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Original Article

Distribution and abundance of dinoflagellates from the coastal waters of Karachi, Pakistan, northern part of the Arabian Sea

Distribuição e abundância de dinoflagelados nas águas costeiras de Karachi, Paquistão, parte norte do Mar da Arábia

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Abstract

The present study reports on seasonal and spatial variations in diversity, distribution and abundance of dinoflegellates and indicates the presence of HAB species in Pakistan waters. A total of 179 taxa, recorded in this study from offshore and near-shore waters, belong to 41 genera in 26 families and 10 orders. The high species count (149 species) was recorded from Manora Island offshore station (MI-1) and 105 spp, 109 spp and 115 spp were encountered from the Mubarak village offshore station (MV-1), Manora near shore station (MI-2) and Mubarak Village near-shore station (MV-2) respectively. *Tripos furca* was the dominant and frequently occurring species (> 1 x10^3 to > 25 x10^3 cells L^{-1} from coastal and >1x 10^5 cells L^{-1} from near-shore stations) in addition to less abundant *Alexandrium catenella*, *Alexandrium* sp., *Alexandrium minutum*, and *Prorocentrum micans* (>10^3 to 25x 10^3cells/L). Another 44 species occurred in relatively low numbers (<10^3 cell L^{-1}). Seventy species were found throughout the study period at all four stations. High number of species in three genera (*Tripos* (38), *Protoperidinium* (34) and *Prorocentrum* (20) was recorded. Potently toxic (16 genera 43 species) and HAB related (19 genera and 30 species) dinoflagellate taxa were also recorded. The percent contribution of dinoflagellates in total phytoplankton population generally remained below 20% except for a few instances. Manora Island stations had comparatively higher Shannon index and equitability and slightly lower dominance index. The PCA plot showed strong positive correlation among chlorophyll-*a* concentration, dissolved oxygen, total number of phytoplankton and dinoflagellates.

Keywords: Harmful algal blooms, Phytoplankton, Karachi coast, Pakistan, Manora.

Resumo

O presente estudo relata variações sazonais e espaciais na diversidade, na distribuição e na abundância de dinoflegelados e indica a presença de espécies de HAB nas águas do Paquistão. Um total de 179 táxons, registrados nesse estudo de águas *offshore* e próximas à costa, pertence a 41 gêneros em 26 famílias e 10 ordens. A alta contagem de espécies (149 espécies) foi registrada na estação *offshore* da Ilha de Manora (MI-1) e 105 spp., 109 spp. e 115 spp. foram encontrados na estação *offshore* da vila de Mubarak (MV-1), Manora perto da estação costeira (MI- 2) e estação próxima à costa da Vila de Mubarak (MV-2), respectivamente. *Tripos furca* foi a espécie dominante e de ocorrência frequente (> 1 x103 a > 25 x103 células L-1 da costa e > 1x 105 células Ll de estações próximas à costa), além de *Alexandrium catenella* menos abundante, *Alexandrium* sp., *Alexandrium minutum* e *Prorocentrum micans* (> 103 a 25x 103 células/L). Outras 44 espécies ocorreram em números relativamente baixos (< 103 células L-1). Setenta espécies foram encontradas durante o período de estudo em todas as quatro estações. Foi registrado um alto número de espécies em três gêneros (*Tripos* (38), *Protoperidinium* (34) e *Prorocentrum* (20). Potencialmente tóxicos (16 gêneros e 43 espécies) e HAB relacionados (19 gêneros e 30 espécies), táxons de dinoflagelados também foram registrados. A contribuição percentual de dinoflagelados na população fitoplanctônica total geralmente permaneceu abaixo de 20%, exceto em alguns casos. As estações da Ilha de Manora tinham índice de Shannon comparativamente mais alto e equitabilidade e índice de dominância ligeiramente mais baixos. O gráfico de PCA mostrou forte correlação positiva entre concentração de clorofila-a e oxigênio dissolvido, número total de fitoplânctons e dinoflagelados.

Palavras-chave: Harmful algal blooms, fitoplâncton, costa de Karachi, Paquistão; Manora.

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1. Introduction

The phytoplankton is a diverse group, including prokaryotic and eukaryotic organisms (Vadrucci et al., 2008), which play a significant role in the primary production, maintenance the ocean's health and as indicators of climate change (Reid et al., 1998; Cermeño et al., 2008). They are adapted to variable environmental conditions (e.g. light, temperature, salinity, nutrients, water circulation pattern), which control their distribution, diversity and migration (Levandowsky and Kaneta, 1987, Behrenfeld et al., 2006). Dinoflagellates form a major component of phytoplankton; occur in a variety of habitat having different shapes and modes of nutrition (Kimor, 1981; Tomas, 1997). A total of 2377 species in 259 genera are known from the world's oceans (Gómez, 2012) including 200 toxic and harmful algal blooms (HAB) forming species (Smayda, 1997; Gómez 2005). Toxins from dinoflagellates have a deleterious impact on other organisms that pose a threat to human and environmental health (Shumway, 1990; Smayda, 1990; Hallegraeff, 1993; Landsberg, 2002; Imai et al., 2006; Steidinger et al., 2008; Richlen et al., 2010). Water discoloration (red, green, brown) indicating dinoflegellate blooms (Smayda, 1990; Hallegraeff, 1993; Landsberg, 2002; Rensel and Whyte, 2003) have been reported from Australia (Hallegraeff, 1992), Japan, Hong Kong and China (Huang and Qi, 1997), and northern Arabian Sea (LeFevre and Grall, 1970; Venugopal et al., 1979; do Rosário Gomes et al., 2014).

A number of potential blooms forming species have been reported from coastal waters of Pakistan in the northern Arabian Sea (Saifullah and Chaghtai, 1990; Baig et al., 2006). In general, reports on phytoplankton from Pakistan are scarce and only a few studies are (Latif et al., 2013; Khokhar et al., 2018, 2020) and the remaining contributions are restricted to taxonomy and coastal waters (Munir et al., 2011, 2013, 2015; Mansoor and Saifullah, 1995). The few reports on dinoflagellates were available on growth rate and seasonal abundance (Munir et al., 2016; Khokhar et al., 2018).

The present study reports on seasonal and spatial variations in diversity, distribution and abundance of dinoflegellates occurring in the coastal and near-shore off Karachi. The presence of HAB species in coastal and near-shore waters, where most of the artisanal fishery operations are located, is alarming for fisheries industry as well as human and environmental health.

2. Materials and Methods

2.1. Study area

The study was conducted at 2 stations (Manora Island (MI) and Mubarak Village (MV) along the Karachi coast during April 2008 to March 2010 (Figure 1). Samples were collected from 4 sites e.g. 2 at Manora Island (MI-1: Manora Island offshore (24°45'4.75"N, 66°59' 9.29"E); MI-2: Manora Island nearshore (24°35'5.91"N, 66°46' 6.34"E) and 2 at Mubarak Village (MV-1: Mubarak Village offshore (24°52'6.18"N, 66°37'21.86"E); MV-2: Mubarak Village nearshore (24°45'39.12"N, 66°26'13.38"E).

2.2. Sample collection and analysis

A total of 144 replicates from offshore waters and 108 from near-shore waters were collected using 1.7L Niskin water sampler from 1m below the surface. Samples were fixed in 1% Lugol's solution in amber bottles and stored at 4°C for further analysis. A Known volume of sample (50 ml) was concentrated (Utermohl, 1958) and cell counts were recorded using an inverted microscope (*Olympus*, IX-51, Japan). Dinoflagellate species were identified following (Taylor, 1987; Tomas, 1997). Species nomenclature was used following Gómez (2012, 2013), Guiry and Guiry (2016) and online websites (http://marinespecies.org, http://ucjeps.berkeley.edu/ina/img). Water parameters, such as, water and air temperature were recorded using mercury thermometer, pH (Hanna HI 9023), transparency (Secchi disc), dissolved oxygen (Wrinkler's method HANNA-C100), salinity (refrectometer) and total chlorophyll (Chl *a*) following Strickland and Parsons (1972). The diversity indices (Shannon wiener, equitability, dominance) and principal component analysis (PCA) were also assessed using PAST version 2.17 software.

3. Results

Occurrence and distribution of dinoflagellate species in the coastal and near-shore waters of Pakistan is shown in Table 1. A total 179 taxa and 154 species belonging to 41 genera were recorded. Offshore waters had 105 (MV-1) to 149 (MI-1) species in 27 (MV-1) and 36 (MI-1) genera, respectively. On the other hand, near-shore waters had representation of 109 species at MI-2 to 115 species at MV-2 representing 30 (MI-2) and 29 (MV-2) genera, respectively. Variable numbers of species were recorded in 41 genera of dinoflagellates (Table 2). Three genera (*Tripos* (38 species), *Protoperidinium* (34 species) and *Prorocentrum* (20 species)) had high species counts. In addition, 5-9 spp. were recorded in 4 genera; 3-4 species in six genera; 2 spp. in 10 genera and only one species in 18 genera. About

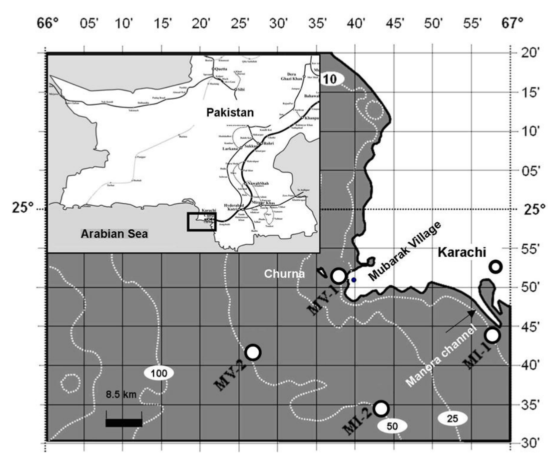

Figure 1. Map of the Karachi coast showing location in the coastal and near-shore waters off of Manora Island (MI-1; 10m contour line and MI-2; 50m contour line) and Mubarak Village (MV-1; 10 m contour line and MV-2; 50 m contour line).

Table 1. Diversity indices of dinoflagellates distributed at four stations in the coastal (MI-1, MV-1) and near-shore (MI-2, MV-2) waters of Pakistan.

	Stations			
	MI-1	**MV-1**	**MV-2**	**MI-2**
Shannon _H	2.72	2.46	2.5	2.68
Equitability _J	0.78	0.75	0.76	0.79
Dominance _D	0.11	0.14	0.14	0.11

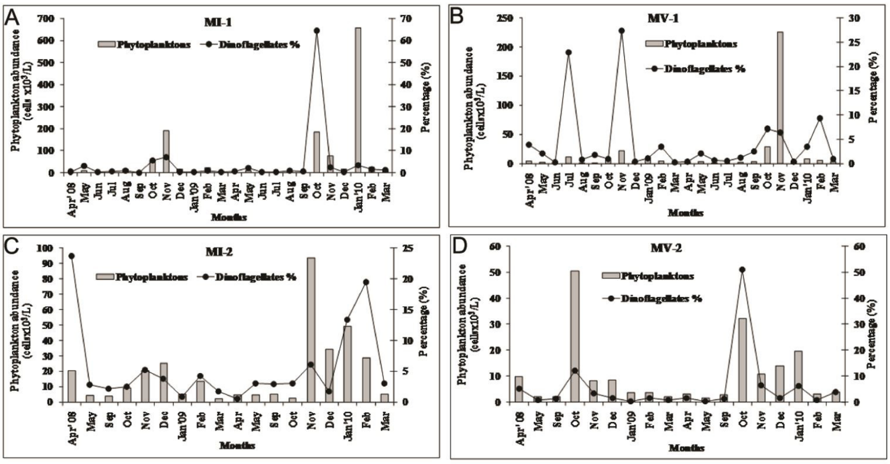

Figure 2. Phytoplankton cell abundance (cellx10^{3}L^{-1}) and dinoflagellates percentage (%) recorded from offshore and nearshore waters along the Sindh coast of Pakistan. A-B: Manora Island and Mubarak Village offshore waters; C-D: Manora Island and Mubarak Village nearshore waters.

39% of the total species (70 species) were distributed at all stations (Table 2). Diversity indices (Table 1) showed that Manora Island stations (MI-1 and MI-2) had slightly higher Shannon index and equitability, and slightly lower dominance thereby depicting high dinoflagellate diversity compared to Mubarak Village stations (MV-1 and MV-2). Variability in occurrence and abundance of dinoflegellate species was recorded at different stations (Table 2, Figure 3). Only one species, *Tripos furca,* was dominantly abundant at all stations (> 1 x10^3 cells L^{-1} at MV-1 and MI-2, > 25 x10^3 cells L^{-1} at MV-2 and >100x 10^3 cells L^{-1} from MI-1).Twenty species were commonly present at all stations (between 1x10^3 and 25x10^3 cells L^{-1}). Some of the species were termed as frequent (51 spp.; present at three stations; <1x10^3 cells L^{-1}), and the rest (107 spp.; <1x10^3 cells L^{-1}) were classified as occasional (present at two stations) and rare (present at only station). The highest total cell density of dinoflagellates was generally observed during NE monsoon i.e., October (149x10^{3}cellsL^{-1} at MI-1) and November (25x10^3 cells L^{-1} at MV-1) (Figure 2).

A total of 73 HAB related species in 27 genera (including 43 potentially toxic species) were recorded from the coastal and near-shore waters (Table 2). Forty two potentially toxic species were noted in following genera: *Alexandrium* (8 spp.), *Dinophysis* (8 spp.), *Prorocentrum* (7 spp.), *Gonyaulax* (4 spp.), *Gymnodinium*, *Karenia*, *Phalacroma* (2 spp. each), and reaming ten genera (*Amphidinium, Azadinium, Diplopsalopsis, Gambierdiscus, Gyrodinium, Heterocapsa, Lingulodinium, Ostreopsis, Protoceratium,*

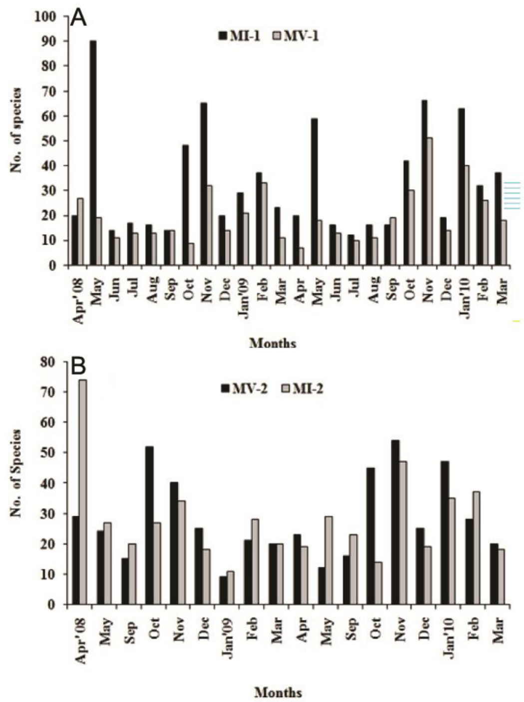

Figure 3. Monthly distribution of Phytoplankton and dinoflagellate species in offshore (MI-1 and MV-1) and nearshore (MI-2 and MV-2) waters along the Sindh coast of Pakistan. Abbreviations are as: MI: Manora Island; MV: Mubarak Village.

Table 2. List of dinoflagellates taxa identified from coastal (MI-1 and MV-1) and near-shore (MV-2 and MI-2) waters (April 2008 - March 2010) showing distribution and abundance (cells L^{-1}) for recorded species (+ = <10^3 cellsL^{-1} (Rare: present only at one station; occasional: present at two stations; Frequent: present at three to four stations); ++ = 10^3-$25x10^3$ Cells L^{-1} (Common); +++ = $25x10^3$ – $75x10^3$ (Abundant); ++++ = >$75x10^3$ (Dominant).

	No. of Taxa	Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
Akashiwo	1	*Akashiwo sanguinea* (Hirasaka 1924) Gert Hansen & Moestrup 2000[d]	+	-	-	+
			1	0	0	1
Alexandrium	9	*Alexandrium* sp1.	++	++	++	++
		Alexandrium tamarense (Lebour) Balech 1995[c]	++	+	++	++
		Alexandrium minutum Halim, 1960[c]	+	+	+	+
		Alexandrium andersonii Balech 1990[a, c]	+	-	-	+
		Alexandrium catenella (Whedon & Kof. 1936) Balech 1985[c]	++	++	++	++
		Alexandrium concavum (Gaarder 1954) Balech 1985[c]	+	+	+	+
		Alexandrium ostenfeldii (Paulsen 1904) Balech & Tangen 1985[c]	+	+	+	+
		Alexandrium pseudogonyaulax (Biecheler 1952) T. Horig. 1983 ex T. Kita & Fukuyo 1992[a, c]	+	-	+	+
		Alexandrium taylorii Balech 1994[a, c]	+	-	+	+
			9	6	8	9
Amphidinium	1	*Amphidinium carterae* Hulburt 1957 [c]	+	-	+	+
			1	0	1	1
Amphisolenia	2	*Amphisolenia* sp1.	+	-	-	-
		Amphisolenia bidentata Schröd. 1900	+	-	+	-
			2	0	1	0
Amylax	2	*Amylax* sp1.	+	+	-	-
		Amylax triacantha (Jörg.) Sournia, 1984[a]	+	+	+	+
			2	2	1	1
Azadinium	1	*Azadinium spinosum* Elbr. & Tillmann. 2009[a, c]	-	-	+	-
			0	0	1	0
Blepharocysta	1	*Blepharocysta splendormaris* (Ehrenb. 1860) Ehrenb. 1873[a]	+	-	-	-
			1	0	0	0
Centrodinium	1	*Centrodinium elongatum* Kofoid, 1907[a]	+	+	+	+
			1	1	1	1
Ceratoperidinium	1	*Ceratoperidinium falcatum* (Kof. & Swezy) Reñé & de Salas 2013[a]	-	-	-	+
			0	0	0	1
Ceratium	2	*Ceratium* sp1[b]	++	+	+	+
		Ceratium hirundinella (O.F.Müll.) Dujard. 1841[b]	+	-	-	-
			2	1	1	1
Cochlodinium	1	*Cochlodinium polykrikoides* Margalef 1961[d]	+	+	-	+
			1	1	0	1
Corythodinium	1	*Corythodinium* sp1.	-	+	-	-

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Table 2. Continued...

	No. of Taxa	Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
			0	1	0	0
Dinophysis	8	*Dinophysis* sp1.[c]	-	-	+	-
		Dinophysis acuminata Clap. & J. Lachm. 1859[c]	+	+	+	+
		Dinophysis acuta Ehrenb. 1839[c]	+	+	+	+
		Dinophysis caudata Kent. 1881[c]	++	+	+	+
		Dinophysis fortii Pavill. 1923[c]	+	+	-	+
		Dinophysis infundibulus J. Schiller 1928[c]	+	-	-	+
		Dinophysis miles Cleve 1900[c]	+	+	+	+
		Dinophysis phalacromoides (Jørg. 1923) F. Gómez, P. López-García & D. Moreira 2011[a,c]	-	-	+	-
			6	5	6	6
Diplopsalis	1	*Diplopsalis* sp1.	-	-	-	+
			0	0	0	1
Diplopsalopsis	2	*Diplopsalopsis bomba* (F. Stein 1883) J.D. Dodge & Toriumi 1993[a,c]	+	-	-	-
		Diplopsalopsis orbicularis (Paulsen) Meunier, 1910[a]	+	+	-	+
			2	1	0	1
Gambierdiscus	1	*Gambierdiscus toxicus* Adachi & Fukuyo 1979[c]	+	-	-	-
			1	0	0	0
Gonyaulax	7	*Gonyaulax diegensis* Kof. 1911	++	+	++	++
		Gonyaulax digitalis (C.H.G. Pouchet 1883) Kof. 1911[c]	+	+	+	+
		Gonyaulax monacantha Pavill. 1916	-	+	-	-
		Gonyaulax polygramma F. Stein 1883[c]	+	+	+	++
		Gonyaulax ceratocoroides Kof. 1910[c]	++	+	+	+
		Gonyaulax turbynei G. Murray & Whitting 1899	+	-	-	-
		Gonyaulax verior Sournia, 1973[c]	+	+	+	+
			6	6	5	5
Gymnodinium	4	*Gymnodinium* sp1.[c]	++	+	++	++
		Gymnodinium catenatum H.W. Graham 1943[c]	+	+	+	+
		Gymnodinium filum M. Lebour 1917[a, d]	+	-	-	-
		Gymnodinium simplex P.A. Dang. 1939[a, d]	+	-	-	-
			4	2	2	2
Gyrodinium	2	*Gyrodinium* sp1.[d]	+	+	+	+
		Gyrodinium varians (A. Wulff 1916) J. Schiller 1933[a,c]	+	-	-	-
			2	1	1	1
Heterocapsa	3	*Heterocapsa* sp1.	+	-	-	+
		Heterocapsa circularisquama T. Horig. 1995[c]	+	+	+	+
		Heterocapsa triquetra (Ehrenb. 1840) F. Stein 1883[a, d]	+	-	-	-
			3	1	1	2
Karenia	2	*Karenia brevis* (C.C. Davis 1948) Gert Hansen & Moestrup 2000[a,c]	+	++	+	+
		Karenia mikimotoi (Miyake & Kominami ex H. Oda 1935) Gert Hansen & Moestrup 2000[c]	+	+	+	+

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Table 2. Continued...

	No. of Taxa	Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
			2	2	2	2
Lepidodinium	1	*Lepidodinium chlorophorum* (Elbr. & Schnepf 1996) Gert Hansen, L. Botes, de Salas 2007[a, d]	+	-	-	-
			1	0	0	0
Lingulodinium	1	*Lingulodinium polyedra* (F. Stein 1883) J.D. Dodge 1989[c]	+	+	+	+
			1	1	1	1
Noctiluca	1	*Noctiluca scintillans* (Macartney 1810) Kof. 1920[d]	++	+	+	+
			1	1	1	1
Oblea	1	*Oblea rotunda* (M. Lebour 1922) Balech 1964 ex Sournia 1973[d]	+	+	+	+
			1	1	1	1
Ornithocercus	3	*Ornithocercus* sp1.	+	-	-	+
		Ornithocercus magnificus F. Stein 1883	-	-	+	-
		Ornithocercus steinii F. Schütt 1900	-	-	-	+
			1	0	1	2
Ostreopsis	1	*Ostreopsis ovata* Fukuyo 1981[c]	+	+	-	+
			1	1	0	1
Oxytoxum	5	*Oxytoxum* sp1.	+	+	+	-
		Oxytoxum curvatum (Kof. 1907) Kof. 1911[a]	-	-	-	+
		Oxytoxum longum J. Schiller 1937[a]	-	-	-	+
		Oxytoxum sceptrum (F. Stein 1883) Schröd. 1906[a]	+	-	-	-
		Oxytoxum scolopax Stein 1883[a]	+	-	+	-
			3	1	2	2
Peridinium	2	*Peridinium* sp1[d]	+	+	+	-
		Peridinium sp2.[d]	+	-	-	-
			2	1	1	0
Phalacroma	2	*Phalacroma mitra* F. Schütt 1895[c]	+	+	+	-
		Phalacroma rotundatum (Clap. & J. Lachm. 1859) Kof. & J.R. Michener 1911[c]	+	-	+	+
			2	1	2	1
Podolampas	2	*Podolampas bipes* F. Stein 1883	+	-	+	-
		Podolampas palmipes F. Stein 1883	+	-	+	+
			2	0	2	1
Pronoctiluca	3	*Pronoctiluca* sp1.	+	-	+	-
		Pronoctiluca pelagica Fabre-Dom. 1889[a]	-	-	+	+
		Pronoctiluca spinifera (Lohmann 1920) J. Schiller 1933[a]	+	+	+	+
			4	1	5	3
Prorocentrum	20	*Prorocentrum* sp1.	+	+	+	+
		Prorocentrum sp2.	++	+	++	+
		Prorocentrum donghaiense D.Lu in Lu & Goebel 2001[d]	+	-	-	-
		Prorocentrum arcuatum Issel 1928[c]	+	-	-	-
		Prorocentrum balticum (Lohmann 1908) A.R. Loebl. 1970[c]	+	+	-	-

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Table 2. Continued...

	No. of Taxa	Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
		Prorocentrum compressum (J.W. Bailey 1851) T.H. Abé ex J.D. Dodge 1975	+	+	+	+
		Prorocentrum concavum Fukuyo 1981[a]	+	-	-	+
		Prorocentrum dentatum F. Stein 1883[d]	+	+	+	+
		Prorocentrum emarginatum Fukuyo 1981[c]	+	+	+	+
		Prorocentrum faustiae S.L. Morton 1998[c]	+	-	-	-
		Prorocentrum formosum M.A. Faust 1993[a]	+	-	-	-
		Prorocentrum gracile F. Schütt 1895[d]	++	+	+	+
		Prorocentrum lima (Ehrenb. 1860) J.D. Dodge 1975[c]	+	-	+	+
		Prorocentrum mexicanum B.F. Osorio 1942[a, d]	+	+	+	+
		Prorocentrum micans Ehrenb. 1834[c]	++	++	++	++
		Prorocentrum minimum (Pavill. 1916) J. Schiller 1931[d]	+	+	+	+
		Prorocentrum redfieldii Bursa 1959[a, d]	+	+	+	+
		Prorocentrum rhathymum A.R. Loebl., J.L. Sherley & R.J. Schmidt 1979[c]	+	+	-	-
		Prorocentrum rostratum F. Stein 1883[a]	+	-	-	-
		Prorocentrum triestinum J. Schiller 1918[d]	++	+	++	++
			20	13	12	13
Protoceratium	1	*Protoceratium reticulatum* (Clap. & J. Lachm. 1859) Buetschli 1885[c]	+	+	+	+
			1	1	1	1
Protoperidinium	34	*Protoperidinium* sp1.	+	+	+	+
		Protoperidinium sp.2.	+	+	-	-
		Protoperidinium abei (Paulsen 1930) Balech 1974	+	+	-	+
		Protoperidinium bipes (Paulsen 1904) Balech 1974	+	-	+	+
		Protoperidinium brevipes (Paulsen 1908) Balech 1974	+	+	+	+
		Protoperidinium cerasus (Paulsen 1907) Balech 1973	-	-	-	+
		Protoperidinium claudicans (Paulsen 1907) Balech 1974	+	+	+	+
		Protoperidinium concavum (L. Mangin 1926) Balech 1974[a]	+	-	-	+
		Protoperidinium conicum (Gran 1900) Balech 1974	+	+	+	+
		Protoperidinium crassipes (Kof. 1907) Balech 1974[a,c]	+	-	-	-
		Protoperidinium curtipes (Jørg. 1912) Balech 1974	-	+	+	-
		Protoperidinium depressum (Bailey 1854) Balech 1974	+	+	+	+
		Protoperidinium divergens (Ehrenb. 1841) Balech 1974	+	+	+	+
		Protoperidinium elegans (Cleve 1900) Balech 1974[a]	-	+	+	-
		Protoperidinium excentricum (Paulsen 1907) Balech 1974	+	+	+	+
		Protoperidinium hirobis (T.H. Abé 1927) Balech 1974	+	+	+	+
		Protoperidinium leonis (Pavill. 1916) Balech 1974	+	+	+	+
		Protoperidinium longipes Balech 1974	+	+	-	-
		Protoperidinium oblongum (Auriv. 1898) Parke & J.D. Dodge 1976	+	+	+	+
		Protoperidinium oceanicum (Vanhöffen 1897) Balech 1974	+	+	+	+

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Table 2. Continued...

	No. of Taxa	Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
		Protoperidinium ovatum C.H.G. Pouchet 1883	++	+	+	+
		Protoperidinium oviforme (P.A. Dangeard 1927) Balech 1974	+	+	+	+
		Protoperidinium pallidum (Ostenf. 1899) Balech 1973[a]	++	+	-	-
		Protoperidinium pellucidum Bergh 1882 ex Loebl. & A.R. Loebl. 1966	-	+	+	+
		Protoperidinium pentagonum (Gran 1902) Balech 1974	+	-	-	-
		Protoperidinium punctulatum (Paulsen 1908) Balech 1974[a]	+	-	-	+
		Protoperidinium pyriforme (Paulsen 1907) Balech 1974[a]	++	+	+	+
		Protoperidinium robustum (Meunier 1910) Hern.-Becerril 1991[a]	+	+	-	-
		Protoperidinium solidicorne (L. Mangin 1922) Balech 1974[a]	+	+	+	-
		Protoperidinium steinii (Jørg. 1899) Balech 1974	++	+	++	+
		Protoperidinium subinerme (Paulsen 1904) A.R. Loebl. 1970[a]	+	-	-	-
		Protoperidinium tenuissimum (Kof. 1907) Balech 1974[a]	+	+	+	+
		Protoperidinium thorianum (Paulsen 1905) Balech 1973[a]	+	-	+	+
		Protoperidinium ventricum (T.H. Abé 1927) Balech 1974[a]	-	-	-	+
			29	25	22	24
Pseudophalacroma	1	*Pseudophalacroma nasutum* (F. Stein 1883) Jørg. 1923[a]	+	-	-	-
			1	0	0	0
Pyrocystis	4	*Pyrocystis* sp1.[d]	+	+	-	-
		Pyrocystis fusiformis (C.W. Thomson 1876 ex Haeckel 1890) V.H. Blackman 1902[d]	-	+	+	+
		Pyrocystis lunula (F. Schütt 1895) F. Schütt 1896[a, d]	+	+	+	+
		Pyrocystis noctiluca J. Murray 1885 ex Haeckel 1890[a, d]	-	-	+	-
			2	3	3	2
Pyrophacus	2	*Pyrophacus horologium* F. Stein 1883[a, d]	+	-	+	-
		Pyrophacus steinii (J. Schiller 1935) D. Wall & B. Dale 1971[d]	+	-	-	-
			1	0	1	0
Scrippsiella	3	*Scrippsiella* sp1.[d]	+	-	-	-
		Scrippsiella spinifera G. Honsell & M. Cabrini 1991[a, d]	+	-	-	-
		Scrippsiella acuminata (Ehrenb. 1836) J. Kretschmann, M. Elbrächter, C. Zinssmeister, S. Soehner, M. Kirsch, W-H. Kusber & M. Gottschling 2015[d]	+	+	++	+
			3	1	1	1
Tripos	38	*Tripos arietinus* (Cleve) F.Gómez, 2013	+	+	+	-
		Tripos azoricus (Cleve) F.Gómez, 2013	+	+	+	+
		Tripos belone (Cleve) F.Gómez, 2013	+	+	-	+
		Tripos brevis (Ostenf. & E.J. Schmidt) F.Gómez, 2013	+	+	+	+
		Tripos candelabrus (Ehrenb.) F.Gómez, 2013	-	+	-	-

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Table 2. Continued...

No. of Taxa		Dinoflagellate taxa	Stations			
			MI-1	MV-1	MV-2	MI-2
		Tripos carriensis (Gourret) F.Gómez, 2013	-	+	-	-
		Tripos contrarius (Gourret) F.Gómez, 2013	+	-	+	+
		Tripos deflexus (Kofoid) F.Gómez, 2013	+	+	-	-
		Tripos dens (Ostenf. & E.J. Schmidt) F.Gómez, 2013	+	+	+	+
		Tripos denticulatus (Jørg. 1920) F. Gómez, 2013[a]	+	+	+	+
		Tripos egyptiacus (Halim) F.Gómez, 2013[a]	+	-	-	-
		Tripos extensus (Gourret) F.Gómez, 2013	+	-	+	+
		Tripos falcatus (Kofoid) F.Gómez, 2013	+	-	+	+
		Tripos furca (Ehrenb.) F.Gómez, 2013[d]	++++	++	+++	++
		Tripos fusus (Ehrenb.) F.Gómez, 2013[d]	++	+	+	+
		Tripos geniculatus (Lemmerm.) F.Gómez, 2013[a]	-	+	+	-
		Tripos gibberus (Gourret 1883) F. Gómez, 2013	-	-	-	+
		Tripos humilis (Jörg.) F.Gómez, 2013	-	-	+	-
		Tripos inflatus (Kof.) F.Gómez, 2013	+	+	-	+
		Tripos kofoidii (Jörg.) F.Gómez, 2013	++	+	+	+
		Tripos limulus (Pouchet) F.Gómez, 2013	-	-	+	-
		Tripos lineatus (Ehrenb.) F.Gómez, 2013[d]	++	+	+	+
		Tripos longipes (Bailey) F.Gómez, 2103	+	+	+	-
		Tripos longirostrus (Gourret) F.Gómez, 2013	+	+	+	+
		Tripos lunula (Schimp. ex G. Karst.) F.Gómez, 2013	-	+	+	-
		Tripos macroceros (Ehrenb.) F.Gómez, 2013	+	+	+	-
		Tripos massiliensis (Gourret) F.Gómez, 2013	+	+	+	+
		Tripos minutus (Jörg.) F.Gómez, 2013	+	-	+	-
		Tripos muelleri Bory 1825[d]	+	+	+	+
		Tripos muelleri sub sp. *vultur* (Cleve 1900) F. Gómez, 2013[a]	+	-	-	-
		Tripos pentagonus (Gourret) F.Gómez, 2013	++	-	+	-
		Tripos pulchellus (Schröd.) F.Gómez, 2013	+	+	+	+
		Tripos ranipes (Cleve) F.Gómez, 2013	-	-	+	-
		Tripos reflexus (Cleve) F.Gómez, 2013	-	-	+	+
		Tripos setaceus (Jørg.) F.Gómez, 2013	-	-	+	-
		Tripos symmetricus (Pavill.) F.Gómez, 2013[a]	+	+	+	-
		Tripos teres (Kof. 1907) Gómez, 2013	+	-	+	-
		Tripos trichoceros (Ehrenb.) Gómez, 2013	+	+	+	-
			28	24	30	19
Warnowia	1	*Warnowia polyphemus* (C.H.G. Pouchet 1895) J. Schiller 1933[a]	-	-	-	+
			0	0	0	1
Total Genera= 41		**Total taxa 179; 154 spp.**	**149**	**105**	**115**	**109**

Note: [a] = New records (51), [b] Fresh water species. [c] Toxic spp, [d] HAB spp.

Protoperidinium) had one species only. In addition, 30 non-toxic HAB related species were also included, *viz.*, *Prorocentrum* (6 spp.), *Pyrocystis* (4 spp.), *Tripos* (4 spp.), *Scrippsiella* (3 spp.), *Gymnodinium, Peridinium, Pyrophacus* (2 spp. each), *Akashiwo, Cochlodinium, Gyrodinium, Heterocapsa, Lepidodinium, Noctiluca scintillans, Oblea* (1 spp. each).

Dinoflagellates had low contribution in total phytoplankton population (<10% at all instances) in offshore and near-shore stations (Figure 2), except for the high values recorded in 2009 October (64% at MI-1, 51% at MV-2), and in 2008 during April (24%, MI-2), July (24%, MV-1) and November (27%, MV-1) and in 2010 during January (14%) and February (20%) (Figure 2). High numbers of species were recorded in April 2008 at MI-2 (73) and in May 2008 at MI-1 (90). Seasonal variations in the number of species at different station follow the pattern observed for total phytoplankton and dinoflagellate abundance, i.e., high diversity was observed in October and November with some exceptions. (Figure 2).

The PCA plot of hydro-biological variables (Figure 4) showed two significant components (PC-1 and PC-2) which represent 99.9% of the total variability in water quality. PC-1 accounted for 94.86% of the total variance, which was

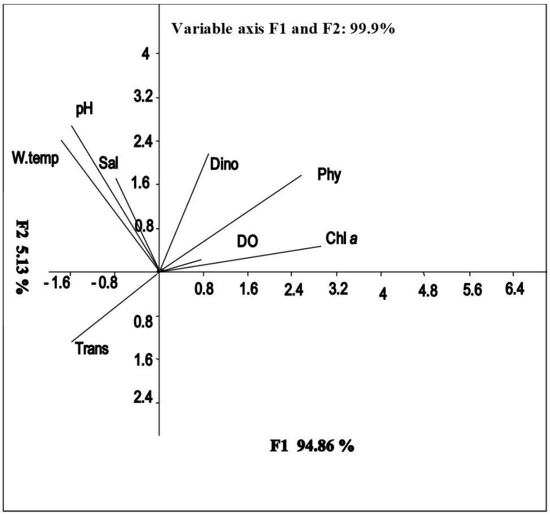

Figure 4. Principal Component analysis (PCA) of hydro-biological variables, such as, phytoplankton (Phy) and dinoflagellates (Dino) abundance, chlorophyll *a* (Chl *a*), dissolved oxygen (DO), salinity (Sal), water temperature (W.tem), pH and transparency (trans) recorded for the coastal and near-shore waters (combined data)

due to the positive loading of chlorophyll-*a* (0.811), dissolved oxygen (0.210), total number of phytoplankton (0.711), dinoflagellates (0.243) and negative loading of salinity (-0.441), pH (-0.441) and transparency (-0.428) and water temperature (-0.493) Figure 4. PC-2 contributed 5.13% of the total variability which was found to be positively loaded by water temperature (0.584), pH (0.64), dissolved oxygen (0.05), salinity (0.41), chlorophyll-*a* (0.114), total number of phytoplankton (0.42), and dinoflagellates (0.59) and negatively loaded by transparency (-0.30). The PCA plot showed that axis I was highly and positively correlated with DO, chlorophyll *a*, cell counts of phytoplankton and dinoflagellates, whereas axis II was strongly correlated with water temperature, pH, and salinity. The transparency of water appeared to be negatively correlated with axis I. The difference in the relative size of axis I and axis II was small with eigen values of 6.37 and 3.44, respectively (Figure 4).

4. Discussion

This study reports on the seasonal variability in population structure and composition of dinoflagellates in the offshore and nearshore waters of Karachi (Northern Arabian Sea). The dinoflagellates are one of the major components in marine ecosystem and play significant role in energy transfer between different trophic levels (Nagata et al., 1996; Ganjian and Makhlogh, 1998; Nuuk, 1999; Ganjian and Makhlogh, 2003; Carter et al., 2005) and their blooms can cause eutrophication (Micheli, 1999) and change water quality (Richardson and Schoeman, 2004; Leterme et al., 2006). Dinoflagellate maintained low proportion (<20%) in the total phytoplankton population with a few exceptions, which is in conformity with other studies reported previously (Azov, 1986; Zingone et al., 1995) and has been attributed to surface temperature and wind conditions (Hinder et al., 2012). It may be noted (Figure 2) that stations towards the west (MV-1 and MV-2) showed peaks of phytoplankton abundance slightly earlier compared to stations towards the east (MI-1 and MI-2). This may be due to the eastwards circulation of water, bringing up-sloped nutrient rich water that has been upwelled off the coast of Oman during the SW monsoon (Swallow, 1984; Elliott and Savidge, 1990). The phytoplankton abundance during the NE monsoon along the Pakistan coast is also the effect of delayed transmission of nutrient rich upwelled water in this area. Higher dinoflagellate abundance in the coastal waters at MI-1 and MV-1 compared to the corresponding near-shore stations may be generally attributed to the coastal effect which may be noted much enhanced in the Manora Island stations where the coastal and near-shore waters appeared to have inputs of sewage and industrial wastes and agricultural runoff through Malir and Layari rivers (Nergis et al., 2012; Chan et al., 2021). The regional effect of temperature and wind conditions and upwelled nutrient-rich water is also evident on a seasonal scale. For the same reason discussed above, the diversity of dinoflagellates is higher at Manora Island stations compared to other two stations off of Mubarak Village. Again the diversity and the species richness were higher in the coastal waters as oppose to the corresponding near-shore stations.

Information recorded on dinoflagellate species (74 species) by Shameel and Tanaka (1992) and others reported in the later on (Mansoor and Saifullah, 1995; Saeed et al.,1995; Baig et al., 2006; Latif et al., 2013; Munir et al., 2011, 2012,, 2013; 2016; Gul and Nawaz, 2014; Khokhar et al., 2018) indicated a total of 235 taxa (204 species) in 40 genera from Pakistan. This is now improved by adding 51 new records to a total of 286 species (255 species). The current study reports 179 taxa, 154 species in 41 genera of dinoflagellates as oppose to worldwide distribution of 2377 species (259 genera) (Gómez, 2012). Similar dinoflagellate species have been reported from other regional waters, for example, India (179 spp; Padmakumar et al., 2012), Arabian Gulf and Sea of Oman (194 spp) (Polikarpov et al., 2016), Kuwait waters in the Persian Gulf (105 spp) (Al-Kandari et al., 2009).

Only six genera (*Tripos, Protoperidinium, Prorocentrum, Alexandrium, Diniphysis* and *Gonyaulax*) that represent high species numbers (seven or more) are recorded in this study. Similar data has been obtained from the Arabian Gulf and Sea of Oman (Polikarpov et al., 2016) where all these genera had higher diversity except for *Alexandrium*. *Tripos* (38 spp.) had highest number of species including five new records, whereas 53 species were reported previously (Shameel and Tanaka, 1992; Munir et al., 2016; Latif et al., 2013) that give rise to a total of 58 species of *Tripos* from coastal and shelf area of Pakistan. Thirty four taxa and 32 spp of *Protoperidinium*, including 12 new records, together with previously reported 27 species (Munir et al., 2016; Latif et al., 2013; Gul and Nawaz, 2014) make a total of 59 species in this genus. A total of 24 species of *Prorocentrum* are now known from Pakistan, including 20 taxa (18 species) and 5 new records (current study) and 15 previously recorded species (Shameel and Tanaka, 1992; Munir et al., 2013). Four new records of *Alexandrium* (current study; 9 taxa, 8 species) improved previously reported 5 species (Munir et al., 2016) to 9 species in this genus. Eight taxa and 7 species of genus

Dinophysis (including one new record) and 7 species of genus *Gonyaulax* are reported here. This report together with previously recorded species makes a total of 16 species of *Dinophysis* and 8 species of *Gonyaulax* (Saeed et al., 1995; Baig et al., 2006; Gul and Saifullah, 2010, 2012; Yaqoob et al., 2013; Latif et al., 2013).

Presence of bloom forming harmful algal species (73 HAB species in 27 genera), including 43 potentially toxic species, recorded in considerable cell density from coastal and near-shore waters imposes a threat to fisheries industry and human health. For example, some of the *Prorocentrum* species (*P. gracile*, *P. micans, P. sigmoides* and *P. triestinum*) have the ability to bloom with red discoloration which is not toxic but can cause fish mortality (Faust and Gulledge, 2002; Cohen-Fernandez et al., 2006; D'Silva et al., 2012; Sahraoui et al., 2013). On the other hand, species of genus *Alexandrium* reported here are toxic and have cosmopolitan distribution (Taylor et al., 2003). This and other HAB species of dinoflagellates have previously been reported from Pakistan waters (Khokhar et al., 2018; Munir et al., 2016), Indian waters (Baliarsingh et al., 2015; Shahi et al., 2015; Padmakumar et al., 2012), Thailand (Karunasagar et al., 1990), Sea of Oman (Al Hashmi et al., 2012; Polikarpov et al., 2016), Kuwait waters (Al-Kandari et al., 2009), Mediterranean Sea (Honsell et al., 1992; Giacobbe et al., 1996; Vila et al., 2001; Lilly et al., 2002; Turki and Balti, 2005) and Australia (Hallegraeff, 2010, Murray et al., 2012; Ajani et al., 2013). In general dinoflagellate toxin causes paralytic shellfish poisoning and diarrhetic shellfish poisoning and other potential hepato and neuro toxins (Anderson et al., 2012; Llewellyn et al., 2006; Wiese et al., 2010). The frequency of HAB events showed an increasing trend over last several decades owing to the changing environmental conditions, such as, wind, temperature, etc. (Smayda, 1990; Anderson et al., 2002; Glibert et al., 2005; Hallegraeff, 1993, 2003, 2010), which consequently has increased upwelling of nutrient rich waters. In addition anthropogenic activities also increase nutrient input in the coastal waters, causing increased planktonic bloom formation (Parab et al., 2006; Gomes et al., 2009). Such blooms tend to deplete dissolved oxygen in the water column and as a result health and abundance of fish in these waters would be effected (Goes et al., 2005). This will also have an implication on the population structure of plankton in the regional waters and in turn will influence the marine food chain and shift the balance towards the HAB species (Ramsdell et al., 2005). Occurrence and increasing cell densities of HAB related dinoflagellates species pose threat to the safety of fishery products as well as human and environmental health. Therefore, regular monitoring of the occurrence, distribution and abundance of HAB related species and their blooms is recommended for fishery management and food and health safety.

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