NEW DATA ON THE DISTRIBUTION OF
Spatulodinium pseudonoctiluca (NOCTILUCALES: KOFOIDIINACEAE) IN THE MEXICAN PACIFIC

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ABSTRACT. In this paper the distribution of the dinoflagellate Spatulodinium pseudonoctiluca in different areas of the Mexican Pacific is depicted based on samples gathered during 2005-2010. This species is first recorded for Bahía de los Ángeles, Loreto and Bahía de Mazatlán in the Gulf of California, and in the southwest portion of the Mexican Pacific at Bahía de Acapulco, Guerrero and Salina Cruz, Oaxaca. This species appears in the study area mainly during the winter-spring period. The mature cells of S. pseudonoctiluca range from 100-173 μm in length and 89-120 μm in width. Cell size of the gymnodiniod stages observed in Bahía de La Paz ranged from 90 to 190 μm in length.

Keywords: Spatulodinium pseudonoctiluca, Gulf of California, Noctilucales, dinoflagellates.

INTRODUCTION

Taxonomy and distribution of naked dinoflagellates are scarcely studied in Mexico. Most studies on naked dinoflagellates have focused on species that form harmful blooms such as Cochlodinium polykrikoides, Gymnodinium catenatum, Gyrodinium falcatum, Gyrodinium intristium and Karenia mikimotoi (Cortés-Altamirano, 1987; Alonso-Rodríguez & Ochoa, 2004; Gárate-Lizárraga et al., 2006; 2008; 2009). Only recent studies are concerned with the distribution of naked dinoflagellates (Gárate-Lizárraga & Verduzo-Díaz, 2007; Gárate-Lizárraga et al., 2007, 2009, 2010a; 2010b). These reports were possible due to the study of living cells. Although most naked dinoflagellates are normally deformed or destroyed by sampling nets and fixative agents, some species are not totally damaged and can be identified during a routine analysis of phytoplankton (Hernández-Becerril & Bravo-Sierra, 2004; Okolodkov & Gárate-Lizárraga, 2006; Gárate-Lizárraga et al., 2010a; 2010b).

The Class Noctiluciphycaceae and their Order Noctilucales encompass three families of peculiar dinoflagellates: Noctilucaceae, Leptodiscaceae, and Kofoidiaceae (Taylor, 1976; Fensome et al., 1993). They differ from most others in that the cell of the main stage of the life-cycle is diploid and its nucleus does not show a dikaryotic organization. These cells are very large, from 1 to 2 mm in diameter, and are filled with large buoyant vacuoles. Kofoidiaceans are characterized typically by (a) retention of both flagella and recognizable episome (with an extracellular discoid or hemispherical capsule in mature cells) and hyposome throughout their life-cycle; (b) high degree of vacuolization in mature cells, and (c) very complex life-cycle involving stages which, taken in isolation, could be (and have been) considered to represent different species (Cachon & Cachon, 1967; Fensome et al., 1993).

Kofoidiaceans are free-living marine, mainly non-photosynthetic dinoflagellates that have been poorly studied in the seas adjacent to Mexico (Gárate-Lizárraga et al., 2007; 2009). According to Fensome et al. (1993), this family includes three genera: Kofoidinium Pavillard, 1928, Spatulodinium J. Cachon et M.Cachon, 1967, and Pomatodinium Cachon et Cachon-Enjumet, 1966. At present the unique valid species currently belonging to Spatulodinium is S. pseudonoctiluca (Pouchet) J. Cachon et M. Cachon ex Loeblich Jr. et Loeblich III, 1969. However, Gómez et al. (2010), using molecu-
lar tools found a second species in the Gulf of Lyon (*Spatulodinium* sp.). Life cycle of the ko-foidiniaceans based on live specimens collected from the north-western Mediterranean was investigated by Cachon and Cachon (1967). They recognized six stages, labelled ‘A’ to ‘F’. Using molecular data, Gómez *et al.* (2010) confirmed that *Gymnodinium lebouriae* is a life stage of *S. pseudonoctiluca*. For the Mexican Pacific, few records of *S. pseudonoctiluca* have been reported (Okolodkov & Gárate-Lizárraga, 2006; Gárate-Lizárraga *et al.*, 2007; 2009). New range extensions as well as immature life stages of *S. pseudonoctiluca* are reported here for the first time in the Mexican Pacific region. Additionally, information about its morphology and ecology is provided.

**MATERIAL AND METHODS**

Samples were collected at eight sites at the Pacific coast of Mexico (Fig. 1): Bahía de La Paz, Los Cabos region, off Bahía Magdalena, Loreto (Baja California Sur), Bahía de Los Ángeles (western Baja California), Bahía de Mazatlán (southeastern Gulf of California), Bahía de Acapulco (central Mexican Pacific), and Salina Cruz (Gulf of Tehuantepec). However, this study was principally done at 2 sampling stations in Bahía de La Paz (Fig. 2). The study areas have been described recently (Alonso-Rodríguez & Ochoa, 2004; Okolodkov & Gárate-Lizárraga 2006; Gárate-Lizárraga *et al.*, 2006; 2007; 2009).

Forty two phytoplankton samples were collected at sampling station 1 (off PEMEX refinery) in Bahía de La Paz (Fig. 2) from January 2009 through December 2010 with surface tows and vertical hauls from a 15-m depth with 20 µm mesh hand net. A portion of each tow was immediately fixed with Lugol acid solution and later preserved in 4% formalin. A sub-sample was taken for live phytoplankton observations. Additional 18 surface water samples were collected for identification and cell counting. At Station 2 (Cuenca Alfonso), nine vertical net hauls were conducted at a 60-m depth site from February through December 2010 (Fig. 2). Eight net phytoplankton samples were collected in Loreto, from February to December 2008. Ten samples were collected in Bahía de Los Ángeles from February through December 2006. Nine vertical net hauls were conducted from 15-m depth to surface at Stations 3, 4, 5, 6, 7, 8, 9 and 10 in July and August 2010 in Los Cabos Region. Four samples were collected in Bahía de Mazatlán in May and June 2005. Three net samples were collected in Bahía de Acapulco in November 2009. Four net samples were collected offshore from Puerto Salina Cruz, Oaxaca during May 26 through 29, 2008. Seawater temperature was recorded at all sampling stations with a bucket thermometer. Temperature and salinity at Station 2 (Cuenca Alfonso) were recorded with a data recorder (SeaBird 19 CTD). Cell counts were made in 2-mL settling chambers under an inverted Carl Zeiss phase-contrast microscope (Germany). A compound Olympus CH2 microscope (Japan) was used to measure cells. A digital SONY Cyber-shot 8.1 MP camera was used for recording images. Other microscopic images were taken (Leica, Solms, Germany).

![Figure 1. Sampling sites located at different areas from the Mexican Pacific. 1) Bahía de La Paz, 2) Los Cabos region, 3) Loreto, 4) Bahía de Los Ángeles, 5) Bahía Magdalena, 6) Bahía de Mazatlán, 7) Bahía de Acapulco, and 8) Salina Cruz.](image)
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RESULTS AND DISCUSSION

Systematic account of Spatulodinium pseudonoctiluca (Pouchet 1885) J. Cachon et M. Cachon ex Loeblich Jr. et Loeblich III, 1969

Basionym: Gymnodinium pseudonoctiluca Pouchet, 1885

Synonyms: Gymnodinium pyrocystis Jörnsen, 1912; Gymnodinium fulgens Kofoid et Swezy 1921; Gymnodinium conicum Kofoid et Swezy 1921; Gymnodinium lebouriae Pavillard 1921.

Morphological characteristics, abundance, and cell size of S. pseudonoctiluca

The species of the family Kofoidiaceae have been poorly studied and particularly so in Mexico, where only two genera, Kofoidinium and Spatulodinium have been reported (Okolodkov & Gárate-Lizárraga, 2006; Gárate-Lizárraga et al., 2007, 2009). The immature morphotype of S. pseudonoctiluca has the epicone, hypocone, cingulum and the sulcus well-differentiated (Figs. 3-8). Some gymnodinioid stages of S. pseudonoctiluca showed a well-developed tentacle (Figs. 9-10). Mature morphotype of S. pseudonoctiluca has a tentacle that resembles that of Noctiluca (Figs. 11-14). The mature cell of S. pseudonoctiluca has a subconical to round shape, deformed into a shallow cone by pushing in the left side so that the right side became somewhat convex. According to Pouchet (1885), the entire epicone is retractile and may almost completely disappear within the body, which is striated with radiating fibrils (Figs. 11 and 13). This species is characterized by a very small epicone and in the noctiluicoid or mature stage has a long unstriated tentacle projecting at a right angle to the longitudinal axis of the body, in the sulcal region. The highly transparent extracellular hemispherical dome, known as shell or ‘coque’ that emerges from the epicone is shown in Fig. 12. Some mature specimens tend to be round and others are slightly oval. The nucleus is round, and appeared as a pale area in the center of the cell (Fig. 14). In some specimens it was not easy to observe the undulated flagellum. Some Lugol-fixed mature stages of S. pseudonoctiluca clearly showed the flagellum (Figs. 16, 21, 22, and 25). This species present an elongate tentacle which varied in length in the specimens observed in this study. Anterior to the tentacle, a small lip is observed (Fig. 18). In general, length of mature stage cell of S. pseudonoctiluca was 100–173 µm, and width was 89–120 µm; gymnodinioid stages observed in Bahía de La Paz were 90–190 µm long.

Spatulodinium pseudonoctiluca was found in all study areas of the Mexican Pacific considered here. The species was observed from 2008 through 2010 at sampling station 1 in Bahía de La Paz. S. pseudonoctiluca was observed for the first time in 2008 during a multispecies microalgal red tide (Gárate-Lizárraga et al., 2009). In bottle samples collected in June 2008, this species reached densities from 1000 to 2000 cells L⁻¹. In November and December 2008, this species was only recorded in net samples. S. pseudonoctiluca was observed mostly from January to June 2009, with a density of 200 and 800 cells L⁻¹ in May and June 2009, respectively. This species was again observed from February through July and from September through November 2010 in net phytoplankton samples. Immature life stages of S. pseudonoctiluca were observed in March, April, and May 2009 and May, July and October 2010 (Figs. 3, 4, 5, 6, and 7-8, respectively). Mature specimens of S. pseudonoctiluca were first observed in this bay during a red tide occurred in June 2008 (Figs. 11 and 12). At Cuenca Alfonso, 18 mature specimens of S. pseudonoctiluca were identified from February through August and 4 and 2 cells in November and December 2010, respectively (Figs. 15 and 16). In the Los Cabos region, 6 and 8 mature specimens of this species were identified in July and August 2010, respectively (Figs. 17 and 18). In Loreto, 2 mature specimens were observed in March 2008 and 2 in May, 2005. In Bahía de Los Ángeles 5 mature cells of S. pseudonoc-
luca were identified among samples collected in March and May 2006 (Figs. 19 and 20). In Bahía Magdalena, 10 mature specimens of *S. pseudonoctiluca* were identified from February through June 2009 and 2 and 4 cells in May and April 2010, respectively (Figs. 21 and 22). In Bahía de Mazatlán, 2 mature specimens were identified in May 2005 and 2 in June, 2005 (Fig. 23). In Bahía de Acapulco, 2 mature specimens were identified in November 2009 (Fig. 24). In Salina Cruz, 3 mature specimens of *S. pseudonoctiluca* and *Spatulodinium* sp. were identified from samples of May 2008 (Fig. 25, and 26).

**Worldwide distribution of *Spatulodinium pseudonoctiluca***

First reports of this species are based on the specimens described as *Gymnodinium pseudonoctiluca* from the coast of Brittany, southeastern English Channel (Pouchet, 1885). Because some immature stages of *S. pseudonoctiluca* were identified as different species the real geographical was underestimated. **Worldwide distribution of *S. pseudonoctiluca*** is sum-
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Marized in Table 1. The new records from many disparate areas suggest that real geographical distribution has been underestimated and *S. pseudonoctiluca* could be cosmopolitan.

**Distribution in the Mexican Pacific**

Mature cells of *Spatulodinium pseudonoctiluca* were first reported along the west coast of the Baja California Peninsula, in Bahía Magdalena and Bahía de La Paz (Okolodkov & Gárate-Lizárraga, 2006; Gárate-Lizárraga et al., 2007; 2009). This species is here first reported for Bahía de Los Ángeles, Los Cabos region, Loreto, Bahía de Mazatlán, Bahía de Acapulco, and the Gulf of Tehuantepec. Also in this study, the presence of gymnodinioid stages of *S. pseudonoctiluca* in Bahía de La Paz is reported for the first time.

In general, in Bahía de La Paz, *S. pseudonoctiluca* occurred at temperatures...
ranging from 19 °C to 30 °C, coinciding with Gómez and Furuya (2007). Salinity was 34.25–35 psu. In Los Cabos region, the specimens were recorded in a range of temperature from 24 °C to 30 °C. At Cuenca Alfonso, temperature ranged from 21.5 °C to 29.5 °C. In Bahía Magdalena, the temperature ranged from 16 °C to 26 °C. In Bahía de Los Ángeles, it ranged from 16 °C to 26 °C. In Bahía de Acapulco, the temperature at the time of finding was 29 °C. In Salina Cruz, temperature was 25 °C and salinity was 32.8–34.4 psu.

According to Gárate-Lizárraga et al. (2009; 2010a; 2010b), heterotrophic dinoflagellates have become an important component of phy-

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topplankton during upwelling conditions in Bahía de La Paz. Heterotrophic dinoflagellates are common in marine pelagic systems and have a potentially important role as herbivores (Hansen, 1991; Jeong et al., 2007). *S. pseudonocitluca* was traditionally considered exclusively heterotrophic (Larsen & Sournia, 1991). Terenko (2005) observed inclusions of benthic diatoms in the cytoplasm of *S. pseudonocitluca*. In this study, small unidentified cell of diatoms (not illustrated), a cell of *Prorocentrum* sp. (Fig. 26), and some other inclusions were observed in some specimens. Gómez et al. (2010) have shown chloroplasts in *S. pseudonocitluca* using epifluorescence microscopy. In our study, some spherical green inclusions were found in both immature and mature stages (Figs. 3–10). Some red spots were found in immature stages (Fig. 9). Kolke et al. (2005) suggest that studies of the characteristics of *Spatulodinium* plastids are necessary to improve determination of whether their chloroplasts are keptoplastids or if they derive from ancient endosymbiosis, as had occurred in other dinoflagellates. Although the genus *Spatulodinium* is considered monotypic, Gómez et al. (2010) found that molecular data indicate at least a second species within the genus. The specimen reported as *Spatulodinium* sp. (Gómez et al., 2010; Fig. 1Q) is quite similar to findings in Salina Cruz in May 2008 (Fig. 26). The specimens of *S. pseudonocitluca* found in this study showed great morphological variation and wide distribution in the Mexican Pacific. Molecular studies are needed to corroborate whether there is more than one species of the *Spatulodinium* genus. Some authors have suggested that *S. pseudonocitluca* have been considered as non-indigenous plankton or introduced species for other areas (Gómez & Boicenco, 2004; Terenko, 2005; Okolodkov et al., 2007). However, this species seems to be well distributed in the Mexican Pacific coastal waters, which discard at the possibility that this species could be invasive in this area. Although Lugol-fixed mature specimens of *Spatulodinium* could be easily identified, immature stages were seen in fixed samples. The use of phytoplankton samples in this study led to find some immature stages. Live phytoplankton samples must be complementary in the study of naked dinoflagellates.

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**REFERENCES**


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