

# Taxonomy and biodiversity of the genus *Oscillatoria* Vauch. ex Gom. (Cyanoprokaryota: Oscillatoriales) with ecological notes from Hooghly in West Bengal, India

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**Abstract.** Research articles in the reference list regarding investigation or exploration of Oscillatoriales exhibited that taxonomic study of freshwater blue-green algae has been a subject of interest of research workers and professional scientists for more than one century in India. *Oscillatoria* Vauch. ex Gom. (Cyanoprokaryota: Oscillatoriales) is a dominant and ubiquitous blue-green alga in Hooghly District of West Bengal, India. Its thallus consists of unsheathed trichome and contains more than 20 cells in a trichome. The recent study was dealt with the taxonomic enumeration of five species of the genus (*O. princeps*, *O. curviceps*, *O. sancta*, *O. limosa*, and *O. jenensis*) which were collected from different freshwater aquatic ecosystems of this district and they were described with ecological data, geographical distributions and colored microphotographs. Here, the relationships between the water chemistry and their occurrences had been also discussed. The analysis of important physico-chemical properties of water revealed that species of *Oscillatoria* prefer to grow in those water bodies prevailing alkaline pH, sufficient to meet the essential nutrients and contain hard and polluted water.

**Keywords:** Taxonomy; *Oscillatoria*; West Bengal; India.

## Introduction

Indeed, blue-green algae (Cyanoprokaryota) are one of the most successful and primitive microbes or plant groups in our planet since the origin of life. They resemble with eukaryotic algae as well as prokaryotic bacteria because they share some common features of both the groups and included in the Kingdom Monera by Whittaker (1969). Blue-green algae are basically aerobic photoautotrophs, although they may be able to live anaerobically. Only warm temperature, water, CO<sub>2</sub>, inorganic substances like nitrogen and phosphorus and sunlight are

sufficient for abundant growth, reproduction and to complete their life cycles (Kasthuri et al., 2016). They are considered the first organism to release elemental oxygen (O<sub>2</sub>) into the primitive atmosphere (Gupta et al., 2006) and primary colonizer in bare areas of rock and soil (Issa et al., 2014). Ultraviolet ray absorbing sheath and a combination of green and unique blue pigments, probably increase their fitness in the exposed land environment (Mur et al., 1999). The morphological simplicity and occurrence of polymorphisms (variations) in nature sometimes make this plant group difficult (Roger and Reddy, 1984) for identifications

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under light microscopy. They show variations in thallus organizations (unicellular, colonial to filamentous) and measurement of vegetative as well as reproductive structures due to response of changes in environmental conditions. They can thrive or adapt in adverse climatic conditions of any ecological ecosystems, being photosynthetic prokaryotes (Seal et al., 2015; Halder, 2016a) and possessing simple thallus structures. *Oscillatoria* Vauch. ex Gom. is a very common and dominant blue-green algal genus of Cyanophyceae and it has been found to occur in almost all the types of freshwater habitats like ponds, moats, irrigation channels, water logged rice fields, lakes, rivers, canals or in any polluted water bodies of urban areas throughout the world. It is a highly pollution tolerant blue-green alga (Patrick, 1965). Occasionally, they are noticed on water surface as dark blue or black algal mass/scum and their colonies may be buoyant as containing of air bubbles. Therefore, they can blow by gentle wind from one place to another in aquatic bodies. Globally, there are 304 species of this genus which are taxonomically accepted in algae database (Guiry and Guiry, 2016) and till date ca. 128 species of this genus have been reported from different places of India (Tiwari et al., 2007). The species of *Oscillatoria* grow in monsoon. In winter, they are mostly observed in water channels, sewage water while in summer their distribution observed only in perennial drains and few water reservoirs (Kesarwani et al., 2015). The genus is characterized by these common features, i) thallus is predominantly blue-green or may be blackish, grayish, olive-green; consists of trichome and sometimes forms macroscopic mat, rarely solitary or in small groups, ii) trichomes flat, simple, uniseriate, usually fine, straight or slightly wavy, cylindrical and show gliding motion under light, iii) constricted or not constricted at cross walls, attenuated or not attenuated to the ends, iv) sheath absent or thin, colorless only in suboptimal (extreme) conditions, v) cells always shorter than wide, without aerotopes but with fine granulation (sometimes prominent at the cross walls), vi) apical or

end cells rounded, hemispherical, sometimes capitate or with narrow calyptas, vii) vegetative reproduction occurs by means of cell division that is perpendicular to the long axis of a trichome or formation of hormogonia or trichome disintegration, e viii) heterocyst is lacking in trichomes (Komárek and Anagnostidis, 2005).

Seasonal variations of water properties (Halder, 2016b) and tropical climatic/environmental conditions (Halder and Sinha, 2013a,b; Halder, 2015a) play important roles in the distribution of cyanobacterial algae in natural water bodies. Few ecological parameters like temperature, light intensity and dissolved solids have a great impact on growth stage and occurrence of blue-green algae (Kullberg, 1977). Maximum growth is attained by most blue-green algae in summer i.e. at higher temperature in comparison to green algae and diatoms (Robarts and Zohary, 1987; Mur et al., 1999). A low ratio between nitrogen and phosphorus compounds in water may favor the development of this algal group (Smith, 1983; Harris et al., 2016).

The alga has a considerable importance to human beings. Ecologically, it plays crucial role in the treatment of sewage effluents, bioremediations and nutrient recycling. Besides these, the alga also showed *in vitro* antimicrobial (Prabakaran, 2011) and antibacterial effects against the pathogenic microbes (Abd El-Aty et al., 2014) due to having antimicrobial substances like terpenes, phenols and phenolic compounds in their cells like other algae (Halder and Sinha, 2014a; Sinha et al., 2015; Halder, 2015b). Thus, it may be utilized as a promising source to manufacture antibacterial drugs in pharmaceutical industry in future. It should be mentioned that recently, different species of Cyanobacteria have been using for extraction of cyanobacterial restriction endonucleases that generally recognize palindromic sequences in DNA, cleave within or near their recognition sequences and produce DNA-fragments of different lengths. Among them, *AvaI* is well known restriction enzyme from *Anabaena*

*variabilis*. Saravanan et al. (2003) purified (through column chromatography) and characterized a new type II restriction endonuclease, *OfoI* from a nonheterocystous cyanobacterium *Oscillatoria foreaui* and the recognition sequence has been detected with the help of primer extension analysis. This enzyme recognizes and cleaves the palindromic hexanucleotide sequence 5'-C↓YCGRG-3' in DNA and producing 5'-protruding ends of defined sizes.

There are many detailed taxonomic floristic reports and information on the genus from India including those of Kamat (1963), Anand (1989), Tiwari (1975), Mahajan and Patel (1989), Kumawat and Jawale (2006), Adhikary (2007), Goyal et al. (2008), Deka and Sarma (2011), Kesarwani et al. (2015) and many other published scientific papers. Abroad India, the commendable algological work of Komarek and Anagnostidis (2005) and McGregor (2007) may be mentionable regarding on the Order Oscillatoriales. Some previous workers who contributed on the taxonomy of the genus from this state (West Bengal) may be cited Martens (1871), Prain (1905), Biswas (1926, 1932), Pal and Santra (1985, 1987), Santra et al. (1988), Sen and Gupta (1987, 1998), Sen and Naskar (2003), Naskar et al. (2008), Chakraborty et al. (2010), Sen Sarkar et al. (2013). The main objective of this study was to investigate the biodiversity of the genus *Oscillatoria* Vauch. ex Gom. from Hooghly, West Bengal, India.

## Materials and Methods

### Sample collection

Algal samples were collected from freshwater bodies located in five different sites viz. Khanyan (site-1), Serampore (site-2), Chinsurah (site-3), Chandannagar (site-4), and Mogra (site-5) of Hooghly district (20° 30' 32"-23° 01' 20" N and 87° 30' 20"-80° 30' 15" E) in West Bengal, India. The map of Hooghly district had

been already provided earlier in few research articles (Halder and Sinha, 2014b; Sinha and Halder, 2014; Halder, 2015c).

### Microscopy

Microscopic study of the five species of *Oscillatoria* Vauch. ex Gom. was made by examining them under Olympus microscope (Model-CH20i). Microphotographs were taken using Canon Power Shot A480 camera. The samples were preserved in 4% formalin and the voucher specimens were deposited in the Departmental Herbarium of R. P. M. College, Uttarpara, Hooghly, West Bengal.

### Identification

This was done with the aid of relevant monographs, manuals and recent literatures (Gomont, 1892; Geitler, 1932; Desikachary, 1959; Prescott, 1962; Prasad and Srivastava, 1992; Gupta, 2005; Jain, 2015; Kesarwani et al., 2015).

### Water analysis

The temperature (°C) and pH of the freshwater were recorded at the sites with the help of mercury thermometers and portable pH meter. The other limnological parameters such as nitrate-nitrogen (NO<sub>3</sub>-N), phosphate (PO<sub>4</sub><sup>3-</sup>), biological oxygen demand (BOD), chemical oxygen demand (COD) and total hardness (TH) of water were estimated following the standard method (APHA, 2005).

## Results

On the basis of traditional morphological features a total number of five species of the above said genus had been identified and described in the present work. All these species had been collected from freshwaters. Among them, two species (*O. princeps* and *O. limosa*) were most common regarding their abundances in this locality.

### Key to the species

1. Trichomes more than 20 µm in diameter ..... *O. princeps*
  - 1'. Trichomes less than 20 µm in diameter ..... 2
2. Trichomes hooked at the apex ..... *O. curviceps*
  - 2'. Trichomes straight or slight bent ..... 3
3. Trichomes cylindrical with constrictions, apex attenuated and capitate with a calyptras ..... *O. sancta*
  - 3'. Trichomes not so ..... 4
4. Trichomes straight, not attenuated and apical cell rounded or often convex ..... *O. limosa*
  - 4'. Trichomes broader (above 17.0 µm), apex widely rounded or sometimes conical-rounded ..... *O. jenensis*

1. *Oscillatoria sancta* (Kütz.) Gom. in Ann. Sci. Nat. Bot., Ser. 7, 16: 209, 1892; Desikachary, Cyanophyta 203, pl. 42, fig. 10, 1959; Prasad and Srivastava, Fr. Water Al. Fl. Andaman and Nicobar Islands v. I. p. 70, pl. 9, fig. 8, 1992; Kesarwani et al., in Phykos 45 (1): 21, 23-24, pl. 1, fig. 18; pl. 3, fig. 43; pl. 4, fig. 44, 2015 (Figure 1. A).

**Description:** Thallus brownish or bluish-green and shining; trichome single, straight, elongated, one end briefly attenuated; cells 13.0-15.5 µm broad and shorter than broad; 4.0-5.0 µm long, distinctly constricted at cross walls and granulated; cell contents light blue-green, homogeneous; apical cell hemispherical and attenuated; cell wall thick.

**Habitat:** Free floating in a pond water at Khanyan (23° 04' N, 88° 32' E).

**Date of collection:** 07.06.2013; Collection number: NH 1280.

**Indian distribution:** Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Delhi, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Andaman and Nicobar Islands, Bihar, Orissa, Arunachal Pradesh, Meghalaya, Tripura, Assam, Sikkim (Gupta, 2012); West Bengal (Banerji, 1938; Kachroo, 1959; Sen and Gupta, 1998, Sikdar and Keshri, 2014).

**Other countries:** It was reported from Britain (Whitton et al., 2003) in Europe; Arkansas (Smith, 2010) in North America; Argentina (Rodriguez et al., 2006) in South America; Cuba (Comas Gonzalez and Moreira González, 2010) in Caribbean Islands; Mauritius (Silva et al., 1996) in Africa; Queensland (Day et al., 1995) in Australia (Giury and Guiry, 2016).

**Remarks:** Trichome constricted at cross wall, apical cell somewhat capitates or sub-capitates, with a calyptras; cells 11-13-(20) µm broad, 4-5 µm long; slightly constricted at the cross walls with conspicuous granules; cell contents coarsely granular-all these species distinguishing characters were observed in this specimen and confirmed that the present species is *Oscillatoria sancta*.

2. *O. princeps* Vauch. ex Gom.; Vaucher in Hist. Conf. 190, pl. 15, fig. 2, 1803; Gomont in Ann. Sci. Nat. Bot., Ser. 7, 16: 201, 206, pl. 6, fig. 9, 1892; Geitler, Kryptogamen-Fl. 947, figs. 598a, 601c-g, 1932; Desikachary, Cyanophyta 210, pl. 37, figs. 1, 10-11, 13-14, 1959; Prescott, Al. Western Great Lakes 489, pl. 110, fig. 1, 1962; Prasad and Srivastava, Fr. Water Al. Fl. Andaman and Nicobar Islands v. I. p. 67, pl. 8, fig. 8 & 10, 1992; Kesarwani et al., in J. Indian Bot. Soc. 94 (1 & 2): 42-43, 2015 (Figure 1. B-C).

**Description:** Thallus blackish blue-green or dark blue-green; trichome solitary, floating, mostly straight or slightly curved at apex, rigid and longer; 25.0-28.0 µm broad and cells 1/5 to 1/7 times as long as broad or more shorter, 3.0-4.0 µm long, cell content olive blue-green, homogeneous, without gas vacuoles, finely granulated, terminal end slightly attenuated, ± bent, truncate with wavy margins and cell wall thick.

**Habitat:** Free floating in a reservoir water at Serampore (22° 76' N, 88° 34' E).

**Date of collection:** 11.06.2013; Collection number: NH 1283.

**Indian distribution:** Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Delhi, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Andaman and Nicobar Islands, Bihar, Orissa, Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Tripura, Assam, Sikkim (Gupta, 2012); West Bengal (Biswas, 1925, 1927, 1949; Banerji, 1938; Kachroo, 1959; Sinha and Mukherjee, 1975; Santra et al., 1988; Sen and Gupta, 1998; Sen and Naskar, 2003; Naskar et al., 2008; Chakraborty et al. 2010; Sikdar and Keshri, 2014).

**Other countries:** It was recorded from Britain (Whitton et al., 2003), Germany (Täuscher, 2015) in Europe; Arkansas (Smith, 2010) in North America; Argentina (Tell, 1985) in South America; Cuba (Comas Gonzalez and Moreira González, 2010) in Caribbean Islands; Mozambique (Silva et al., 1996) in Africa; New South Wales (Day et al., 1995) in Australia (Guiry and Guiry, 2016).

**Remarks:** Trichome is much broader (above 20 µm) than other species and slightly or briefly attenuated at the apices and slight bent; cells 25-55-(80) µm broad, 3-8.7 µm long and not constricted at the cross walls and not granulated but cell content is granular. These important characteristics resemble the present specimen as *O. princeps*.

3. *Oscillatoria limosa* (Dillw.) C. Ag. in Disp. Alg. Suec. 4: 35, 1812 as

*Conferva limosa* Dillw.; Geitler, Kryptogamen-Flora 944, fig. 598d, 1932; Desikachary, Cyanophyta 206, pl. 42, fig.11, 1959; Prescott, Al. Western Great Lakes 489, pl. 109, fig. 17, 1962; Prasad and Srivastava, Fr. Water Al. Fl. Andaman and Nicobar Islands v. I. 65, pl. 9, figs. 4, 14, 1992; Gupta, Al. Fl. Dehradun District Uttaranchal 238, pl. 62, fig 9, 2005 (Figure 1. D-E).

**Synonymous:** *Oscillatoria limosa* C. Ag. ex Gom.

**Description:** Thallus dark blue-green or light yellow-green; trichome straight, solitary or form mats; trichome 13.0-14.5 µm broad and 3.0-5.0 µm long; not attenuated and without constriction at the cross-walls; apical cell often convex with thickened outer cell wall, flat-rounded or obtuse-rounded, no calyptras; cell content olive-green, finely granulated, granules uniformly distributed, rarely with thin and colorless sheath.

**Habitat:** Free floating in water logged rice field at Chinsurah (22° 88' N, 88° 39' E).

**Date of collection:** 03.09.2013; Collection number: NH 1314.

**Indian distribution:** Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Bihar, Orissa, Manipur, Meghalaya, Nagaland, Assam, (Gupta, 2012); West Bengal (Martens, 1871; Prain, 1905; Biswas, 1926; Kachroo, 1959; Sen and Gupta, 1987, 1998; Santra et al., 1988; Sen and Naskar, 2003; Naskar et al., 2008; Chakraborty et al. 2010, Sen Sarkar et al., 2013; Sikdar and Keshri, 2014).

**Other countries:** Britain (Whitton et al., 2003), Germany (Täuscher, 2015), Italy (Di Pippo et al., 2014) in Europe; Arkansas (Smith, 2010), Mexico (Figueroa-Torres et al., 2015) in North America; Argentina (Tell, 1985), Brazil (Bicudo and Martau, 1974) in South America; Cuba (Comas Gonzalez and Moreira González, 2010) in Caribbean Islands; Mozambique (Silva et al., 1996), Egypt (Nassar and Khairy, 2014) in Africa; New South Wales

and Queensland (Day et al., 1995) in Australia.

**Remarks:** Trichome straight; cells 13-18-(20)  $\mu\text{m}$  in diameter, 3.7-5.0  $\mu\text{m}$  long which are not constricted at the cross walls, cell content usually granular-these features come close to the species *O. limosa*.

4. *Oscillatoria curviceps* C. Ag. ex Gom. in Syst. Alg. 68, 1824; Desikachary, Cyanophyta 209, pl. 38, fig. 2; pl. 39, figs. 9-10 and pl. 42, fig. 10, 1959; Prasad and Srivastava, Fr. Water Al. Fl. Andaman and Nicobar Islands v. I. 62, pl. 9, fig. 12, 1992; Jain in J. Exp. Biol. Agric. Sci. 3(2):133, pl.1, fig. 4, 2015 (Figure 1. F).

**Description:** Trichomes free floating, blue-green, forming an expanded mass; cells 11.0-13.0  $\mu\text{m}$  broad, cells 1/3–1/6 as long as broad, 3.0-5.0  $\mu\text{m}$  long, often granulate at cross walls, trichomes straight or terminally curved; end cell broadly rounded often with lightly thickened outer membrane, not capitates and not constricted at cross walls.

**Habitat:** Drain water at Chandannagar (22° 86' N, 88° 36' E).

**Date of collection:** 18.08.2013; Collection number: NH 1305.

**Indian distribution:** Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Andaman and Nicobar Islands, Bihar, Orissa, Assam (Gupta, 2012); West Bengal (Santra et al., 1988; Sen and Naskar, 2003; Naskar et al., 2008).

**Other countries:** Germany (Täuscher, 2015), Romania (Caraus, 2012) in Europe; Arkansas (Smith, 2010) in North America; Argentina (Tell, 1985) in South America; Mozambique (Silva et al., 1996), Egypt (Nassar and Khairy, 2014) in Africa; New South Wales (Day et al., 1995) in Australia; New Zealand (Broady and Merican, 2012), Singapore (Pham et al., 2011); Nepal (Rai et al., 2010), Bangladesh (Silva et al., 1996) in Asia.

**Remarks:** Trichome hook shaped, mostly forming an expanded blue-green mass, apical cell broadly rounded, not capitates. Cells 10-14-(17)  $\mu\text{m}$  in diameter, 3.0-5.0  $\mu\text{m}$  long; not constricted at the cross walls, which may be granulate. The present specimen contains all these distinguishing characters and therefore, confirmed that this species is *O. curviceps*.

5. *Oscillatoria jenensis* G. Schmid in Jahrb. Wiss. Bot. 60: 572, figs. 1-2, 1921; Kamat in phykos 13: 29, 1974; Kesarwani et al., in Phykos 45(1): 27, pl. 2, fig. 27, 2015 (Figure 1. G-H).

**Description:** Trichome flat, blue-green or yellow-green, solitary, straight but with short attenuation at end; terminal cell often pale olive-green, sometimes capitate or with narrow calyptras or with two thorn-like structures, widely rounded or sometimes conical-rounded, often asymmetrical; 17.5-20.0  $\mu\text{m}$  wide, 2.0-4.0  $\mu\text{m}$  long, constricted or not constricted at the cross walls; cells without aerotopes but with prominent granules; reproduction by trichome disintegration.

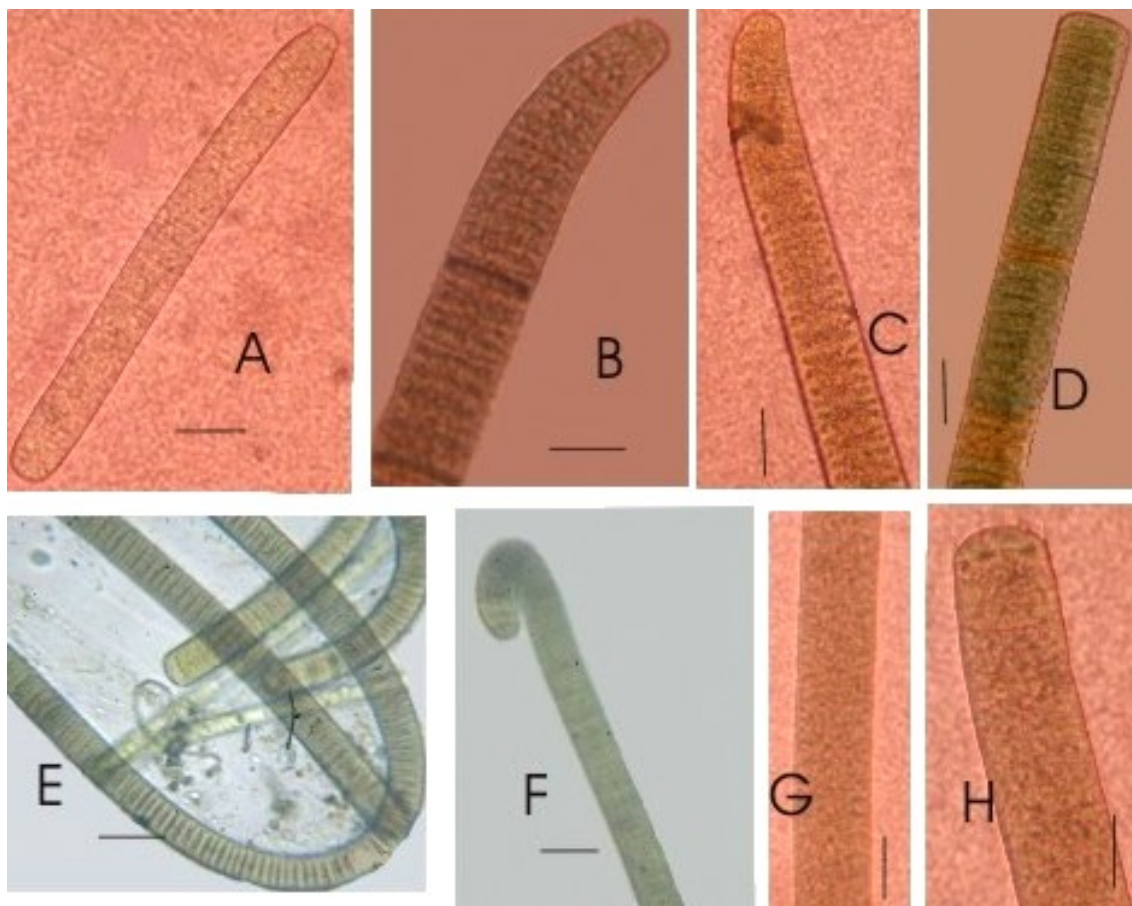
**Habitat:** Free floating in moat water at Mogra (22° 97' N, 88° 37' E).

**Date of collection:** 14.04.2013; Collection number: NH 1265.

**Indian distribution:** Maharashtra (Kamat, 1974); Uttar Pradesh (Kesarwani et al., 2015).

**Other countries:** Romania (Caraus, 2012), Spain (Alvarez-Cobelas and Gallardo, 1988) in Europe; Cuba (Comas González, 2008) in Caribbean Islands; Mozambique (Silva et al., 1996) in Africa; Queensland (Bostock and Holland, 2010) in Australia; Pakistan (Lashari et al., 2009) in Asia.

**Remarks:** The present species is closely related and looks like *O. princeps* var. *pseudolimosa* Ghose but cellular measurements and other morphological features coincided with the type species of *O. jenensis*. It appears to be new report from this state (West Bengal).



**Figure 1.** A. *Oscillatoria sancta*, B-C. *O. princeps*, D-E. *O. limosa*, F. *O. curviceps*, G-H. *O. jenensis*. Bar = 15  $\mu$ m.

## Discussion

Algae generally grow in water bodies and constitute the major group of primary producers (Halder, 2015d) although, global biodiversity and natural habitats of algae are being lost at an unprecedented rate as a result of anthropogenic human activities. Therefore, measurements must be taken now to combat this trend and also for their conservations. A key goal of taxonomic investigation is the exploration of biodiversity (Sinha et al., 2016) of available or existing species/genera from a particular geographical area, locality or region or to know the present status of specific species or genera/genus from those places. In this

study, taxonomic results showed that the genus is cosmopolitan in distribution through out the district and showed a great diversity in respect of their species richness. From floristic survey in this region, a total number of five species had been documented and described. These are *O. sancta* (Kütz.) Gom., *O. princeps* Vauch. ex Gom., *O. limosa* (Dillw.) C. Ag., *O. curviceps* C. Ag. ex Gom. and *O. jenensis* G. Schmid. Among them, *O. princeps* and *O. limosa* were continuous in distribution (dominant) among the four seasons while *O. sancta* was found throughout the year except winter and *O. curviceps* was less frequent but *O. jenensis* was rare in phenology from this area and represented only in summer (Table 1).

**Table 1.** Showing species phenology and abundances.

	Species	Species phenology				Abundance
		Summer (Mar-May)	Monsoon (Jun-Aug)	Post-monsoon (Sept-Nov)	Winter (Dec-Feb)	
1	<i>O. sancta</i> (Kütz.) Gom.	+	+	+	-	Frequent
2	<i>O. princeps</i> Vauch. ex Gom.	+	+	+	+	Dominant
3	<i>O. limosa</i> (Dillw.) C. Ag.	+	+	+	+	Dominant
4	<i>O. curviceps</i> C. Ag. ex Gom.	-	+	+	-	Frequent
5	<i>O. jenesis</i> G. Schmid.	+	-	-	-	Rare

The symbol + represented present while – represented absent of species.

They were all found only in fresh water habitats particularly in lentic water bodies. In the taxonomy of blue-green algae, measurement of trichome and cell size play an important role at the species level identifications. According to Roger and Reddy (1984), in nature numerous morphological variations or deviations which are not genetically stable exist within specific algal taxa. This opinion is found to be true in this study because *Oscillatoria* exhibited so. Here, morphological characters like colour, measurement of width of trichome, nature of apical cell, constriction and granulation have been taken as the distinguishing features for segregating or delimiting the species of this taxon.

The occurrence and diversity of blue-green algae are directly affected by physical and chemical limnological factors of water bodies. The result of water analysis of few limnological parameters has been added in this article. Temperature effects on blooming and dominance of blue-green algae (Robarts and Zohary, 1987). They require warm temperature for their accelerated growth which was also observed in the present work. Species of *Oscillatoria* attain growth in a range between 30.5 °C to 33.5 °C. Thus, the result is inconformity with earlier findings of (Konopka and Brock, 1978). pH as a determining factor of distribution of the genus in water bodies ranged from 7.7 to 8.0. In all the study sites, pH of water was found within the alkaline range like the previous observations (Halder, 2015e; 2016c,d). A close relationship between

alkaline water and occurrence of cyanobacteria has been also stated by several workers (Verma and Mohanty, 1995; Nayak and Prasanna, 2007). During the present investigation, the amount of dissolved oxygen (DO) ranged between 5.8 to 6.6 mg.L<sup>-1</sup>. It showed that studied aquatic bodies were still with sufficient oxygen levels and not highly polluted. BOD was observed from 3.2-4.6 mg.L<sup>-1</sup> which suggested that water was not becoming anaerobic. For assessing organic pollution, COD was measured and noticed in a range from 40.0-90.0 mg.L<sup>-1</sup>. The analysis of both BOD and COD values indicated that pollution load was present in all the studied aquatic bodies. Most of the ecological studies revealed that if, nutrients levels increase rapidly cyanobacterial bloom occurs and can result an entropic condition in aquatic environments. The primary nutrients like nitrate-nitrogen and phosphates have a great influence on optimal growth, productivity of algae and they are also correlated to each other. In this study, species of *Oscillatoria* were found dominant even in availability of lower nutrient contents in water bodies. Nitrate-nitrogen and phosphates had been estimated from 0.10-0.22 mg.L<sup>-1</sup> and 0.20-0.36 mg.L<sup>-1</sup>, respectively. Lower concentration of the nutrient parameters was also measured in another study by the author (Halder, 2016e). Total hardness is an important factor for algal occurrence. It was recorded from 164.0-310.0 mg.L<sup>-1</sup> concentrations. Thus, the result exhibited that *Oscillatoria* tends to tolerate a wide range of total hardness values. Therefore,



from the analysis of water parameters it could be reported that blooming of *Oscillatoria* preferably noticed in alkaline pH, hard water and polluted aquatic bodies.

Besides these, all those above parameters had a great impact on their phenology and growth.

**Table 2.** Physico-chemical characteristics of waters in the five collection sites in Hooghly.

	Physico-chemical parameter	Khanyan (Site-1) Results	Serampore (Site-2) Results	Chinsurah (Site-3) Results	Chandannagar (Site-4) Results	Mogra (Site-5) Results
1	Temp. (°C)	32.00±0.28	32.50±0.28	30.50±0.28	31.50±0.28	33.50±0.28
2	pH	7.90±0.05	7.80±0.05	8.00±0.04	7.80±0.05	7.70±0.05
3	DO (mg.L <sup>-1</sup> )	6.00±0.11	5.80±0.12	6.40±0.13	6.20±0.12	6.60±0.11
4	BOD (mg.L <sup>-1</sup> )	4.40±0.12	4.60±0.11	3.60±0.11	4.20±0.13	3.20±0.12
5	COD (mg.L <sup>-1</sup> )	80.00±5.70	90.00±5.70	50.00±5.70	70.00±5.70	40.00±5.70
6	NO <sub>3</sub> -N (mg.L <sup>-1</sup> )	0.20±0.05	0.22±0.05	0.12±0.06	0.15±0.05	0.10±0.05
7	PO <sub>4</sub> <sup>3-</sup> (mg.L <sup>-1</sup> )	0.34±0.06	0.36±0.05	0.22±0.07	0.24±0.05	0.20±0.06
8	TH (mg.L <sup>-1</sup> )	252.0±5.70	310.0±2.80	164.0±5.70	218.0±2.60	184.0±5.70

Values are Mean ± SEM; Temp. = Temperature, DO = Dissolved oxygen, BOD = Biological oxygen demand, COD = Chemical oxygen demand, NO<sub>3</sub>-N = Nitrate-nitrogen, PO<sub>4</sub><sup>3-</sup> = Phosphate, TH = Total hardness.

## Conclusion

Morpho-taxonomic study will be helpful for routine identification, to know biodiversity and geographical occurrences of different species of the genus. Besides these, the genus is very common and abundantly found in a wide variety of habitats. Sometimes, it forms a thick blue-green or slight blackish mass in stagnant water bodies. It can be recognized under compound microscope by its unsheathed trichome. Species of *Oscillatoria* grow rapidly if, water is found warmer, alkaline, nutrient rich, hard and polluted. In future, these cyanobacterial species can be used for bioremediations, nutrient recycling and careful screening methods to isolate new restriction enzymes.

## Conflict of interest statement

Author declare that they have no conflict of interests.

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