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The Dinoflagellate Genera *Protoperidinium* and *Podolampas* from Pakistan's Shelf and Deep Sea Vicinity (North Arabian Sea)

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Abstract

The present paper describes in detail the taxonomy, morphology and ecology of two dinoflagellate genera, *Protoperidinium* and *Podolampas*, from the North Arabian Sea bordering Pakistan's coastline. Diagnostic descriptions and illustrations based on light and scanning microscopic observation of the organisms are provided for all 13 species of the two genera form the study area. The spatial distribution revealed that most species were rare except Podolampas bipes and Protoperidinium depressum which were common and the number of species was higher on the Indus delta shelf than on the Balochistan shelf. The number of species recorded during the monsoon transition period was higher than the northeast monsoon season.

Keywords: Phytoplankton, dinoflagellates, taxonomy, ecology, North Arabian Sea.

Introduction

Dinoflagellates are one of the major components of the photosynthetic organisms that form the base of the aquatic food chain (Sournia, 1986; Dodge, 1987; Balech, 1988; Hallegraeff and Lucas, 1988; Horner, 2002; Polat and Koray, 2002; Hernández-Becerril *et al*., 2008) and are second in importance only to the diatoms (Hernández-Becerril, 1988; Pulat and Özel, 2003; Licea *et al*., 2004; Balkis, 2005).

The dinoflagellate genera *Protoperidinium* Bergh, 1882 and *Podolampas* Stein, 1883 belong to the order Peridiniales. Which include thecate motile forms characterized by the presence of a rigid cellulose wall (theca) composing of a series of polygonal plates, the shape and arrangement of which is used extensively in the taxonomy of the genera. The genus *Protoperidinium* is one of the most diverse and wide spread groups among marine phytoplankton (Faust, 2002). Its species are distributed globally and they often dominate in coastal ecosystem (Evagelopoulos, 2002; Faust, 2002; Okolodkov, 2008; Taylor *et al*., 2008). *Podolampas* Stein is a planktonic marine dinoflagellate species occurring preferably in tropical waters (Taylor, 1976; Burns and Mitchell, 1982; Steidinger and Tangen, 1997; Gómez *et al*., 2010). Gómez (2005) described 264 species of *Protoperidinium* and seven species of *Podolampas* in the world. It has been reported from various parts of the world (Graham, 1942; Wood, 1954; Abé, 1966; Taylor, 1987; Hernández-Becerril, 1991; Fensome, *et al.,* 1993; Okolodkov, 2005) but information from the Pakistan's water is scanty. The main objective of this study is to provide new information on the morphology, taxonomy and distribution of *Protoperidinium* and *Podolampas* taxa from North Arabian Sea shelf of Pakistan and the adjacent deep sea.

Materials and Methods

The present work is based on the samples that were collected during the cruise of Norwegian research vessel, "Dr. Fridtjof Nansen" carried out jointly by Pakistan and Norwegian governments on Pakistan shelf and vicinity during the period of 19.01.1977 to 20.6.1977. The ship surveyed the Pakistani waters, between the 15m-depth contour and 150 nautical miles offshore (Figure 1a). With the entire area of sampling divided into 13 transects and as many as 230 standard stations were sampled repeatedly from several depths. The map showing location of sampling stations (Figure 1b), the cruise track and methodology have already been described in detail elsewhere (Saifullah, 1979; Chaghtai and Saifullah, 1988; Saifullah *et al*., 2008).

The phytoplankton samples were collected by horizontal net tow of five minutes duration with mesh

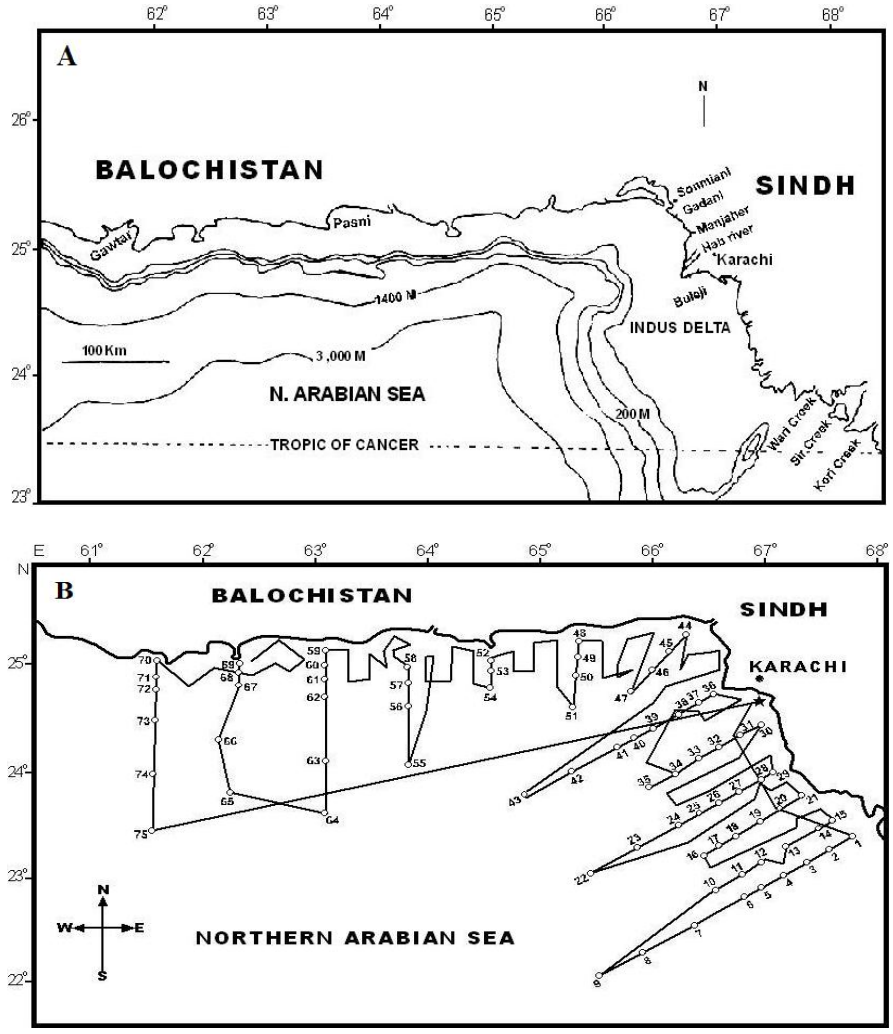

Figure 1. A. The location of the study area of Pakistan shelf and the adjacent deep waters. **B**. The sampling stations in the North Arabian Sea shelf of Pakistan.

size of 40µm. They were also collected by vertical and oblique hauls from a depth not exceeding 50m. After collection all phytoplankton samples were immediately fixed with 4% formalin. Water samples mount by using trypan blue were examined to obtain information on plate patterns to aid species identification and photographs were taken by digital camera. Some samples were then examined using scanning electron microscopy (SEM). For SEM fixed samples were desalted using a 10% step gradient from seawater to freshwater on filter paper and dehydrated by using of acetone (10-100%) coated with gold using a Denton sputter-edge coater (USA) and examined under a SEM ((Jeol-JSM-6380 LV. Japan). Ocular micrometer was used for measuring the size. Simultaneous to the collection of phytoplankton samples, observations on water temperature and water salinity were also recorded (Anonymous, 1978). The distribution of all the species was worked out for the entire Pakistan shelf area and temperature and salinity ranges in which they occurred were also recorded.

The following is an account of the species including only the salient and diagnostic features.

Results

Peridiniales Haeckel
Protoperidiniaceae Bujak & Davis
***Protoperidinium* Bergh 1882**

Syn: *Peridinium* Ehrenberg

Thecate species, cell shape and size variable; epitheca and hypotheca more or less equal; girdle may be depressed or not; sulcus with lists; many species with apical and antapical horns; surface marking diverse from poroids to spines to areolae; plate formula variable.

Subgenus: *Protoperidinium* (Gran) Balech
Group: *Orthoperidinium*
Section: *Oceanica* Jörgensen
***Protoperidinium claudicans* (Paulsen) Balech 1974 (Figure 2a)**

Dodge, 1982, p.182, figs. 20G, H; Steidinger and Tangen, 1997, p.536, pl. 51; Hernández Becerril, 1991, p.5, pl.1, figs.8, 9.

Bas: *Peridinium claudicans* Paulsen, 1907, p.16,

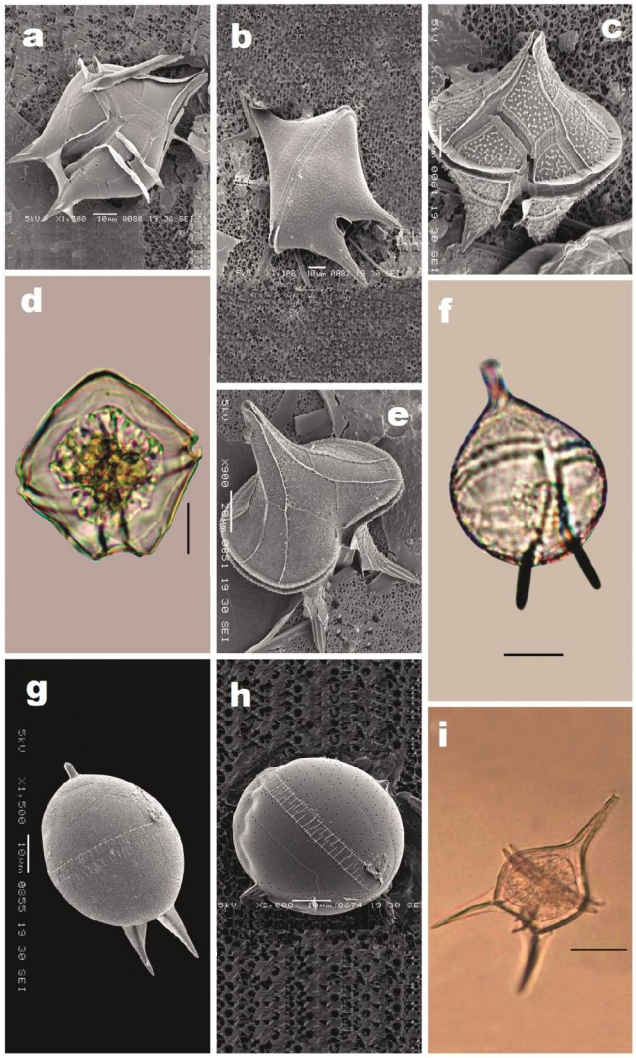

Figure 2. Light microscopy (LM) and Scanning microscopy (SEM); **a**. *Protoperidinium claudicans,* SEM; **b.** *P. oblongum*, SEM; **c**. *P. depressum*, SEM; **d**. *P. conicum*, LM; **e**. *P. elegans,* SEM; **f**. *P. oviforme*, LM; **g**. *P. nipponicum*, SEM;. **h**. *P. ovum*, SEM; **i**. *P. longipes*, LM. (Scale Bars: Figures a, b, c, d, f, g, h, i= 10µm and Figure e=20µm).

fig. 22.

Medium sized species, cell pyriform; epitheca with convex size, epitheca drawn into short apical horn, hypothecal pore is absent; hypotheca is drawn into two conical horns with two spines; girdle list conspicuous.

Tabulation: ortho, quadra/penta.
Dimensions: Length: 75-90 µm Width: 45-62 µm
Ecological Distribution: Temperature: 22.18-28.81 ºC Salinity: 35.79-36.68 ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); Gulf of Mexico (Okolodkov, 2008); Greece (Evagelopoulos, 2002); Sea of Oman (Al-Hashmi *et al.*, 2012).
Protoperidinium oblongum (Aurivillius) Parke and Dodge 1976 (Figure 2b)

Steidinger and Tangen, 1997, p.541, pl. 52; Evagelopoulos, 2002, p.44, figs. 7-9, 36.

Bas: *Peridinium divergens* Ehrenberg var. *oblongum* Aurivillius.

Syn: *Peridinium oblongum* Lebour, 1925, p. 121, pl. 24, fig. 1a-c.

Medium sized pecies, cell pyriform shape, epitheca forms an apical horn; cingulum descending and not excavate; hpotheca forms two long, tubular, pointed and diverging antapical horns; ornamentation of the plates is reticulated.

Tabulation: ortho, quadra
Dimensions: Length: 80-120 µm Width: 50-75 µm
Ecological Distribution: Temperature: 21.36-29.00 ºC Salinity: 35.79-36.65 ppt
Geographical Distribution: Greece (Evagelopoulos, 2002); Gulf of Mexico (Okolodkov, 2008); Australia and New Zealand (Chang *et al*., 2012).
Protoperidinium depressum (Bailey) Balech 1974 (Figure 2c)

Steidinger and Tangen, 1997, p.5 38, pl. 52; Okolodkov, 2008, p. 118, pl. 6, figs.1-3.

Bas: *Peridinium depressum* Bailey, 1854, p.12, figs.33-34

Cell large size, flattened obliquely; epitheca and hypotheca with straight margins, hypothecal pore absent, apical and antapical horns are conical; girdle slightly left handed, sulcus short; surface reticulate.

Tabulation: ortho, quadra
Dimensions: Length: 130-160 µm Width: 90-110 µm
Ecological Distribution: Temperature: 21.36-29.16ºC Salinity: 35.89-36.88 ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); Gulf of Mexico (Okolodkov, 2008).

Section: *Conica* Jörgensen
Protoperidinium conicum (Gran) Balech 1974 (Figure 2d)

Okolodkov, 2008, p.103, pl.1, figs.1-6; Balech, 1974, p.58; Dodge, 1982, figs. 21G,H.

Bas: *Peridinium conicum* Gran, 1902, p. 189, fig.14.

Medium sized cell; epitheca conical with straight sides; hypotheca with biconical antapex; girdle slightly concave; sulcus with list, reaching base; spines absent; surface reticulated.

Tabulation: Ortho, hexa.
Dimensions: Length: 70-90 µm Width: 45-70 µm
Ecological Distribution: Temperature: 22.53-25.19ºC Salinity: 36.25-36.63 ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); Thermaikos Bay (Evagelopoulos, 2002); Southern Gulf of Mexico (Okolodkov, 2008).

Group: *Metaperidinium*
Section: *Divergentia* Jörgensen
Protoperidinium elegans (Cleve) Balech 1974 (Figure 2e)

Steidinger and Tangen, 1997, p. 540, pl. 54; Hernández-Becerril, 1991, p.9, pl.1, fig.12.

Bas: *Peridinium elegans* Cleve, 1900a, p.16, figs.15, 16.

Cell larger, epitheca conical, side more or less concave, apical horn directly attached with epitheca; hypotheca trapezoidal with antapical horns slightly divergent with corrugated ends; Theca reticulated.

Tabulation: meta, quadra
Dimensions: Length: 130-180 µm Width: 125-145 µm
Ecological Distribution: Temperature: 22.51-28.64ºC Salinity: 36.25-36.68ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); North America, Mexico (Okolodkov 2005).

Section: *Piriformia* Jörgensen
Protoperidinium oviforme (Dangeard) Balech 1974 (Figure 2f)

Evagelopoulos, 2002, p.47, figs. 28-29, 49; Okalodkov, 2008, p.139, pl.14, figs. 5-8.

Bas: *Peridinium oviforme* Dangeard, 1927 (Ann. de I'Inst. Océanogr.4,8, décembre):356, fig. 21a-f.

Cell pyriform, epitheca and hypotheca rounded, epitheca forms a neck-like protrusion; cingulum is right handed; hypotheca with two solid spines furnished with wings; sulcal list is prominent.

Tabulation: meta, penta.
Dimensions: Length: 65-85 µm Width: 35-45 µm
Ecological Distribution: Temperature: 21.10-29.19ºC Salinity: 36.15-36.65ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); Gulf of Mexico (Okolodkov, 2008); Brazil (Odebrecht, 2010).

Group: *Paraperidinium*

Section: *Pellucida* Jörgensen
Protoperidinium nipponicum (Abé) Balech 1974 (Figure 2g)

Syn: *Peridinium nipponicum* Abé, 1927, p. 396, fig. 16.

Cell ovoid, with a short, well separated apical horn. Two winged antapical spines set well ventrally; lists on both sides of sulcus continuous with wings of spines; girdle right handed, not depressed.

Tabulation: para-hexa.
Dimensions: Length: 40-60 µm Width: 30-40 µm
Ecological Distribution: Temperature: 21.10-29.19ºC Salinity: 36.15-36.65ppt
Geographical Distribution: Indian Ocean (Taylor, 1976); Gulf of Mexico (Steidinger *et al*., 2009).
Protoperidinium ovum (Schiller) Balech 1974 (Figure 2h)

Okolodkov, 2008, p.116, pl.54, figs.1-4.

Bas: *Peridinium ovum* Schiller, 1911, p.332, figs.1A-D.

Syn: *Peridinium nipponicum* Abè, 1927, p.396, fig.16.

Small size species, cell oval, epitheca and hypotheca almost spherical, epitheca with short affixed apical horn; hypthecal pore is present, attached with two short winged antapical spines, girdle not depressed; sulcus wide.

Tabulation: para, hexa.
Dimensions: Length: 35-50 µm Width: 26-46 µm
Ecological Distribution: Temperature: 23.65-29.19ºC Salinity: 36.48.36.65ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991);

Atlantic Islands, Canary Islands (Gil-Rodríguez *et al*., 2003, Anon 2011); Gulf of Mexico (Okolodkov, 2008); South America, Brazil (Odebrecht, 2010).

Protoperidinium longipes Balech 1974 (Figure 2i)

Balech, 1974, p.67; Pesantes, 1978, p. 35, pl. 23, figs. 5,6; Hernández-Becerril, 1991, p-10, pl. 2, fig. 15.

Bas: *Peridinium longipes* Karsten, 1907, p. 418, pl. 53, figs. 6a, b.

Medium size species, cell elongated, body rotund in outline tapering into long apical and antapical horns, girdle even, right handed; antapical spines equal in length; sulcal list wide.

Tabulation: meta, penta.
Dimensions: Length: 115-135 µm Width: 45-60 µm
Ecological Distribution: Temperature: 24.63-29.00ºC Salinity: 36.15-36.65ppt
Geographical Distribution: Gulf of California and Baja California (Hernández Becerril, 1991); Brazil (Odebrecht, 2010).

Podolampadaceae Lindemann
Podolampas Stein 1883

Syn: *Parrocelia* Göurret, 1883

Cell broadly pear-shaped, tapering to an apical horn often with a spine; girdle not apparent, probably fused with precingular plates; 1-3 prominent antapical spines; theca porulate.

Podolampas bipes var. *bipes* Stein 1883 (Figure 3a)

P. bipes Stein, 1883, p. 119, fig. 362; Steidinger and Williams, 1970, p. 60, pl. 36, fig. 125; Taylor, 1976; p. 171, pl. 27, fig. 288.

Syn: *Parrocelia ovalis* Göurret, 1883, p. 81, pl. 3, fig. 48.

Body pear-shaped, broad, cell flattened, apical horn narrow and small, girdle not apparent, fused with precingular plates; flagellar pore in ventral area; two equal antapical spines supporting transverse wings; theca porulate.

Dimensions: Length: 100-125µm Width: 36-75 µm

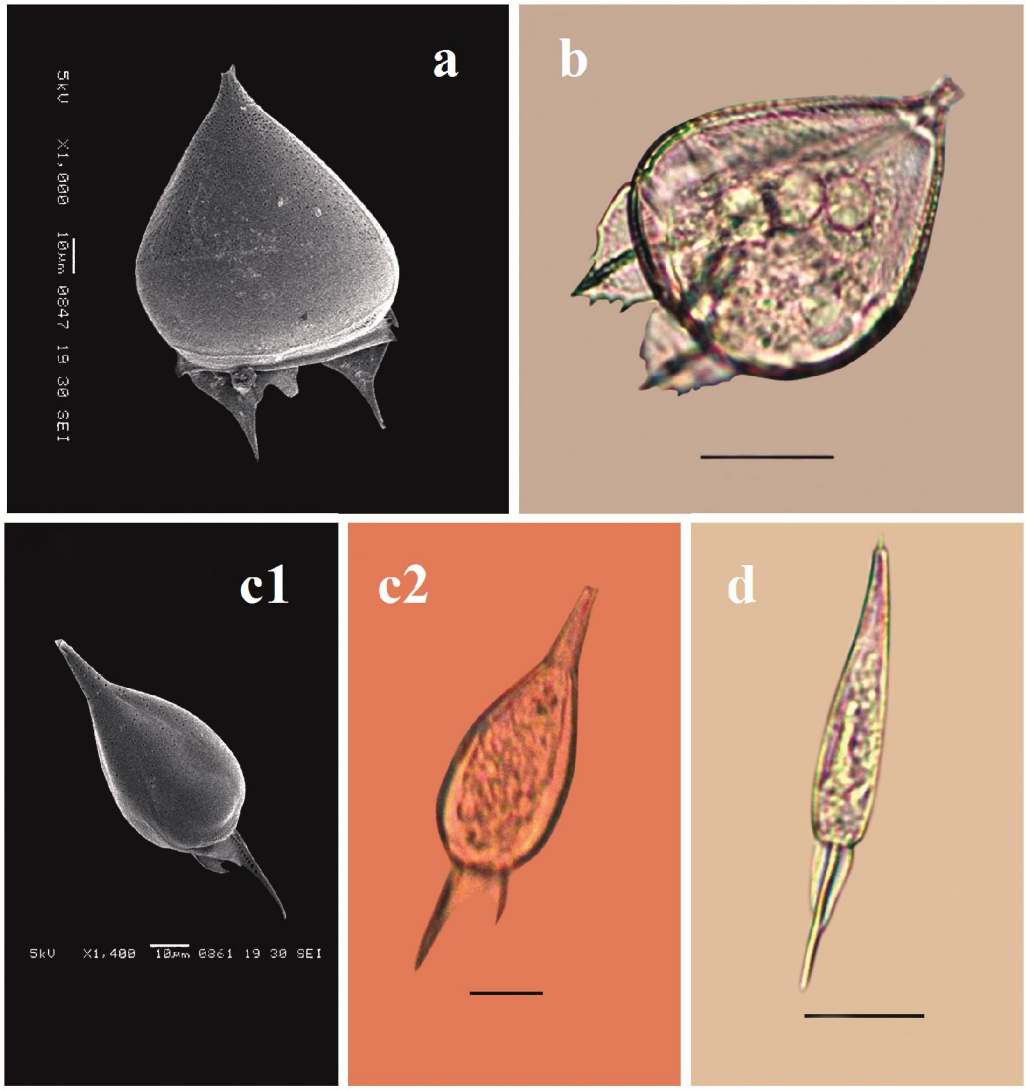

Figure 2. Light microscopy (LM) and Scanning microscopy (SEM); **a**. *Protoperidinium claudicans,* SEM; **b.** *P. oblongum*, SEM; **c**. *P. depressum*, SEM; **d**. *P. conicum*, LM; **e**. *P. elegans,* SEM; **f**. *P. oviforme*, LM; **g**. *P. nipponicum*, SEM;. **h**. *P. ovum*, SEM; **i**. *P. longipes*, LM. (Scale Bars: Figures a, b, c, d, f, g, h, i= 10µm and Figure e=20 µm).

Ecological Distribution: Temperature: 20.51-29.16ºC Salinity: 35.91-36.88 ppt
Geographical Distribution: Indian Ocean, Malaya, Arabian sea, G. of Aden, Red sea (Cleve, 1901, 1903); Red sea, G. of Aden (Ostenfeld and Schmidt, 1901); Red sea, Arabian sea, Indian Ocean (Schröder, 1906); Arabian sea (Subramanyan, 1958); Zanziber (Ballantine, 1961).

Podolampas bipes var. *reticulata* (Kofoid) Taylor 1976 (Figure 3b)

Kofoid, 1907, p. 187, pl. 2, fig. 11**;** Steidinger and Williams, 1970, p. 60, pl. 36, figs. 126a, b; Taylor, 1976; p. 171, pl. 27, fig. 287.

Antapicals equal size but wider than longer and reticulate while in *P. bipes var. bipes* they are not reticulate.

Dimensions: Length: 75-100µm Width: 35-70 µm
Ecological Distribution: Temperature: 24.81-29.00ºC Salinity: 36.24-36.58 ppt
Geographical Distribution: Indian Ocean (Matzenauer, 1933; Taylor, 1976); Australia and New Zealand; Papua New Guinea (Schweikert and Elbrächter 2004).

Podolampas palmipes Stein 1883 (Figures 3c1, c2)

Stein, 1883; Wood, 1954, p. 317, figs. 252a-b,-1968, p. 119, fig. 365; Taylor, 1976; p. 171, pl. 27, figs. 278, 279; Burns and Mitchell, 1982, p. 76, fig. 19.

Body pear-shaped, narrow anteriorly, posteriorly wide, apical horn narrow, cylindrical; flagellar pore in ventral side; two strong unequal antapical spines supporting tranverse wing, left antapical spine longer than right; wings fused.

Dimensions: Length: 80-100 µm Width: 25-40 µm
Ecological Distribution: Temperature: 23.81-28.88ºC Salinity: 36.15-36.66 ppt
Geographical Distribution: Arabian sea, G. of Aden, Red sea (Cleve, 1900b, 1903); Red sea, G. of Aden (Ostenfeld and Schmidt, 1901); Red sea to Sunda sea (Schröder, 1906); Indian ocean (Matzenauer, 1933; Wood, 1963); Arabian sea (Subrahmanyan, 1958).

Podolampas spinifera Okamura 1912 (Figure 3d)

Okamura, 1912, p. 17, pl. 2, figs. 35-36; Wood, 1968, p. 120, fig. 366; Taylor, 1976; p. 172, pl. 27, figs. 284, 285.

Cell elongated, pear-shaped; anteriorly narrow, posteriorly broad, apical horn narrow tube like with small spine; antapex rounded with single spine supporting a wing.

Dimensions: Length: 75-98µm Width: 18 µm Length of spine: 28µm
Ecological Distribution: Temperature: 22.51-25.10ºC Salinity: 36.25-36.63 ppt
Geographical Distribution: Indian Ocean (Wood, 1963; Taylor, 1976); New Zealand (Chang *et al*., 2012); Brazil (Odebrecht, 2010); France (Anon, 2012).

Discussion

This work is an extension of studies on marine dinoflagellates from the Pakistan's continental shelf. Chaghtai and Saifullah (1988), Mansoor and Saifullah (1995) and Saifullah *et al*. (2002, 2008) Gul and Saifullah (2011) have studied in detail species of *Ceratium, Amphisolenia, Ornithocercus* and *Prorocentrum* from the shelf. The remaining genera have remained so far undescribed.

Protoperidinium is one of the largest predominantly marine heterotrophic genus (Evagelopoulos, 2002). Gómez (2005) lists 264 species of this genus from the world's oceans. It was earlier identified and described as *Peridinium* Ehrenberg but later on the basis of cell size and shape, the plates arrangement, structure of the sulcus and presence of apical and antapical horns it has been separated and given the present designation. Therefore, almost all the species with few exceptions have been transferred to this genus. Recent studies involving detail Scanning Electron Microscopy (SEM) studies of the amphiesma helped significantly in the transfer of species of *Peridinium* to *Protoperidinium* (Balech, 1974; Taylor, 1976; Dodge, 1987; Hernández-Becerril, 1991; Okolodkov, 2008).

Protoperidinium genus is divided into two subgenera *Protoperidinium* and *Archaeperidinium* on the basis of numbers of intercalary plates. The former subgenus is characterized with an apical pore, a transitional plate, and three girdle and anterior intercalary plates. It is further subdivided into three groups (*Orthoperidinium, Metaperidinium* and *Paraperidinium*) on the basis of apical plate and six sections on the basis of again morphological differences (Dodge, 1982; Hernández-Becerril, 1991; Balech, 1994; Okolodkov, 2008). *Orthoperidinium* contained three sections *Oceanica, Tabulata* and *Conica, Metaperidinium* two sections *Piriformia* and *Divergentia* and *Paraperidinium* only one section *Pellucida* (Taylor, 1976; Hernández-Becerril, 1991; Okolodkov, 2008).

Members of *Oceanica* have an ortho-quadra tabulation (rarely penta or hexa), and have well-developed hollow antapical horns. An apical horn may or may not be well built up and girdle displacement is left handed (Taylor, 1976; Balech, 1988). *P. claudicans* (Figure 2a) is reported for the first time from Pakistan shelf. It resembles morphologically with that described by Hernández-Becerril (1991), Evagelopoulos (2002) and

Okolodkov (2008). It is a tropical or warm temperate species. *P. oblongum* (Figure 2b) and *P. oceanicum* are two different species (Lebour, 1925; Dodge, 1982). *P. oblongum* also differs with *P. oceanicum* on the basis of lack of apical horn and antapical horns not being slender (Dodge, 1982; Evagelopoulos, 2002). There was much confusion between *P. depressum* and *P. divergens*, being very similar in size and shape. Later it became established that *P. depressum* (Figure 2c) has an "ortho" first apical plate whereas *P. divergens* has a "meta" first apical plate (Okolodkov, 2008). Hassan and Saifullah (1972) reported *Peridinium depressum* for the first time from north Arabian Sea. This species is distinguished from *P. murrayi* Kofoid by the presence of a shorter less-abruptly apical horn combined with a larger body and the antapical horns are also being comparatively shorter. *Protoperidinium conicum* (Figure 2d) belongs to the group *Orthoperidinium* and section *Conica*. Members of this section are characterized by the presence of "ortho" apical plate and usually have "hexa" anterior intercalary plate. It is a medium sized species with conical shape of epitheca and left handed girdle. Antapical hollow with small spines. It is cosmopolitan, eurythermal and halotolerant species (Hernández-Becerril, 1991).

Members of section *Divergentia* are characterized by meta/quadra (rarely hexa) plate combination and by the presence of an antapex more or less divided into antapical horns. In the present study *P. elegans* (Figure 2e) was observed, which is very common in tropical areas. It is characterized by hollow, elongate and non-acute antapicals. *P. oviforme* (Figure 2f) is medim-sized pyriform species, most similar to *P. ovum* in shape but have "meta-penta" tabulation belonging to the section *Piriformia*, (Abé, 1981).

P. nipponicum (Figure 2g) is "para-hexa" species. It is a medium to small ovoid species can be distinguished from *P. ovum* by a difference in antapical spine development. More recent knowledge revealed that there are two fairly long antapical spines with fins, with well developed spiny fins in between. These fins projecting down between the large spines give the impression of two additional short spines (Taylor, 1976). *P. ovum* (Figure 2h) is a medium-sized, ovoid species. The closely related species is *P. nipponicum* which apparently differs in the nature of the antapical spines and sulcal lists. *P. longipes* (Figure 2i) belongs to the section *Pellucida* which is characterized by "para-hexa" plate combination. They are all missing antapical horns, although antapical spines are common and have right handed girdle displacement. Ortho, penta and quadra plate configurations have been reported in some members. *P. longipes* is a tropical species and has very long, narrow apical horn and strongly divergent horns. Taylor (1976) described this species as *Peridinium diabolus* var. *longipes*.

The genus *Podolampas* is a pear shaped cell with an apical horn and 1 or 2 antapical spines (Steidinger and Williams, 1970; Burns and Mitchell, 1982). *Podolampas bipes var. bipes* (Figure 3a) is recognized by relatively strong antapical spines with accessory lists which have smooth margins. Reticulation is usually absent or very weak and restricted to a small distal portion of the lists. The large pericingular plates have a basic reticulation on them which is only faintly developed. *P. bipes var. reticulata* (Figure 3b) is very similar to the *var. bipes* in thecal features although the ground reticulation is more strongly developed on the precingular plates. The antapical spines are usually shorter than the *var. bipes* and the margins of the lists associated with them are irregularly serrated. The lists are usually reticulated over most of their distal portions.

P. palmipes (Figures 3c1, c2) is relatively more slender than *P. bipes* and *P. elegans* and more broadly pear-shaped than *P. spinifera*. There are two antapical spines with associated lists, the left spine being markedly longer and more strongly developed than the right spine. *P. spinifera* (Figure 3d) possesses a single posterior spine and also a small curved apical spine. The posterior fin associated with the spine is apparently tripartite and curved in a scoop-like shape. *P. bipes* and *P. palmipes* were frequent only along the Indus delta shelf. Cleve (1901, 1903), Schröder (1906) and Subrahmanyan (1958) reported *P. bipes* from north Arabian Sea and Taylor (1976) reported them from Indian Ocean.

Dinoflagellates occur preferably in the tropical waters (Taylor, 1987; Licea *et al.,* 2004), hence a greater proportion of the species in the study area were tropical or subtropical in nature. *Podolampas bipes* var. *bipes* and *Protoperidinium depressum* were frequent species occupying 42% and 37% stations respectively on the shelf and adjacent deep sea area (Table 1). These were not only the frequent species in the area but also very abundant on certain occasions and locations. Generally most species were either neritic or neritic-oceanic (Wood, 1968) because the study area included mostly the shelf area and partly deep sea vicinity.

Species diversity in terms of number of species was higher towards the Indus delta and less towards the Balochistan shelf (Table 1) because the former area was more heterogeneous in environmental parameters than the later (Anonymous, 1978; Saifullah, 1979). The intrusion of Indus river water into the delta disturbs the uniform temperature and salinity regimes, causing heterogeneity in the delta area, which favours high diversity (Pearl, 1988; Alkawri and Ramaiah, 2010). Besides, the Indus Delta shelf is larger in size than Balochistan shelf allowing more species to occur.

The study period included the NE monsoon

Table 1. Number of stations occupied by different species in different seasons, areas and frequency of occurrence

Name of species	Seasonal occurrence		Different areas			Frequency of occurrence (%)
	N-E monsoon (Jan to Mar)	Transition period (Apr to Jun)	Indus delta	Balochistan	Total Stations	
Protoperidinium claudicans	14	20	13	21	34	6.52
Protoperidinium conicum	5	13	12	6	18	7.82
Protoperidinium depressum	29	58	45	42	87	37.82
Protoperidinium elegans	9	9	12	6	18	7.82
Protoperidinium longipes	8	5	7	6	13	5.65
Protoperidinium nipponicum	12	10	12	10	22	9.56
Protoperidinium oblongum	15	19	40	26	66	28.69
Protoperidinium oviforme	10	12	12	10	22	9.65
Protoperidinium ovum	2	6	5	3	8	3.47
Podolampas bipes var. bipes	42	56	49	49	98	42.60
Podolampas bipes var. reticulata	6	12	14	4	18	7.82
Podolampas palmipes	8	14	12	10	22	9.56
Podolampas spinifera	1	1	2	0	02	0.87

season (Jan-March) and the spring intermonsoon period between the NE and SW monsoon season (April- June). A majority of the species occurred in the transition period (Table 1) which indicates the preference for relatively higher temperatures by dinflagellates (Graham, 1941; Hoshiai *et al.,* 2003). Out of the thirteen species of *Protoperidinium* and *Podolampas* recorded, only *Protoperidinium conicum* and *Podolampas spinifera* occurred in a narrow range of temperature (22.5-25.0°C) and salinity (36.2-36.6 ppt) others remaining species occurred in wider ranges of both parameters. *P. bipes* and *P. palmipes* commonly occurred in both areas while *P. spinifera* rarley occurred on Indus delta and complete absent on Balochistan shelf (Table 1).

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