



Taxonomic studies of marine dinoflagellates and distribution in the coastal waters of Kakinada, Andhra Pradesh, India

A Bhowal^{1a,b}, J Purushothaman^{*a} & A Siddique^{a,b}

^aZoological Survey of India, Protozoology Section, M Block, New Alipore, Kolkata, West Bengal – 700 053, India

^bDepartment of Zoology, University of Calcutta, Kolkata, West Bengal – 700 019, India

*[E-mail: jasbose@gmail.com]

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The present study reports an account of dinoflagellates collected during the Bay of Bengal winter monsoon survey in January 2018 from the coastal waters of Kakinada, Andhra Pradesh, India. Water samples were collected from four stations parallel to the coastline at Kakinada, Andhra Pradesh. A total of 14 species of dinoflagellates belonging to six families under three orders of class Dinophyceae have been obtained from Kakinada, 10 of which are newly reported from this area. The species obtained have been described in brief, along with their known distribution records, numerical abundance and additional ecological attributes.

[**Keywords:** Bay of Bengal, Dinoflagellata, Microplankton, Plankton, Protists]

Introduction

Dinoflagellates are protist organisms of the size range 20 – 200 μm which are classified into a functional group as microplankton. Structurally, they have distinct characters - two flagella one of which transversely circles the cell body and the other one goes around the length of the cell body. Mostly, they are armoured and non-armoured flagellates. They are known to exhibit different trophic habits: autotrophy, heterotrophy, as well as mixotrophy. As a result, in the marine food web, dinoflagellates act both as primary producers and primary consumers (sometimes both in the same ecosystem, within the same cell), and are widely known for their role in causing algal blooms in water bodies¹.

Kakinada city is located in the coastal state of Andhra Pradesh, 150 kilometres from Visakhapatnam. Kakinada's southeast boundary is formed by the Kakinada Bay (which is drained by Godavari River) and Coringa Wildlife Sanctuary, the second-largest mangrove forest in India². The study location is of importance chiefly due to its proximity to the mangrove area, since it can help detect any habitat shift in dinoflagellate community (e.g. from mangrove to neritic shift, or from neritic to oceanic shift). Another important criterion for choosing this site is its proximity to the Kakinada fishing harbour, which is exposed to anthropogenic activities. Plankton studies at such

locations can reveal potential species shift, or change in the dynamics of the dinoflagellate community, since some members of this taxon are toxic³⁻⁴, and are potentially responsible for harmful algal blooms¹.

Previous investigations from this area consisted of only one study on the phytoplankton community along the coastal Kakinada⁵, while other studies on microplankton in this region were mostly concerned with the area of Visakhapatnam⁶⁻⁷. Dinoflagellate studies along India's east coast have been sporadic (although mostly concentrated on the coastal state of Tamil Nadu⁸⁻¹⁰), and sufficient investigations have been conducted in the open sea region of the Bay of Bengal as well¹¹⁻¹³. Sampling at Kakinada yielded microplankton of various taxa, and the focus of this paper is on the infraphylum Dinoflagellata obtained from this survey. The main objective of this work has been to identify and expand knowledge about the spatio-temporal distribution of planktonic dinoflagellates and additionally create a database on the dinoflagellates inhabiting the north-eastern coastal waters of Bay of Bengal. In this research article, a systematic account of the dinoflagellates from the coastal region of Kakinada, Western Bay of Bengal has been provided.

Materials and Methods

A survey was conducted from the Bay of Bengal coastal waters of Kakinada, Andhra Pradesh during

the winter monsoon season in January 2018 (Fig. 1). Water samples were collected from 10 m depth intervals from four stations parallel to the coastline. The four sampling stations are as follows: Station 1: APK1 (17°02'19.4" N, 82°20'32.6" E), Station 2: APK2 (17°01'00.2" N, 82°23'31.1" E), Station 3: APK3 (16°58'40.3" N, 82°25'31.6" E) and Station 4: APK4 (16°57'18.7" N, 82°27'19.0" E). Thus, APK1 is the station nearest to the coast, while APK4 is the station farthest from the coast. Sampling was conducted by availing mechanized fishery trawler. Samples were obtained from surface (0 m) and sub-surface (10, 20, 30, and 40 m) depths of seawater level by a Niskin sampler for dinoflagellate specimen collection. The water samples were pre-filtered through a 200 µm bolting silk net. The samples containing dinoflagellate specimens were preserved in 4 % neutral formaldehyde and 3 % acidic Lugol's Iodine for microscopic analysis. Prior to this analysis, the initial samples were allowed to settle for 2 days. Specimens were pipetted out from settled water samples in the Sedgewick rafter counting chamber, and dinoflagellate specimens were observed and photographed under an inverted microscope (Leica

DMIL LED) for Light Microphotographs (LM) and under Zeiss EVO 18 Special Edition version 5.09 at 15 kV for Scanning Electron Microscope (SEM) photographs (Fig. 2). After the photographs were obtained, the dinoflagellates were subsequently identified up to species level based on available literature^{11,14-16}. The voucher specimens have been deposited in the collections of the Zoological Survey of India National Zoological Museum collections with registration numbers. To obtain environmental data, a multiparameter probe was used to assess environmental parameters such as salinity, temperature, and Dissolved Oxygen (DO), and a Niskin sampler was used to collect water samples for analysis of nutrients and chlorophyll-*a*.

For the representation of the data obtained from current study, Microsoft Excel (MS Office 2021) and PAST software (version 4.13) were used to construct figures (graphs, tables and matrix plot). The species diversity analyses (Shannon's diversity index, species evenness, and richness), were performed in PAST software. The map of the study area was plotted using Ocean Data Viewer (version 5.6.2).

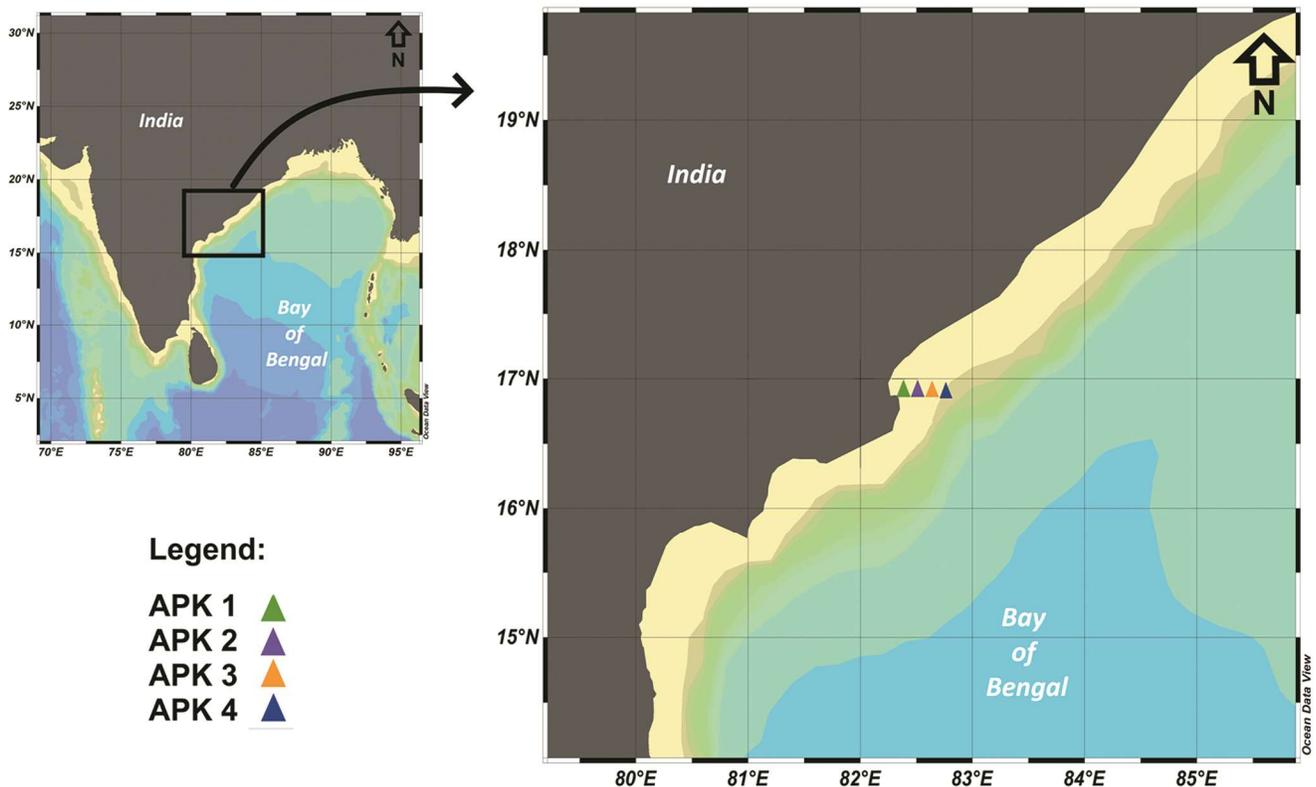


Fig. 1 — Map of study area represented by four stations (APK1 green triangle; APK2 purple triangle; APK 3 orange triangle and APK 4 blue triangle)

Results and Discussion

The species assemblage was dominated by *Triplos trichoceros*, *Protoperidinium depressum* and *Dinophysis caudata* in terms of numerical abundance. Among the rarest species were *Ornithocercus magnificus* and *Protoperidinium brochii* (Figs. 3 & 4).

In terms of their presence in the water column, *Triplos trichoceros* and *Dinophysis caudata* dominated the surface as well as subsurface depths of the study area. *Triplos trichoceros* reached its highest abundance of 107 individuals per litre (ind./L) in station APK3 at 10 m depth and *Dinophysis caudata* reached its

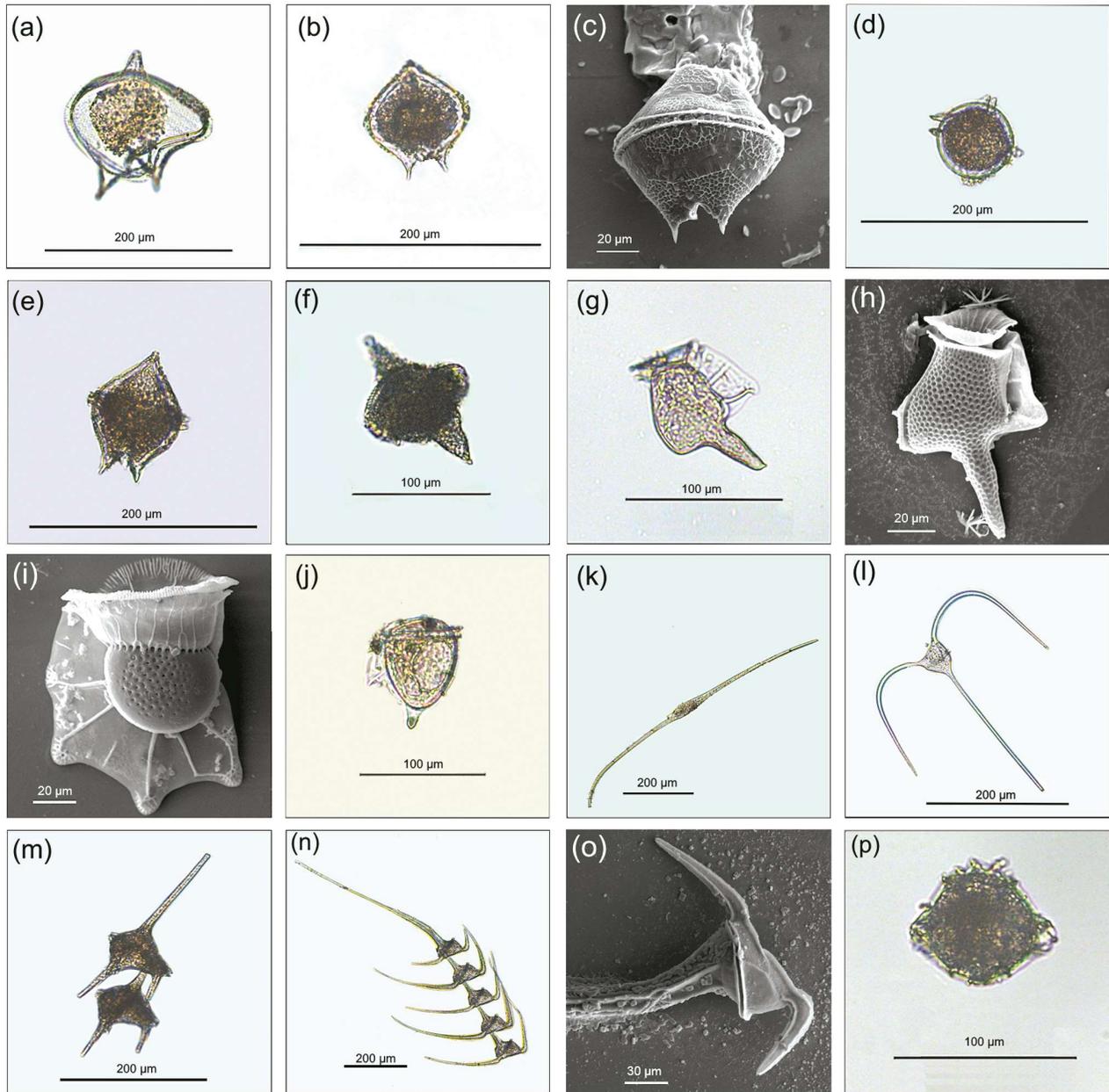


Fig. 2 — Micrographs (Light microscope and SEM images) of species recorded from Kakinada coastal waters: (a) *Protoperidinium depressum* (Bailey) Balech 1974; (b) *Protoperidinium brochii* (Kofoid & Swezy) Balech, 1974; (c) *Protoperidinium leonis* (Pavillard) Balech 1974; (d) *Protoperidinium ovum* (J. Schiller) Balech 1974; (e) *Protoperidinium pallidum* (Ostenfeld) Balech 1973; (f) *Spiraulax kofoidii* H. W. Graham, 1942; (g) *Dinophysis caudata* Saville-Kent 1881; (h) *Dinophysis caudata* Saville-Kent 1881; (i) *Ornithocercus magnificus* Stein 1883; (j) *Phalacroma doryphorum* Stein 1883; (k) *Triplos inflatus* (Kofoid) F. Gómez, 2013; (l) *Triplos trichoceros* (Ehrenberg) F. Gómez, 2013; (m) *Triplos candelabrum* (Ehrenberg) F. Gómez, 2013; (n) *Triplos vultur* (Cleve) F. Gómez 2013; (o) *Triplos vultur* (Cleve) F. Gómez 2013 magnified view; and (p) *Triadinium polyedricum* (Pouchet) Dodge, 1981



Fig. 3 — Sunburst chart depicting the proportion of each taxon found in Kakinada. The average numerical abundance of each species has been taken to construct the chart, and each segment of the chart is directly proportional to the numerical abundance of that species

highest abundance of 84 ind./L in station APK2 at surface, while, *Triadinium polyedricum* was more prevalent in the surface waters of all stations, followed by *Protoperidinium leonis* (Fig. 4). Certain species were restricted to the subsurface waters (*Phalacroma doryphorum*, *Spiraulax kofoidii*, *O. magnificus*, *Tripos vultur*) as can be seen in the matrix plot (Fig. 4). Dinoflagellate species abundance ranged from 154 to 200 (ind./L) on an average across the four stations in the Kakinada coastal waters. When considering the depth-wise abundance of each station, APK3 30 m had the highest numerical abundance (250 ind./L) and APK2 20 m the least (143 ind./L)

(Fig. 5). The species abundance varied slightly between surface (average of 177 ind./L) and subsurface (average of 192 ind./L) depths. This study also revealed that the *Protoperidinium* genus is most widespread in all stations, all water depths (up to 40 m), and with the most members (5 species).

Certain diversity indices were calculated to get an idea of the dinoflagellate species community composition (Table 1). The Shannon-Weiner diversity index (H') was calculated for the four stations, at each depth interval. The H' value ranged from 1.1 to 2.212, with the highest value at station APK3, 20 m depth. The surface and subsurface average H' values were

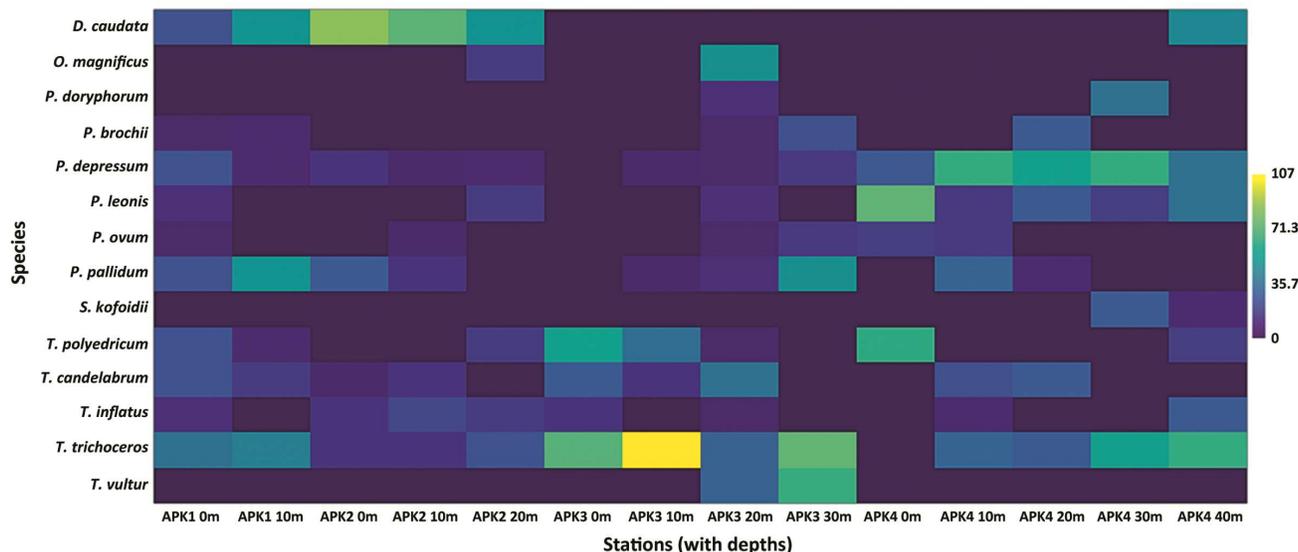


Fig. 4 — Station and depth-wise matrix plot of dinoflagellate abundance (ind./L) of each species in the study area. Colour bar: Dark blue represents minimum abundance per litre while yellow represents maximum abundance per litre

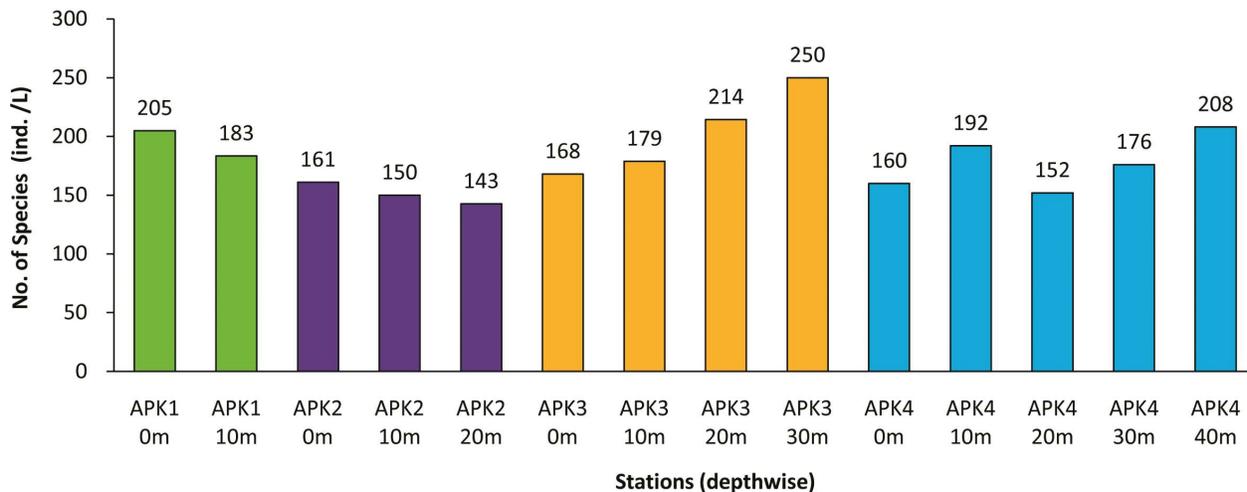


Fig. 5 — Station and depth-wise total abundance of dinoflagellates

Table 1 — Station and depth-wise diversity indices of dinoflagellate community in Kakinada

Stations (with depth)	Taxa or Species Richness (S)	Shannon (H')	Evenness (e ^{H/S})
APK1 0 m	10.000	2.194	0.897
APK1 10 m	7.000	1.694	0.778
APK2 0 m	6.000	1.433	0.698
APK2 10 m	7.000	1.608	0.713
APK2 20 m	7.000	1.823	0.884
APK3 0 m	4.000	1.246	0.869
APK3 10 m	5.000	1.100	0.601
APK3 20 m	12.000	2.212	0.761
APK3 30 m	6.000	1.634	0.854
APK4 0 m	4.000	1.257	0.879
APK4 10 m	7.000	1.786	0.852
APK4 20 m	6.000	1.696	0.909
APK4 30 m	5.000	1.529	0.922
APK4 40 m	7.000	1.830	0.890

1.53 and 1.69, respectively. Among the four stations, APK1 showed highest average diversity (1.94). Evenness was measured between all the stations and the value ranged from 0.601 to 0.922, with the most evenness recorded at station APK4 30 m depth. Evenness values across most depths and stations remained above 0.75, which shows that most of the dinoflagellate communities were quite evenly spaced out, since most evenness values were closer to 1. Among the four stations, APK4 exhibited highest average evenness (0.89). Species richness was found to be highest in station APK3 at a depth of 20 m. Twelve of the 14 recorded species were found here. The lowest species richness (four species) was recorded from the surface waters of stations APK3 and APK4.

The average values of physicochemical or environmental parameters (temperature, salinity, nutrients, DO and chlorophyll-*a* concentration) obtained from this study in each station has been shown in Table 2. There has been no definitive correlation between the dinoflagellate abundance and richness as a whole with these parameters. Although, some species abundance selectively showed correlation with certain environmental parameters: the mixotrophic species *T. inflatus* revealed to have strong positive correlation ($r = 0.62$) with phosphate concentration while another mixotroph *T. candelabrum* exhibited strong positive correlation ($r = 0.74$) with chlorophyll-*a* concentration; the heterotrophic species *Protoperidinium leonis* exhibited strong negative correlation ($r = -0.72$) with chlorophyll-*a* concentration, while another heterotrophic species *P. brochii* showed significant positive correlation ($r = 0.62$) with nitrate concentration.

Previous work from this region comprised of a single study conducted on the phytoplankton community off Kakinada⁵ in the fall intermonsoon season (from where two species recorded in this study had also been found). The species *Dinophysis caudata*, known to form toxic algal blooms^{4,17}, was prevalent in two stations (APK1, APK2), though their numbers (an average of 23 ind./L across all the stations, with the highest number, 84 ind./L, recorded in the surface waters of station APK2) possessed no

imminent threat to the current ecosystem since no algal bloom was observed. As previously mentioned, dinoflagellates show multiple nutrition modes or “trophyl”. The species obtained from this study was no different and comprised of six heterotrophic species (*e.g. Protoperidinium spp.*), seven mixotrophic species (*e.g. Dinophysis caudata, Spiraulax kofoidii*) and one autotrophic species (*Triadinium polyedricum*). The mixotrophic genera and species are of several types. For example, the species *Ornithocercus magnificus* is known to harbour cyanobacteria within its body¹⁸, thus obtaining their mixotrophic status by virtue of their ectosymbionts¹⁹ and specimens found in current study bore the same. On the other hand, mixotrophs that have acquired plastids and make use of them for phototrophic activities¹⁹, as seen in *Dinophysis caudata* was also among the species obtained from this study. Among other interesting findings, two chain forming species *Triplos candelabrum* and *Triplos vultur*¹⁵ were recorded from the study site, where they formed chains of 2 – 3 individuals and 2 – 5 individuals, respectively.

A comprehensive account of Dinoflagellata of Kakinada, Andhra Pradesh, has been provided. The dinoflagellates obtained belonged to a single class, three orders, six families, seven genera and 14 species (Table 3; Fig. 3) of which, 10 were new records to the area. The identified taxa comprised seven genera and six families: Protoperidiniaceae (one genus, five species), Dinophysiaceae (two genera, two species), Oxyphysaceae (one genus, one species), Ceratiaceae (one genus, four species), Goniodomataceae (one genus, one species), Peridiniida incertae sedis (one genus, one species). Family Protoperidiniaceae and Peridiniida incertae sedis falls under the order Peridinales; Families Dinophysiaceae and Oxyphysaceae fall under the order Dinophysiales; and families Ceratiaceae and Goniodomataceae fall under the order Gonyaulacales. Here, the classification is described and new geographical records of the newly reported taxa are added.

The systematic account of the identified dinoflagellates (an elaboration on Table 3) is given as follows:

Table 2 — Environmental parameters (station averages) in Kakinada

Station	Temperature (°C)	Salinity	DO (ml/l)	Chl- <i>a</i> (µg/l)	Nitrate (µM/L)	Nitrite (µM/L)	Phosphate (µM/L)	Silicate (µM/L)	Ammonium (µM/L)
APK 1	26.49	30.85	6.070	0.130	2.980	0.560	0.960	5.295	0.205
APK 2	25.92	30.96	5.746	0.130	2.946	0.814	1.224	5.149	0.364
APK 3	26.24	30.66	5.505	0.105	3.914	0.764	0.935	6.475	0.324
APK 4	26.24	31.29	5.961	0.015	2.084	0.741	1.075	4.624	0.188

Table 3 — Systematic list of species recorded from Kakinada in winter monsoon, 2018
(New records to the region are denoted with an “**”)

Class	Order	Family	Genus	Species
DINOPHYCEAE Fritsch, 1927	PERIDINIALES Haeckel, 1894	PROTOPERIDINIACEAE J.P Bujak & E.H Davies	<i>Protooperidinium</i> Bergh, 1881	<i>Protooperidinium depressum</i> (Bailey) Balech 1974 <i>Protooperidinium brochii</i> (Kofoid & Swezy) Balech, 1974* <i>Protooperidinium leonis</i> (Pavillard) Balech 1974 <i>Protooperidinium ovum</i> (J.Schiller) Balech 1974* <i>Protooperidinium pallidum</i> (Ostenfeld) Balech 1973*
		PERIDINIIDA incertae sedis	<i>Spiraulax</i> Kofoid, 1911	<i>Spiraulax kofoidii</i> H.W Graham, 1942*
	DINOPHYSALES Lindemann, 1928	DINOPHYSIACEAE Stein, 1883	<i>Dinophysis</i> Ehrenberg, 1839 <i>Ornithocercus</i> Stein, 1883	<i>Dinophysis caudata</i> Saville-Kent 1881 <i>Ornithocercus magnificus</i> Stein 1883*
		OXYPHYSACEAE Sournia, 1984	<i>Phalacroma</i> Stein, 1883	<i>Phalacroma doryphorum</i> Stein 1883*
	GONYAULACALES Taylor, 1980	CERATIACEAE Kofoid, 1907	<i>Tripes</i> Bory de Saint-Vincent, 1823	<i>Tripes inflatus</i> (Kofoid) F.Gómez, 2013* <i>Tripes trichoceros</i> (Ehrenberg) Gómez, 2013 <i>Tripes candelabrum</i> (Ehrenberg) F.Gómez, 2013* <i>Tripes vultur</i> (Cleve) F.Gómez 2013*
		GONIODOMATACEAE Lindemann, 1928	<i>Triadinium</i> Dodge, 1981	<i>Triadinium polyedricum</i> (Pouchet) Dodge, 1981*

Systematic position

Kingdom CHROMISTA Cavalier-Smith 1981
Infrakingdom ALVEOLATA Cavalier-Smith, 1991
Phylum MYZOOZOA Cavalier-Smith & Chao 2004
Subphylum DINOZOA Cavalier-Smith 1981
Infraphylum DINOFLAGELLATA Bütschli, 1855
Class DINOPHYCEAE Fritsch, 1927
Order PERIDINIALES Haeckel, 1894
Family PROTOPERIDINIACEAE J.P Bujak & E.H
Davies
Genus *Protooperidinium* Bergh, 1881

1. *Protooperidinium depressum* (Bailey) Balech 1974

Diagnostic characters: Thecate dinoflagellate. Body surface granular with single large apical horn and two smaller diverging antapical spines. Epitheca concave and depressed obliquely (Fig. 2a).

Distribution: Cosmopolitan. Andhra Pradesh, India⁵, Gulf of Mannar⁹, Tamil Nadu coast, India¹⁰, South Andaman region, India²⁰, Great Nicobar Island, Andaman Sea²¹, Bay of Bengal¹¹⁻¹³, North Arabian Sea^{22,23}, Yellow Sea, East China Sea²⁴, ROPME Sea Area, Iranian coastal waters²⁵, Mediterranean waters²⁶, Black Sea²⁷, South-eastern Mexican Pacific Ocean²⁸, Brazil waters²⁹, New Zealand coastal waters³⁰, Australian waters³¹, Caribbean Sea³².

This species was recorded from the stations APK1, APK2, APK4 (surface and subsurface depths) and APK3 (subsurface depths) in Kakinada waters from the state of Andhra Pradesh.

2. *Protooperidinium brochii* (Kofoid & Swezy) Balech, 1974

Diagnostic characters: Thecate dinoflagellate with roundish body. Single small apical horn and two small slightly curved divergent antapical horns present. Presence of ring-like, almost circular girdle. Ventral portion of the body, between two antapical horns hollowed out (Fig. 2b).

Distribution: South Andaman region, India²⁰, Indian Ocean¹¹, Mediterranean waters²⁶, Black Sea²⁷, South-eastern Mexican Pacific Ocean²⁸, Brazil waters²⁹, New Zealand coastal waters³⁰, Australian waters³¹, South China Sea²⁴.

This species was recorded from the station APK1 (surface and subsurface depths), APK3 and APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

3. *Protooperidinium leonis* (Pavillard) Balech 1974

Diagnostic characters: Thecate dinoflagellate with pentagon shaped body. Presence of two small

antapical spines. Length and width of body almost of the same dimension. Presence of broad-based spines on body surface. Outline of epitheca straight edged. Surface of epitheca slightly concave in the ventral region (Fig. 2c).

Distribution: Gulf of Mannar⁹, Tamil Nadu coast, India¹⁰, South Andaman region, India²⁰, Bay of Bengal¹²⁻¹³, North Arabian Sea²³, Great Nicobar Island, Andaman Sea²¹, Andaman Sea, Indian Ocean¹¹, ROPME Sea Area, Iranian coastal waters²⁵, Black Sea²⁷, Yellow Sea²⁴, Mediterranean waters²⁶, Mexican waters, Pacific Ocean³³, Brazil waters²⁹, New Zealand coastal waters³⁰, Australian waters³¹.

This species was recorded from the station APK1 (surface waters), APK2, APK3 (subsurface depths), and APK4 (surface and subsurface depths) in Kakinada waters from the state of Andhra Pradesh.

4. *Protoperidinium ovum* (J. Schiller) Balech 1974

Diagnostic characters: Thecate dinoflagellate with ovoid shaped body. Apical horn short but prominent, separated from ovoid cell. Presence of two short antapical horns, which run parallel to each other and are slightly curved. Presence of a hypothecal pore. Presence of prominent left sulcal list (Fig. 2d).

Distribution: Bay of Bengal¹², Andaman Sea¹¹, North Arabian Sea²², Mediterranean waters²⁶, Black Sea²⁷, Mexican waters, Pacific Ocean³³, Brazil waters²⁹, Canary Islands³⁴, Australian waters³¹.

This species was recorded from the station APK1 (surface waters), APK2, APK3 (subsurface depths), and APK4 (surface and subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

5. *Protoperidinium pallidum* (Ostenfeld) Balech 1973

Diagnostic characters: Pear shaped elongated, dorsoventrally compressed body. Single short apical horn and two small diverging antapical spines present. Reticular body surface (Fig. 2e).

Distribution: Coastal and oceanic from cold temperate to warm temperate waters; worldwide distribution. Tamil Nadu coast, India¹⁰, South Andaman region, India²⁰, Bay of Bengal¹³, Indian Ocean¹¹, Yellow Sea, East China Sea²⁴, ROPME Sea Area, Iranian coastal waters²⁵, Mediterranean waters²⁶, Black Sea²⁷, Mexican waters, Pacific Ocean³³, New Zealand coastal waters³⁰, Australian waters³¹.

This species was recorded from the stations APK1, APK2 (surface and subsurface depths), APK3

and APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Family PERIDINIIDA incertae sedis

Genus *Spiraulax* Kofoid, 1911

6. *Spiraulax kofoidii* H.W Graham, 1942

Diagnostic characters: Fusiform body shape. Presence of well-developed theca with areolated surface. Presence of a distinct antapical spine, narrow cingulum, and a well-formed sulcal lists (Fig. 2f).

Taxonomic Remarks: This species was formerly described and placed under the order Gonyaulacales but now is shifted to a temporary family Peridinnida incertae sedis under the order Peridiniales.

Distribution: Tamil Nadu coast, India¹⁰, Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵, Brazil waters²⁹, Canary Islands³⁴, Caribbean Sea³², Mexican waters, Pacific Ocean³³, Australian waters³¹.

This species was observed from the station APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Order DINOPHYSIALES Lindemann, 1928

Family DINOPHYSIACEAE Stein, 1883

Genus *Dinophysis* Ehrenberg, 1839

7. *Dinophysis caudata* Saville-Kent, 1881

Diagnostic characters: Thecate dinoflagellate with an areolated surface. Body shaped like irregular trapezium. Left sulcal list spans the length of main body. Dorsal body margin curves gradually, and ventral margin runs straight along the body. Posterior ventral projection possesses a characteristic finger-like structure (Fig. 2g & h).

Distribution: Sundarbans³⁶, Tamil Nadu coast, India^{8,10}, Andhra Pradesh, India⁵⁻⁶, Gulf of Mannar⁹, Bay of Bengal^{3,8}, North Arabian Sea²³, Indian Ocean¹¹, Australian waters³¹, ROPME Sea Area, Iranian coastal waters²⁵, Black Sea²⁷, Korean waters and the East China Sea, Pacific Ocean³⁷, Eastern Pacific Ocean³⁸, Peru waters³, Argentine Sea³⁹, Mediterranean waters²⁶, Caribbean Sea³², Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵.

This species was recorded from the station APK1, APK2 (surface and subsurface depths), and APK4 (subsurface depths) in Kakinada waters from the state of Andhra Pradesh.

Genus *Ornithocercus* Stein, 1883

8. *Ornithocercus magnificus* Stein 1883

Diagnostic characters: Thecate dinoflagellate with slightly asymmetrical, round cell body. Scattered pores present on the body surface. Presence of left sulcal list. Presence of 5 main posteriorly positioned ribs, of which 3 ribs situated antapically. These main ribs form anastomoses between them (Fig. 2i).

Distribution: Cosmopolitan in warm temperate to tropical waters. Tamil Nadu coast, India¹⁰, Bay of Bengal¹²⁻¹³, Great Nicobar Island, Andaman Sea²¹, Kochi coast, India⁴⁰ and Karnataka coast, India⁴¹, Maldives³⁹, Indian Ocean¹¹, ROPME Sea Area, Iranian coastal waters²⁵, Mediterranean waters²⁶, Gulf of Mexico⁴², Caribbean Sea³², Mexican waters, Pacific Ocean³³, Brazil waters²⁹, Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵, Eastern Pacific Ocean³⁸, Australian waters³¹.

This species was recorded from the stations APK2 and APK3 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Family OXYPHYSACEAE Sournia, 1984

Genus *Phalacroma* Stein 1883

9. *Phalacroma doryphorum* Stein 1883

Diagnostic characters: Thecate dinoflagellate with a broad round convex epitheca and a narrowed, asymmetrical hypotheca. From the hypotheca arises a triangular antapical spine. Cell body ovoid in shape. Presence of a convex cingulum (Fig. 2j).

Distribution: Bay of Bengal¹², Andaman Sea¹¹, Maldives³⁹, Indian Ocean¹¹, Eastern Pacific Ocean³⁸, Gulf of Mexico⁴², Mexican waters, Pacific Ocean³³, Australian waters³¹, Mediterranean waters²⁶, Portugal⁴³, Canary Islands, Atlantic Ocean³⁴.

This species was recorded from the stations APK3 and APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Order GONYAULACALES Taylor, 1980

Family CERATIACEAE Kofoid, 1907

Genus *Tripes* Bory de Saint-Vincent, 1823

10. *Tripes inflatus* (Kofoid), F. Gómez, 2013

Diagnostic characters: Thecate, elongated and spindle-shaped dinoflagellate. Body inflated slightly. Epitheca tapers to a single apical horn. Hypotheca forms a prominent left antapical horn, which abruptly curves at the distal end, and a reduced right antapical

horn. The left antapical and the apical horns are equal in length (Fig. 2k).

Distribution: Tamil Nadu coast, India¹⁰, Gulf of Mannar⁹, North Arabian Sea²³, Indian Ocean¹¹, Mediterranean waters⁴², Mexican waters, Pacific Ocean³³, West Indies, the Antilles⁴⁴, New Zealand coastal waters³⁰, Australian waters³¹.

This species was recorded from the station APK1 (surface waters), APK2, APK3 (surface and subsurface depths), and APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

11. *Tripes trichoceros* (Ehrenberg) F. Gómez, 2013

Diagnostic characters: Thecate dinoflagellate with small, almost flat, subtrapezoidal body. Presence of thin elongated apical and antapical horns. Apical horn straight and long. Antapical horns bend at an angle and run lateral-posteriorly. Due to the bend, a shallow notch is formed between the proximal parts of the antapical horns. Distally, all three horns are parallel to each other (Fig. 2l).

Distribution: Sundarbans³⁶, Tamil Nadu coast, India^{8,10}, Gulf of Mannar⁹, Bay of Bengal^{6,13}, Great Nicobar Island, Andaman Sea²¹, Indian Ocean¹¹, ROPME Sea Area, Iranian coastal waters²⁵, Mediterranean waters²⁶, Black Sea²⁷, Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵, Gulf of Mexico¹⁵, Mexican waters, Pacific Ocean³³, Australian waters³¹, Caribbean Sea³².

This species was widespread and recorded from the stations APK1, APK2, APK3 (surface and subsurface depths), and APK4 (subsurface depths) in Kakinada waters, from the state of Andhra Pradesh.

12. *Tripes candelabrum* (Ehrenberg) F. Gómez, 2013

Diagnostic characters: Thecate dinoflagellate with surface pores and a cell body broader than long. Presence of a tapering, distinct apical horn arising from the epitheca. Presence of two short diverging antapical horns arising from the hypotheca, with one horn slightly longer than the other. This is a chain-forming species (Fig. 2m).

Distribution: Warm temperate to tropical waters; worldwide distribution. Tamil Nadu coast, India¹⁰, Andaman Sea^{11,21}, Indian Ocean¹¹, ROPME Sea Area, Iranian coastal waters²⁵, Mediterranean waters²⁶, Black Sea²⁷, Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵, Brazil waters²⁹, Gulf of Mexico¹⁵,

Mexican waters, Pacific Ocean³³, New Zealand coastal waters³⁰, Australian waters³¹.

This species was recorded from the stations APK1, APK2, APK3 (surface and subsurface depths), and APK4 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

13. *Tripos vultur* (Cleve) F. Gómez, 2013

Diagnostic characters: Thecate dinoflagellate with robust cell body. Epitheca forms a straight, tapering apical horn, while from the hypotheca arises two antapical horns bent at abrupt angles with respect to the body. The antapical horns are directed outwards. The specimens have been seen forming chains (Fig. 2n & o).

Distribution: South Andaman region, India²⁰, Great Nicobar Island, Andaman Sea²¹, Bay of Bengal¹³, Indian Ocean¹¹, Mediterranean waters²⁶, Vitória-Trindade Seamount Chain, South Atlantic Ocean³⁵, Brazil waters²⁹, Mexican waters, Pacific Ocean³³, Australian waters³¹.

This species was recorded from the station APK3 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Family GONIODOMATACEAE Lindemann, 1928

Genus *Triadinium* Dodge, 1981

14. *Triadinium polyedricum* (Pouchet) Dodge, 1981

Diagnostic characters: Thecate dinoflagellate with an areolated surface. Body shape polyhedral. The equatorial girdle encompassed by conspicuous lists. Surrounding the apical pore are three almost equal-sized plates, and near the antapex three additional plates are present. Antapex is flattened. Presence of crested thecal sutures. In some forms, a megacytic growth process takes place, altering the shape of some plates, since this growth produces wide pore-free bands (Fig. 2p).

Distribution: South Andaman region, India²⁰, Andaman Sea^{3,21}, Bay of Bengal¹³, Indian Ocean¹¹, ROPME Sea Area, Iranian coastal waters²⁵, Black Sea²⁷, Caribbean Sea³², Mexican waters, Pacific Ocean³³, New Zealand coastal waters³⁰, Australian waters³¹.

This species was recorded from the stations APK1, APK3, APK4 (surface and subsurface depths), and APK2 (subsurface depths) for the first time in Kakinada waters, and in the state of Andhra Pradesh.

Conclusion

During the winter monsoon research survey in Bay of Bengal coastal waters, 14 species of dinoflagellates

belonging to seven genera and six families of Dinophyceae have been recorded from Kakinada coast. Of the 14 species, 10 species are new records from the coastal state of Andhra Pradesh: *Protoperidinium brochii*, *P. ovum*, *P. pallidum*, *Ornithocercus magnificus*, *Phalacroma doryphorum*, *Triadinium polyedricum*, *Tripos candelabrum*, *T. inflatus*, *T. vultur* and *Spiraulax kofoidii*. The average numerical abundance ranged from 154 to 200 ind./L, with a notable gradual shift in number from near coast to away from coast. No particular correlation has been established between the dinoflagellate community and the environmental factors (except for a few species). As understood, the very limited correlations between the biotic (species composition) and abiotic factors (environmental parameters) in a pelagic system do not convincingly give a clear picture of the interplay between the two. Possibly, prolonged sampling with expanded study area may be useful in this regard. As it stands, this study gives a snapshot idea of the dinoflagellate species community in the selected area of study in the winter monsoon season. Expanding from this preliminary investigation, further studies are required in the coastal region of Kakinada to compare seasonal diversity as well as inter-annual variations in species diversity and to delineate the dinoflagellate community structure in the study area.

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Conflict of Interest

Authors declare no conflict of interest of any financial and academic nature in this work.

Ethical Statement

Human subjects or animals were not involved in this study.

Authors Contributions

AB: Sample collection & identification, manuscript writing, methodology, formal analysis, and manuscript

editing; JP: Conceptualisation of the manuscript, sample collection & identification, manuscript writing, methodology, funding acquisition, and overall supervision; and AS: Sample collection and manuscript writing & editing.

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