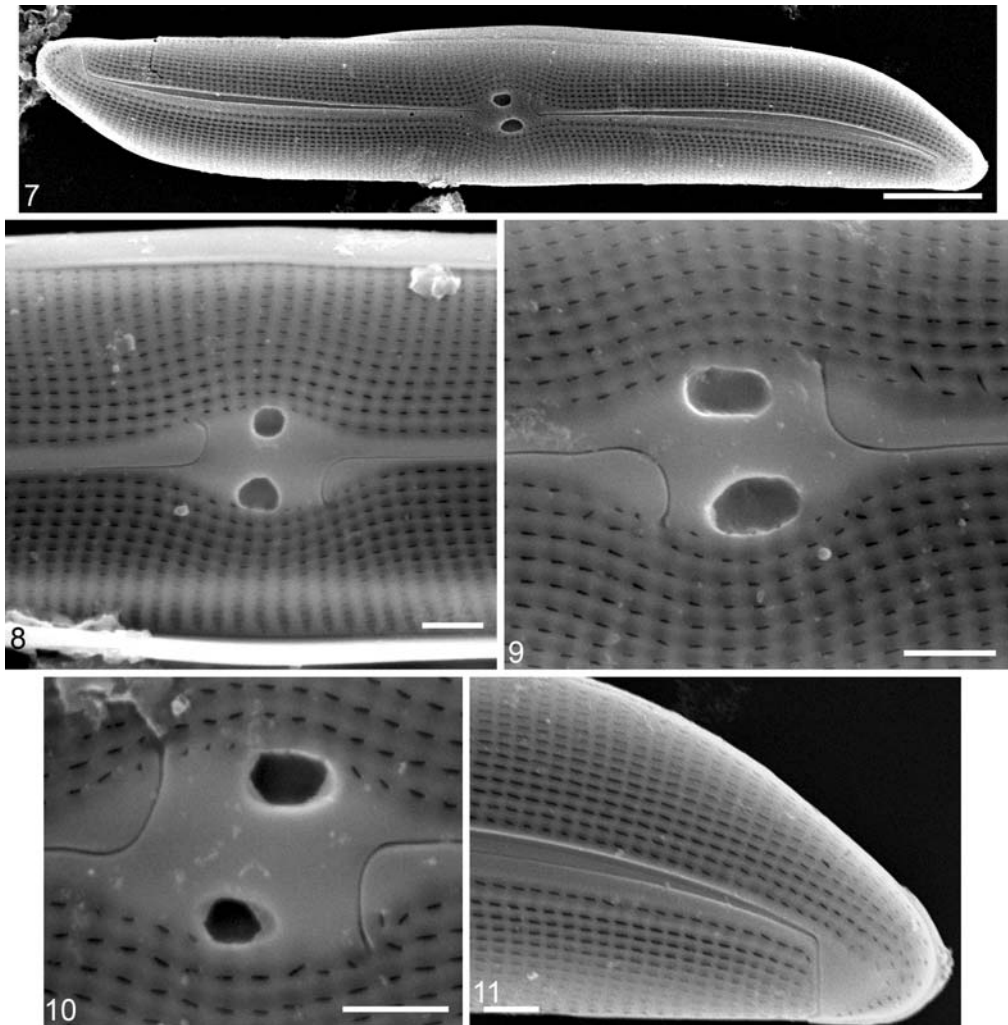
A review of the classical monographs by Peragallo (1891), treatments of specific taxa by Reid and Williams (2003) and Stidolph (1988, 1992, 1993) and Sterrenburg (1994, 1995, 2001), freshwater floras by Krammer and Lange-Bertalot (1986) and Patrick and Reimer (1966), and previous floristic work on Hawaii (Fungladda *et al.* 1983) failed to identify a species to which we could assign this taxon. Thus, we continue to add to the knowledge of the freshwater diatom flora of Hawaii. This *Gyrosigma* species occurred with 26% relative abundance of the diatom flora in the sample in which

it was found. While recent papers have begun to demonstrate the unique nature of the Hawaiian flora, a significant amount of research is yet needed to document even the relatively common members of the freshwater diatom flora of Hawaii.

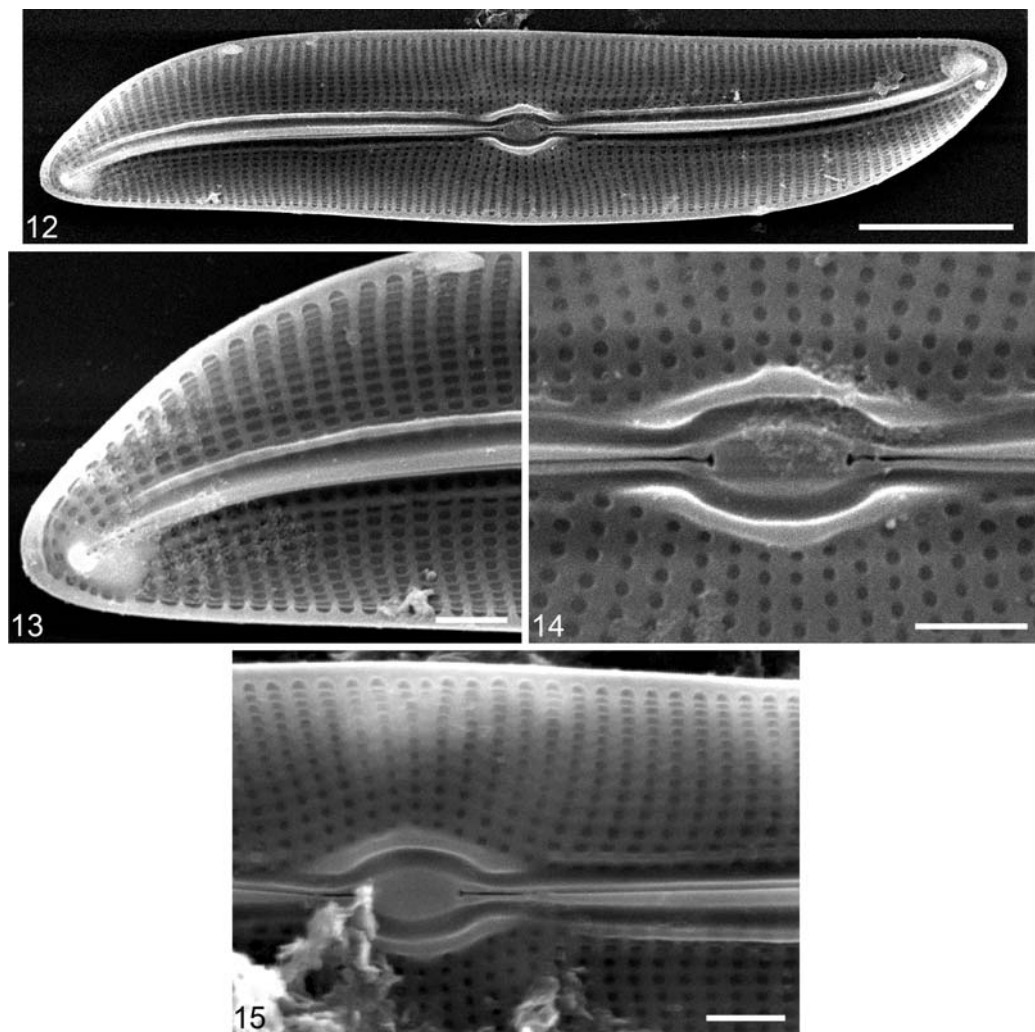
Our observations on this *Gyrosigma* from Hawaii suggest that while it has many similarities with other members of the genus, it also has some unique features. With other members of the Pleurosigmatataceae Mereschkowsky, *G. krammeri* has valves that are linear and parallel-sided, a sigmoid raphe system, and triangular hyaline areas at the apices of the valve externally (Sterrenburg 1991; Stidolph 1988; Reid 2002; Reid & Williams 2003). The presence of thickened ‘central bars’ around the central area internally, and external proximal raphe ends that are deflected in opposite directions, are features also shared across members of the genera *Gyrosigma*, *Pleurosigma* W. Smith and *Toxonidea* Donkin.

The external proximal raphe ends of *G. krammeri* are variable. Sterrenburg (1993) described two types of external proximal raphe ends in *Gyrosigma*; ‘crooks’ where the curvature of the raphe is smooth and round, and ‘hooks’ where the raphe is angular and bent to a nearly 90 degree angle (Sterrenburg 1993, Fig. 3a, b). ‘Hooks’ are reported by Sterrenburg (1993) to occur in isomorphic species only, as in *G. krammeri* (an isomorphic taxon), and our observations confirm this relationship.

The presence of large depressions or openings to a single depression is illustrated in ‘*Gyrosigma* spec. cf. *scalproides* (Rabenhorst) Cleve’ (Metzeltin & Lange-Bertalot 1998, Pl. 128, figs 3 and 4) from South America, and ‘*Gyrosigma* (?nov.) spec.’ from Ecuador (Rumrich *et al.* 2000, Pl. 108, fig. 5). Our specimens also appear to have a thickened elongated rib running from the central bar on the primary side nearly to the helictoglossa. Also present is a rib that is significantly less thickened



**Figs 7–11.** *Gyrosigma krammeri* Kociolek, Graeff & Lowe, *sp. nov.* External valve views. 7 – Entire valve showing shape of valve, sigmoid raphe and central area with two depressions. Scale bar = 5  $\mu\text{m}$ . 8–10 – Elliptical central area with two depressions and proximal raphe ends which are both ‘hooks’. Scale bars = 1  $\mu\text{m}$ . 11 – Valve terminus showing deflected distal raphe end, triangular hyaline area of the axial area and areolae at the very apex of the valve. All SEM. Scale bar = 1  $\mu\text{m}$ .



**Figs 12–15.** *Gyrosigma krammeri* Kociolek, Graeff & Lowe, *sp. nov.* Internal valve views. 12 – Entire valve view showing elevated axial area bordered by a more distinct (top) and less distinct (bottom) rib. Scale bar = 5  $\mu$ m. 13 – Terminus of the valve showing helictoglossa and elevated axial area bordered by a rib. Scale bar = 1  $\mu$ m. 14 & 15 – Central area of the valve, with central area a slightly elevated disc bearing the dilated proximal raphe ends. The central nodule is bordered on both sides by central bars which are connected to the axial ribs. All SEM. Scale bars = 1  $\mu$ m.

but evident on the secondary side of the axial area and extending from the central bar, nearly reaching the helictoglossae, similarly to the thickened rib on the opposite side of the axial area. These longitudinal ribs resemble the situation in members of the Amphipleuraceae Grunow, where thickened ribs on both sides of the axial area may extend uninterruptedly from one helictoglossa to the other (Round *et al.* 1990). In some species

currently referred to *Frustulia* the ribs may be entire, shortened, or even absent (unpublished observations).

Another species resembling *G. krammeri* is *G. moresbyana* Reichardt (Reichardt 1988), a rare freshwater species described from Papua New Guinea. Like *G. krammeri*, *G. moresbyana* is more angular and has nearly parallel sides instead of being more smoothly sigmoid, has triangular,

unornamented areas at the apices, and appears to have rounded structures in the central area. Unfortunately, Reichardt (1988) did not publish electron micrographs when presenting his new species. The nature of the rounded structures in the central area has not been detailed, but they appear to be restricted to the corners of the central area. The New Guinea species is much larger than *G. krammeri* (81–114 µm long and 10.5–11.9 µm wide, versus length 32–46 µm, breadth 5.5–7.0 µm for *G. krammeri*). *Gyrosigma moresbyana* also has slightly more coarse transverse (27–28/10 µm) and longitudinal striae (35 in 10 µm) than those present in *G. krammeri* (30–32/10 µm transverse striae; 40–42/10 µm longitudinal striae.). The two appear to be distinctly different species. Further research is needed to determine the structure of the central area of *G. moresbyana*, and whether it might be closely related to *G. krammeri*.

There are several possible connections between *G. krammeri* and other taxa. A South America/Hawaii connection is suggested between *G. krammeri* and ‘*Gyrosigma* (?nov.) spec.’, though such a relationship is not common amongst the biota of Hawaii, as most species on the islands have their off-island sister taxa occurring in Asia, South Pacific or North America. But for freshwater diatoms this link has been noted before, particularly for *Frustulia neomundana* Rumrich & Lange-Bertalot in Rumrich *et al.* (2000). It will be interesting to see whether a connection between phylogenetic relationships and biogeographic distributions relating Hawaii and South America will be demonstrated in other groups of freshwater diatoms. On the other hand, the possible similarity between Pacific Island and Hawaiian taxa, reflected in unconfirmed similarities between *G. krammeri* and *G. moresbyana*, might point to other relationships. We look forward to examining further the relationships and biogeographic implications of other members of the freshwater Hawaiian diatom flora.

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