Revista de Biología Marina y Oceanografía
Vol. 51, Nº1: 197-201, abril 2016
DOI 10.4067/S0718-19572016000100021

RESEARCH NOTE

Proliferation of *Falcula hyalina* and *Cylindrotheca closterium* (Bacillariophyceae) on copepods in Bahía de La Paz, Gulf of California, Mexico

Proliferación de *Falcula hyalina* y *Cylindrotheca closterium* (Bacillariophyceae) sobre copépodos en Bahía de La Paz, Golfo de California, México

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Abstract.- A proliferation of the epizoic diatoms *Falcula hyalina* and *Cylindrotheca closterium* occurred, respectively, on the exoskeleton of marine copepods *Acartia tonsa* and *Paracalanus* sp. Samples were collected in February and in October 2013 in Bahía de La Paz. Both represent the first proliferations of this epizoic microalgae reported in the Gulf of California. Seawater temperature was 19°C in February and 28°C in October. A short morphological description, cell measurements and distribution of both species are provided.

Key words: Epizoic diatoms, *Cylindrotheca closterium*, *Falcula hyalina*, Bloom, Bahía de La Paz, Gulf of California

INTRODUCTION

Marine zooplankton is often a common host for a variety of parasitic and epizoic animals and plants (Russell & Norris 1971). The exoskeleton of copepods constitutes a convenient habitat for a variety of epibiontic bacteria, microalgae, and protozoans (Carman & Dobbs 1997, Walkusz & Rolbiecki 2007). A variety of pennate diatoms are associated with planktonic copepods as epibionts (Hiromi *et al*. 1985, Gárate-Lizárraga & Muñetón-Gómez 2009, Fernandes & Calixto-Feres 2012). Although infestation of diatoms on the external surface of marine copepods is known since the 19th century, little attention has been paid to this phenomenon (Hiromi *et al*. 1985). Authors have mentioned that the main epizoic diatoms on copepods were *Pseudohimantidium pacificum* Hustedt & Krasske in Krasske, 1941, *Falcula hyalina* Takano, 1983, *Protoraphis atlantica* R.A. Gibson, 1978, *Sceptronema orientale* Takano, 1983, and *Licmophora unidenticulata* Takano, 1983 (Gibson 1978, Takano 1983, González & Vergara 1984, Hiromi *et al*. 1985, Fernandes & Calixto-Feres 2012). There is little information concerning the associations of diatoms on marine crustacean in coastal waters of Mexico. Gárate-Lizárraga & Muñetón-Gómez (2009) reported the presence of *P. pacificum* and *Licmophora* sp. on marine copepods in Bahía de La Paz. Symbioses among diatoms, dinoflagellates, and cyanobacteria have been reported in this bay (Gárate-Lizárraga & Muñetón-Gómez 2009, Gárate-Lizárraga 2013, Gárate-Lizárraga *et al.* 2014). This is the first report of proliferation of two epizoic diatoms species, *Falcula hyalina* and *Cylindrotheca closterium* Ehrenberg, 1841 on the surface of copepods from Bahía de La Paz.

MATERIALS AND METHODS

As part of a continuing microalgae monitoring program, phytoplankton samples were collected at 2 sampling stations in Bahía de La Paz (Fig. 1; Station 1, 24°8240.363N, 110°20240.293W and Station 2, 24°10236.473N, 110°21231.623W). Surface water and net phytoplankton (20 µm mesh) samples were collected at Station 1 on 16 October 2013 and at Station 2 on 12 February 2013. Phytoplankton samples were fixed with acidified Lugol's solution and later preserved in 4% formalin solution. Identification and cell counts of diatoms in water samples were made in 5 ml settling chambers under an inverted Carl Zeiss phase-contrast microscope (Utermöhl 1958). Sea surface temperature was measured with a bucket thermometer. Copepods were identified to the genus or species level using the taxonomic keys by Palomares *et al*. (1998). A digital Konus® camera (8.1 MP) was used to record images.

RESULTS AND DISCUSSION

In net phytoplankton samples collected on 12 February 2013, 2 specimens of *Acartia tonsa* Dana, 1849 were infested by the diatom *Falcula hyalina*. In samples collected on 25 October 2013, one specimen of *Paracalanus* sp. was fully infested by the diatom *Cylindrotheca closterium*. Seawater temperature was 19°C in February and 28°C in October.

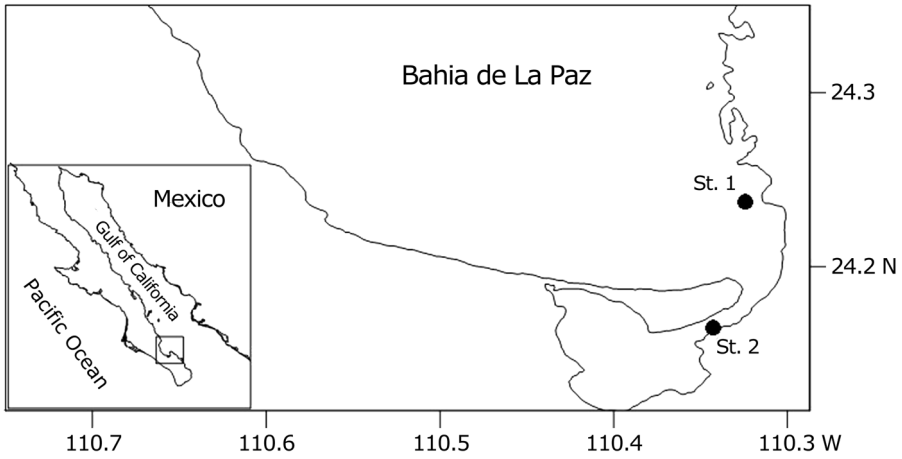

Figure 1. Location of two sampling stations in Bahía de La Paz, Gulf of California / Localización de dos estaciones de muestreo en la Bahía de La Paz

Falcula hyalina Takano, 1983 (Figs. 2A-E)

References: Takano 1983, p. 32, figs. 4-14; Prasad *et al*. 1989, p. 121, figs. 2-10; Fernandes & Calixto-Feres 2012, p. 840, figs. 18-27; Donadel & Carvalho-Torgan 2016, p. 186-187, figs. 5-22.

Dimensions: Cells are 22-36 µm long and 3-5 µm wide (n= 30).

Clusters of the diatom *F. hyalina* were observed on carapace of specimens of *A. tonsa* (Figs. 2A-D). Clusters of *F. hyalina* were denser on the prosome of the copepods (Figs. 2B-C). Small clusters of 5-7 cells of *Falcula hyalina* were observed on setae of the furca of *Acartia tonsa* (Fig. 2D). The frustules of *F. hyalina* are linear and lunate, slightly arcuate in valve view (Fig. 2E), with 2 plate-like chromatophores in the middle of the cell. Live cells are bright green in color (Figs. 2A-E). The poles of cells are rounded (Fig. 2E). According to Hiromi *et al*. (1985), *F. hyalina* shows noticeable preference for the genus *Acartia* as host. Fernandes & Calixto-Feres (2012) found that host copepods of *F. hyalina* in Baía de Paranaguá in Paraná, Brazil were *Acartia lilljeborgii* Giesbrecht, 1889, *Acartia tonsa*, *Oithona oswaldocruzii* Oliveira, 1945, and *Pseudodiaptomus richardi* Dahl F., 1894.

Regional distribution and remarks

Reported once in the Gulf of California (Meave del Castillo *et al*. 2003). Although *Acartia tonsa* specimens were fully infested, only 2000 cells L^{-1} were counted in a quantitative phytoplankton sample. This diatom can reach concentrations of several hundred cells on one animal (Hargraves & Hanisak 2011, this study). This is the first bloom of *F. hyalina* ever reported in the Gulf of California.

General distribution

Falcula hyalina has been reported off Japan, China, and Western Australia, and in Florida and the Gulf of Mexico (Takano 1983, Hiromi *et al*. 1985, Prasad *et al*. 1989, Hargraves & Hanisak 2011, Li *et al*. 2014). Recent records show presence in Brazil (Souza-Mosimann *et al*. 1989, Fernandes & Calixto-Feres 2012, Donadel & Carvalho-Torgan 2016).

Cylindrotheca closterium (Ehrenberg) Reimann & J.C.Lewin, 1964 (Figs. 3A-E)

Basionym: *Ceratoneis closterium* Ehrenberg

Synonyms: *Nitzschia closterium* (Ehrenberg) W. Smith, *Nitzschiella closterium* (Ehrenberg) Rabenhorst

References: Reimann & Lewin 1964, p. 289, pl. 124, figs. 1-4; Cupp 1943, p. 200, figs. 153a-c; Moreno *et al*. (1996), p. 61, pl. 18, figs. 13; Sunesen & Sar 2007, p. 501, figs. 4H-J.; Hoppenrath *et al*. (2009), p. 109, figs. 46 p-q.

Dimensions: Straight cells are 65-96 µm long and 1.5-4.0 µm wide (n= 30).

Regional distribution and remarks

Common in neritic plankton in the Gulf of California (Cupp 1943, Moreno *et al*. 1996). *C. closterium* was found on one fully infested specimen of *Paracalanus* sp. during October 2013 (Fig. 3A). *C. closterium* specimens were solitary cells; however, some two-celled chains were observed. Occasionally, they were also found embedded in dense mucilage aggregates. Valves were weakly silicified, usually straight, and often curved (Figs. 3D-E). Two bright brown chloroplasts are present in the

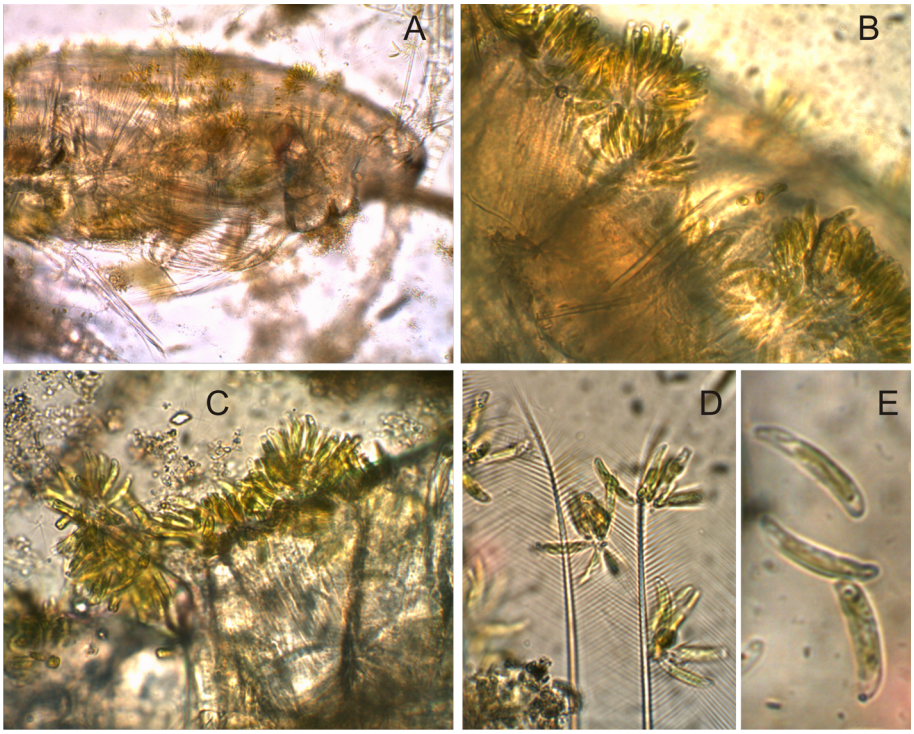

Figure 2. Different aspects of infestation of *Falcula hyalina* cells on a specimen of *Acartia tonsa*. (A) Specimen of *Acartia tonsa* with clusters of *Falcula hyalina* on their caparace. (B and C) Clusters of *Falcula hyalina*. (D) Small clusters of 5-7 cells of *Falcula hyalina* on the setae of furca of *Acartia tonsa*. (E) Free cells of *Falcula hyalina* / Diferentes aspectos de la infestación de las células de *Falcula hyalina* sobre un espécimen de *Acartia tonsa*. (A) Espécimen de *Acartia tonsa* con racimos de *Falcula hyalina* sobre su caparazón. (B y C) Racimos de *Falcula hyalina*. (D) Racimos pequeños de 5-7 células de *Falcula hyalina* sobre las setas de la furca de *Acartia tonsa*. (E) Células libres de *Falcula hyalina*

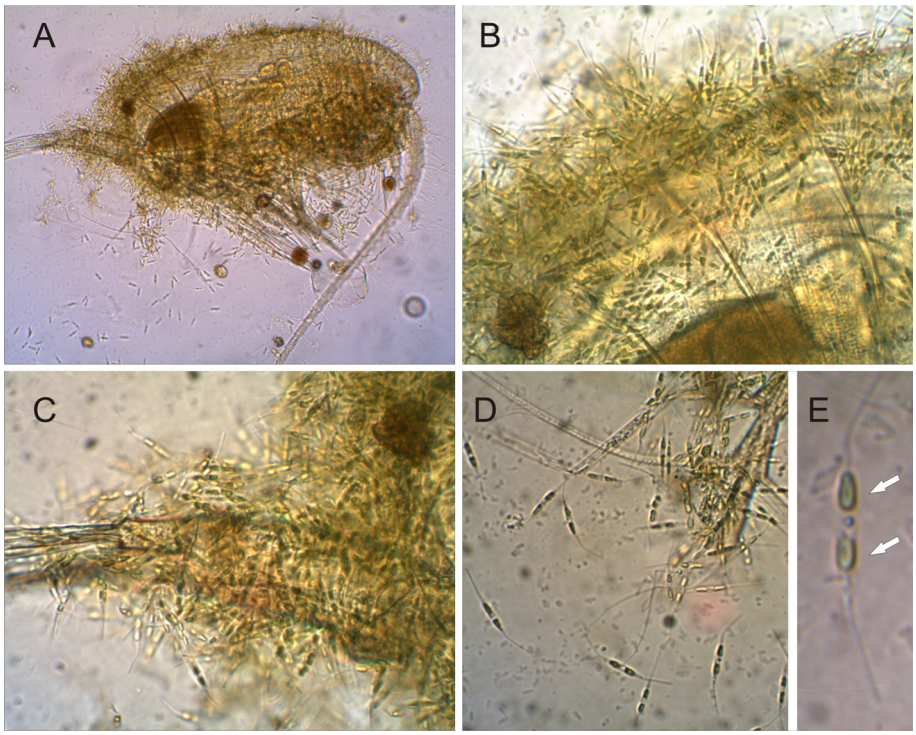

Figure 3. Different aspects of the infestation of *Cylindrotheca closterium* on a specimen of *Paracalanus*. (A) Complete specimen of *Paracalanus* fully infested by *Cylindrotheca closterium*. (B) Metasome, (C) urosome and (D) furca of *Paracalanus* showing hundreds of cells of *Cylindrotheca closterium*. (E) Single specimen of *Cylindrotheca closterium*; white arrows indicate 2 chloroplasts / Diferentes aspectos de la infestación de *Cylindrotheca closterium* sobre un espécimen de *Paracalanus*. (A) Espécimen completo de *Paracalanus* totalmente infestado por *Cylindrotheca closterium*. (B) Metasoma (C) urosoma y furca (D) de *Paracalanus* mostrando cientos de células de *Cylindrotheca closterium*. (E) Espécimen único de *Cylindrotheca closterium*; las flechas blancas muestran los 2 cloroplastos

middle of the cells (Figs. 3A-E). Moderate concentrations (150 $\times 10^{-3}$ cells L^{-1}) of *C. closterium* were counted. *C. closterium* is a common species in phytoplankton samples from Bahía de La Paz (Gárate-Lizárraga 2012, 2013; Gárate-Lizárraga *et al*. 2014). Blooms of *C. closterium* have been reported along the west coast of Southern Baja California (Licea *et al*. 1999, Gárate-Lizárraga *et al*. 2001), as well as in several lagoons in the Gulf of California (Ayala-Rodríguez 2008, Gárate-Lizárraga *et al*. 2009) and the Yucatán peninsula, Gulf of Mexico (Merino-Virgilio *et al*. 2014). This is the first report of a bloom of *C. closterium* infesting carapaces of copepods.

General distribution

According to Hasle & Syvertsen (1997), this diatom is a cosmopolitan species in temperate and tropical waters.

Epizoic diatoms are distributed widely in both marine and freshwater environments, and some occur on substrata, including live hosts, plants and animals (Totti *et al*. 2011). There are many benefits for microalgae that usually are related to the epizoic *modus vivendi* (Round 1981), such as protection against grazing, which is hardly to be made on live animals, and a nutritional advantage, as the epibiontic microalgae can exploit the host catabolites and CO_2 supply for their growth (Totti *et al*. 2011). The proliferation of epizoic diatoms on copepods carapaces could help the diatoms to have a wider distribution range due to the swimming ability and migration of copepods. However, proliferations of diatoms on copepods could be also injurious to the host, by reducing the ability to obtain food, and reproduction (Hiromi *et al*. 1985). Proliferation of epizoic diatoms has been related to juvenile lobster mortality (Hargraves & Maranda 2002). On the other hand, copepods molt as soon as they reach the end of the stage duration time (Carlotti & Nival 1992). The molts of the copepods fully infested by diatoms could reach the sea floor where diatoms can also develop. This may be the case of *Cylindrotheca closterium*, which has been considered both a planktonic and benthic species (tycoplanktonic). Future research could include quantitative studies on the importance of attached diatoms to primary productivity in various habitats (Tiffany 2011). Epizoic diatoms play an important role for invertebrate grazers and thus the entire ecosystem.

Acknowledgments

The projects were funded by Instituto Politécnico Nacional (SIP-20130549, SIP-20130752, and SIP 20150500). We thank two anonymous reviewers for their constructive comments, which helped us to improve the manuscript.

Literature cited

Ayala-Rodríguez AG. 2008. Grupos funcionales del fitoplancton y estado trófico del Sistema Lagunar Topoloampo-Ohuira-Santa María. Tesis de Maestría, CICIMAR-IPN, La Paz, 149 pp.

Carlotti F & P Nival. 1992. Model of growth and development of copepod: Study of molting and mortality related to physiological processes during the course of individual molt cycle. Marine Ecology Progress Series 84: 219-233.

Carman KR & FC Dobbs. 1997. Epibiotic microorganisms on copepods and other marine crustaceans. Microscopy Research and Technique 37: 116-135.

Cupp EE. 1943. Marine plankton diatoms of the west Coast of North America. Bulletin, Scripps Institution of Oceanography 5(1): 1-238.

Donadel L & L Carvalho-Torgan. 2016. *Falcula hyalina* (Fragilariaceae, Bacillariophyta) from a coastal lagoon, Southern Brazil: an additional approach on its morphology. Phytotaxa 243 (2): 185-189.

Fernandes LF & M Calixto-Feres. 2012. Morphology and distribution of two epizoic diatoms (Bacillariophyta) in Brazil. Acta Botanica Brasilica 26: 866-841.

Gárate-Lizárraga I. 2012. Proliferation of *Amphidinium carterae* (Gymnodiniales: Gymnodiniaceae) in Bahía de La Paz, Gulf of California. CICIMAR Oceánides 27: 1-13.

Gárate-Lizárraga I. 2013. Bloom of *Cochlodinium polykrikoides* (Dinophyceae: Gymnodiniales) in Bahía de La Paz, Gulf of California. Marine Pollution Bulletin 67: 217-222.

Gárate-Lizárraga I & MS Muñetón-Gómez. 2009. Primer registro de la diatomea epibionte *Pseudohimantidium pacificum* y de otras asociaciones simbióticas en el Golfo de California. Acta Botanica Mexicana 88: 33-47.

Gárate-Lizárraga I, ML Hernández-Orozco, CJ Band-Schmidt & G Serrano-Casillas. 2001. Red tides along the coasts of Baja California Sur, Mexico (1984-2001). Oceánides 16: 127-134.

Gárate-Lizárraga I, CJ Band-Schmidt, DJ López-Cortés & JJ Bustillos-Guzmán. 2009. Raphidophytes in Bahía de La Paz, Gulf of California. Harmful Algae News 40: 1-4.

Gárate-Lizárraga I, MS Muñetón-Gómez, B Pérez-Cruz & JA Díaz-Ortíz. 2014. Bloom of *Gonyaulax spinifera* (Dinophyceae: Gonyaulacales) in Ensenada de La Paz lagoon, Gulf of California. CICIMAR, Oceánides 29(1): 11-18.

Gibson RA. 1978. *Pseudohimantidium pacificum*, an epizoic diatom new to Florida Current (Western North Atlantic Ocean). Journal of Phycology 14: 371-373.

González H & L Vergara. 1984. Interacción ecológica entre la diatomea epizoica *Pseudohimantidium pacificum* Hust. & Krasske 1941 y copépodos del género *Corycaeus*. Revista de Biología Marina 20(1): 77-90.

Hargraves PE & L Maranda. 2002. Potentially toxic or harmful microalgae from the northeast coast. Northeastern Naturalist 9(1): 81-120.

Hargraves PE & MD Hanisak. 2011. The significance of chlorophyll size fractionation in the Indian River Lagoon, Florida. Florida Scientist 74: 151-167.

Hasle GR & EE Syvertsen. 1997. Marine diatoms. In: Tomas CR (ed). Identifying marine phytoplankton, pp. 1-385. Academic Press, San Diego.

Hiromi J, S Kadota & H Takano. 1985. Diatom infestation of marine copepods (Review). Bulletin Tokai Regional Fisheries Research Laboratory 117: 37-45.

Hoppenrath M, M Elbrächter & G Drebes. 2009. Marine phytoplankton: Selected microphytoplankton species from the North Sea around Helgoland and Sylt, 264 pp. E. Schweizerbart Science Publishers, Stuttgart.

Li XS, CP Chen, JR Liang, WZ Wu & YH Gao. 2014. Morphology and occurrence of a marine epizoic diatom *Falcula hyalina* Takano (Bacillariophyta) in China. Algological Studies 145/146: 169-179.

Licea S, S Gómez-Aguirre, R Cortés-Altamirano & S Gómez. 1999. Notas sobre algunos florecimientos algales y la presencia de especies tóxicas en cinco localidades del Pacífico mexicano (1996-1999). En: Tresierra-Aguilar AE & ZG Culquichicón-Malpica (eds). VIII Congreso Latinoamericano de Ciencias del Mar. ALICMAR y Universidad Nacional de Trujillo, Trujillo, pp. 335-337.

Meave-del Castillo ME, ME Zamudio-Resendiz, JA Aké-Castillo, S Guerra-Martínez & IF Barbosa-Ledesma. 2003. Biodiversidad de diatomeas (Bacillariophyta) en la columna de agua del Pacífico mexicano. En: Barreiro T, ME Meave del Castillo, G Figueroa-Torres & M Signoret (eds). Planctología mexicana, pp. 43-84. Sociedad Mexicana de Planctología, Ciudad de México.

Merino-Virgilio F del C, YB Okolodkov, AC Aguilar-Trujillo, I Osorio-Moreno & JA Herrera-Silveira. 2014. Florecimientos algales nocivos en las aguas costeras del norte de Yucatán (2001-2013). En: Botello AV, J Rendón von Osten, JA Benítez & G Gold-Bouchot (eds). Golfo de México. Contaminación e impacto ambiental: diagnóstico y tendencias, pp. 161-180. UAC, UNAM-ICMYL, CINVESTAV-Unidad Mérida, Campeche.

Moreno JL, S Licea-Durán & H Santoyo. 1996. Diatomeas del Golfo de California, 273 pp. Universidad Autónoma de Baja California Sur-SEPFOMES-PROMARCO, Ciudad de México.

Palomares R, E Suárez-Morales & S Hernández-Trujillo. 1998. Catálogo de los copépodos (Crustacea) pelágicos del Pacífico mexicano, 352 pp. Centro Interdisciplinario de Ciencias Marinas / El Colegio de la Frontera Sur, Ciudad de México.

Prasad AKSK, RJ Livingston & GL Ray. 1989. The marine epizoic diatom *Falcula hyalina* from Choctawhatchee Bay, the Northeastern Gulf of Mexico: Frustule morphology and ecology. Diatom Research 4: 119-129.

Reimann BEF & JC Lewin. 1964. The diatom genus *Cylindrotheca* Rabenhorst. Journal of the Royal Microscopical Society 83: 283-296.

Round FE. 1981. The ecology of algae, 653 pp. Cambridge University Press, Cambridge.

Russell DJ & RE Norris. 1971. Ecology and taxonomy of an epizoic diatom. Pacific Science 25: 357-367.

Souza-Mosimann RM, GF Fernandes & LF Fernandes. 1989. Contribuição ao conhecimento das diatomáceas da Baía de Tijucas- Santa Catarina- Brasil. Insula 19: 95-122.

Sunesen I & E Sar. 2007. Marine diatoms from Buenos Aires coastal waters (Argentina). III. Potentially harmful genus *Asterionellopsis*, *Cerataulina*, *Ceratoneis* y *Leptocylindrus*. Revista Chilena de Historia Natural 80: 493-507.

Takano H. 1983. New and rare diatoms from Japanese marine waters–XI. Three new species epizoic on copepods. Bulletin Tokai Regional Fisheries Research Laboratory111: 23-35.

Tiffany MA. 2011. Epizoic and epiphytic diatoms. In: Seckbach J & JP Kociolek (eds). The diatom world: cellular origin, life in extreme habitats and astrobiology, pp. 195-209, Springer, Dordrecht.

Totti C, T Romagnoli, M De Stefano, CG Di Camillo & G Bavestrello. 2011. The diversity of epizoic diatoms: relationships between diatoms and marine invertebrates. In: Seckbach J & JP Kociolek (eds). All flesh in grass: cellular origin, life in extreme habitats and astrobiology, pp. 323-343, Springer, Berlin.

Utermöhl H. 1958. Zur Vervollkommung der quantitativen Phytoplankton Methodik. Mitteilungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie 9: 1-38.

Walkusz W & L Rolbiecki. 2007. Epibionts (*Paracineta*) and parasites (*Ellobiopsis*) on copepods from Spitsbergen (Kongsfjorden area). Oceanologia 49: 369-380.

Received 31 August 2015 and accepted 13 January 2016

Associated Editor: Pilar Muñoz M.