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Benthic dinoflagellates from Red Sea, Egypt: Early records



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Abstract Dinoflagellates from Red Sea are hardly studied, in particular the benthic forms. Samples collected from shallow intertidal zone, Ain Sokhna, Egypt were microscopically examined. Three genera with seven species were recorded. The most frequently-encountered was *Katodinium* sp., a small mushroom-like with epitheca being consistently larger than hypotheca. Light micrographs revealed the presence of a nucleus in the hyposome and descending cingulum. Scanning electromicrographs (SEM) confirmed this orientation and revealed the presence of apical pore system. Another species showed similarity to the mushroom-like morphology but with large conical episome and small hyposome. Heterotrophic, naked *Gyrodinium cf. dominans* and *Gyrodinium* sp. were also observed where in the former, there were conspicuous longitudinal striations. A frequently-observed species had naked *Gyrodinium*-like morphology but with much smaller size. One photosynthetic species had a characteristic stigma similar to type B eyespot in “dinotoms” and episome being slightly larger than hyposome. *Gymnodinium* sp. with sulcus extending slightly in the episome but deeply to the end of hyposome was also recorded. This genus is reported to be mostly toxic and its presence should be monitored. Finally, this study presents some early records for benthic dinoflagellates from rather underexplored locality and raises alerts about genus with reported toxicity.

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Introduction

Dinoflagellates are unicellular eukaryotic protists with characteristic morphological features upon which their taxonomic characterization relies (Hoppenrath et al., 2009). The shape and extent of the sulcus and the cingulum displacement are morphological characters that have taxonomic value at the genus and species levels. Similarly, the absence of thecal plates

underneath the plasma membrane or their presence and the pattern of tabulation are all morphological characters that are taxonomically informative (Hoppenrath et al., 2009, 2014). Dinoflagellates are mostly marine (nearly 90%) and only 10% are freshwater. The majority of dinoflagellates are planktonic and only small percentage is benthic (Hoppenrath et al., 2014). Benthic dinoflagellates are usually found in the interstitial spaces between sand grains and in the intertidal shallow zone where mixing is observed. Benthic dinoflagellates are found epiphytically on macroalgae and corals in the intertidal and subtidal zones. (Hoppenrath et al., 2014). Benthic naked dinoflagellates and thinly-thecate species are usually

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too delicate to handle, too tiny to observe and collect and too difficult to culture as they usually feed on living preys. In the past, studies focused mainly on basic morphology and fine structure description. Nowadays, many dinoflagellate taxonomists adopt a combined taxonomic approach for more accurate description of taxa (Takano and Horiguchi, 2004; Moestrup and Daugbjerg, 2007; Hoppenrath et al., 2012). This approach overcomes pitfalls resulting from using single aspect of identification. It encompasses general morphology, fine structural studies and molecular and phylogenetic analyses to give a holistic picture of the taxa involved and allow the construction of robust taxonomy (Takano and Horiguchi, 2005). Red Sea is one of the richest water bodies with unique biodiversity that is largely underexplored (Zakaria and Al-Shehri, 2011). There are few studies that focused on certain species of benthic dinoflagellates from Red Sea, but not from Ain Sokhna, Egypt where the study took place, e.g. (Catania, 2012 who studied dinoflagellates from Saudi Arabia; Saburova and Chomérat, 2014 who studied dinoflagellates from Gulf of Aqaba but not from Egypt) but no intensive comprehensive studies on those communities were found. It is noteworthy that there has been a dramatic increase in recent revelations of toxicity of certain benthic dinoflagellates such as *Ostreopsis ovata* (Faimali et al., 1985) and *Gambierdiscus* (Catania, 2012). Moreover, there are some reports on the occurrence of dinoflagellates in the Egyptian Mediterranean waters (Aleem, 1993; Ismael and Halim, 2012) we therefore investigated some of the species present in the Red Sea coastal area located 80 km on Cairo-Suez road.

Materials and methods

Sample collection and examination

Sampling was performed in October 2014 (Autumn) from Ain Sokhna area, Suez Governorate approximately 120 km east of Cairo, Egypt (for map see Fig. 1). The latitude and longitude coordinates of the study area are 29.6000° N and 32.3167° E. Sampling was aimed at the intertidal zone from bottom to top in a vertical manner. Samples were taken from a depth of 60 cm. Microscopic examination was performed using Leica inverted microscope and supplemented with Leica suite application software. Epifluorescent microscope was used (oil

immersion lens) with differential interface contrast accessories. For morphometric measurements, tables of calibrations of ocular micrometer with slide micrometers were used.

Scanning electron microscopy

Fixation in Lugol's solution (AppliChem, Germany) was performed on dinoflagellate cells, either picked or used directly from raw samples, for a week to ensure sedimentation of all dinoflagellates (Morton, 2001). The fixed sample was then loaded onto 5 µm isopore membrane (TMT PO1300, Milipore) and washed with distilled water twice for 10 min to prevent the formation of salt crystals from remaining sea water. The cells mounted on the filter were then subjected to dehydration with ethanol series (30–50%, 70–85–95%) once at each concentration for 10 min. The final step of dehydration with ethanol using 100% concentration was repeated twice. At each step, the ethanol was loaded into syringe connected to the filtration unit and injected gradually before stopping with some ethanol still in syringe for ten minutes after which the rest of ethanol was injected and the filtrate was discarded (Sampedro et al., 2011). This allows through rinsing of sample. The hexamethyldisilazane (HMDS), previously used by Jung et al. (2010) as dehydrating agent was then used. The HMDS was loaded with a syringe into filtration unit, allowed to stand for an hour, then the rest was injected through and the filtrate was discarded. The filter-containing sample was left to dry at room temperature for twenty minutes. The sample was put in an oven for five minutes at 55 °C. The membrane was then mounted onto electron microscope stub (0.5" Aluminum specimen stub G301, Agar scientific) using glued double-face sticker (Plano, Germany). The stub was then inserted in gold–palladium sputter for coating with metal under argon saturated atmosphere. When a vacuum was created the sputtering started at 40 mA for 150 s and the sample was ready for electron microscopy. The Scanning electron microscope (Tescan-Vega, Germany) supplied with VEGA3 software was used to visualize cells at 15–20 kV.

Epi-fluorescence test of plate pattern

For epifluorescence microscopy, cells were stained with 1% calcofluor white (Sigma) solution. A drop of stained cell solution was placed on a microscope slide and covered with a cover

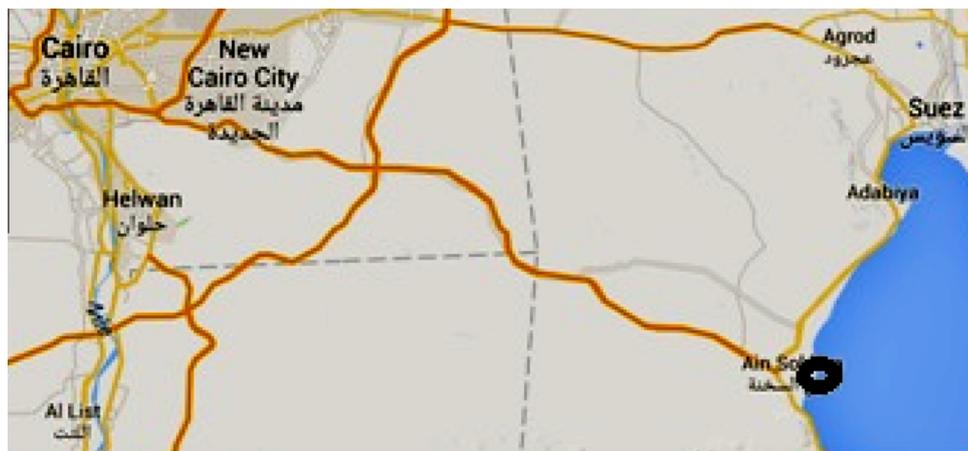


Figure 1 Map showing study area (denoted by a circle). The map was obtained from Google maps.

slip with one drop of the white solution placed on one end of cover and a tissue placed on opposite side to attract liquid by capillarity and allow the uptake of stain by cells. The cells were analyzed immediately on Leica epifluorescence microscope using 40 and 100× oil immersion objectives. Blue filter was used for examination of sample (see Fig. 2).

Results

Initial microscopic examination of the bottle sample from the shallow intertidal zone revealed that the sample contained several microscopic flora and fauna including crustaceans, ciliates, nematodes, diatoms and microalgal flagellates of different types and shapes as well as nanoflagellates. Seven dinoflagellate species were recorded namely; *Katodinium* spp., *Gyrodinium* sp., and *Gymnodinium* sp. The dinoflagellate cells were picked up and examined under high magnification which revealed the absence of any chloroplasts, stigma but food vacuoles were present. The nucleus was in the hyposome with permanently condensed chromosomes (Fig. 3). The calcofluor test for detecting plates was negative. SEM revealed the displacement of the cingulum in a descending fashion with descending extent nearly equal to one cingulum width (Fig. 4). The size of this dinophyte cell was 7–22 μm in length and 10–20 μm in width. The sulcus extended to the antapical side. Trichocyst was also observed (Fig. 4) as well as the presence of peduncle as a feeding apparatus (Fig. 5). The apical pore complex associated with thecal plates was observed (Figs. 6 and 7 and illustrated in line drawing Fig. 8) with suggested tabulation pattern being closest to peridinioid type of tabulation (Figs. 7 and 8). The description fits well with that of *Katodinium fungiforme* and confirmed by Dr. Mona Hoppenrath (Loeblich, 1965). There was an observed dynamic aggregation around the prey (Fig. 9).

The second frequently-observed species was *Gyrodinium*-like fusiform dinoflagellate of size range (length 20–40 μm and width 10–20 μm). When this dinoflagellate was observed using oil immersion lens, there were clear striations that run from epicone to hypocone with the epicone being moderately shorter than the hypocone and striations are found in both cones (Figs. 10–14). Stigma was observed and the nucleus was noticeably large and intermediate in position (Fig. 14). The cingulum is descending. No chloroplasts were observed and sulcus was deflected to the left side and extending to the

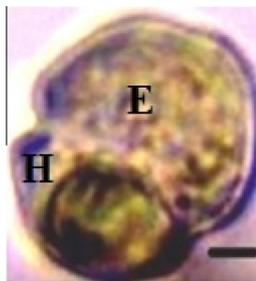


Figure 2 Light micrograph showing the epitheca (denoted E) and hypotheca (denoted H) with large food vacuole in the hypotheca of *Katodinium fungiforme* (scale bar 1 μm).

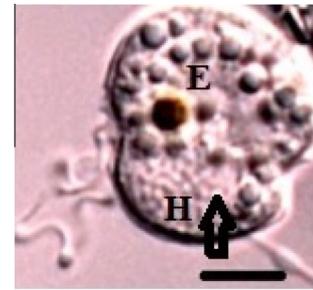


Figure 3 Light micrograph showing epitheca, hypotheca, nucleus granular in appearance and denoted by an upward arrow in the hypotheca. Transverse (to right of photo) and longitudinal flagella (to the left of photo with twisting appearance) of *K. fungiforme* (scale bar 2 μm).

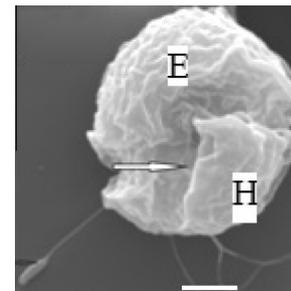


Figure 4 SEM showing descending cingulum, sulcus (white arrow) and trichocyst (indicated by fine black arrow, left bottom) extending out of cell of *K. fungiforme* (scale bar 2 μm).

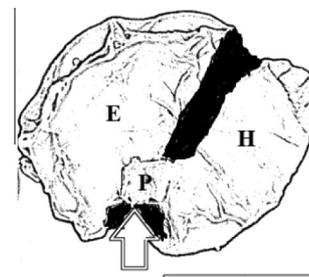


Figure 5 Line drawing based on SEM showing remains of peduncle (denoted as P and white arrow) of *K. fungiforme* (scale bar 10 μm). The cingulum is in bold font.

epicone. The description fits well with that of *Gyrodinium* of *dominans* (Hulburt, 1957).

The third interesting taxon was of limited occurrence. Its small size as well as its hyposome being larger than episome was observed (Figs. 15–17). Its size range is 8–17 in length and 6–12 in width and the nucleus is intermediate in position (Fig. 16). Scanning electron microscopy also confirmed the presence of the naked *Gyrodinium*-like dinophyte with a displaced cingulum (Fig. 18). Although of limited occurrence, the binary fission of this species was also recorded (Figs. 19–23).

The other rarely-encountered dinoflagellate was mushroom-like photosynthetic *Katodinium* species of similar size to that of the heterotrophic *K. fungiforme* (Fig. 24). The

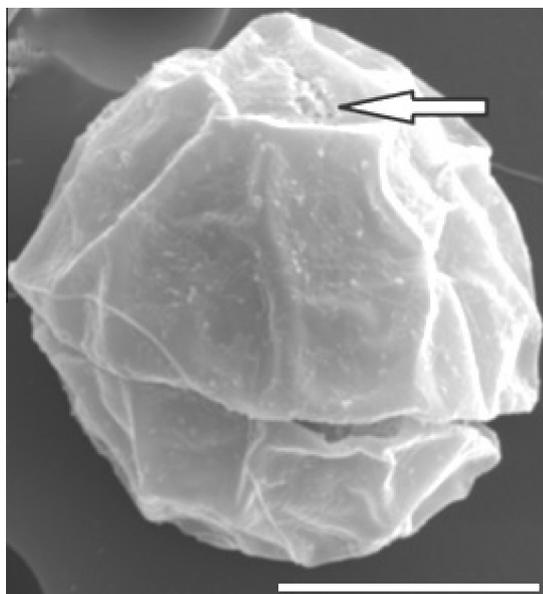


Figure 6 SEM showing apical pore system (white arrow) associated with theca of *K. fungiforme* (scale bar 5 μm). The borders between thecal plates are also apparent.

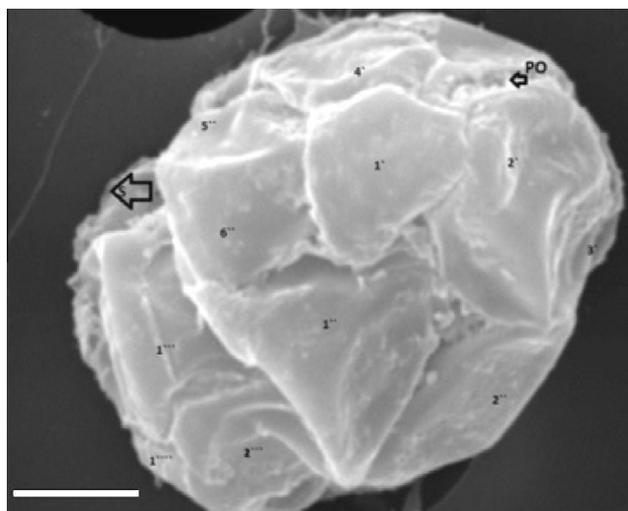


Figure 7 SEM apical pore system (white arrow) associated with theca showing a seemingly peridinioid pattern of tabulation of *K. fungiforme* (scale bar 5 μm). This is a proposed plate arrangement that awaits further confirmation.

light micrograph taken by high magnification showed the presence of central globular pyrenoid as well as orange stigma (Fig. 25). This is a photosynthetic species.

Another rarely-observed heterotrophic mushroom-like dinoflagellate had a conical larger episome than hyposome of size (12 μm in length and 8 μm in width) (Fig. 26). One photosynthetic species was only twice observed which had a characteristic stigma similar to type B eye spot in “dinotoms” (Fig. 27) and episome being slightly larger than hyposome (52 μm in length and 40 μm in width). The last rarely-observed species has sulcus extending slightly in the episome but deeply toward the end of hyposome. Its size was 40 μm

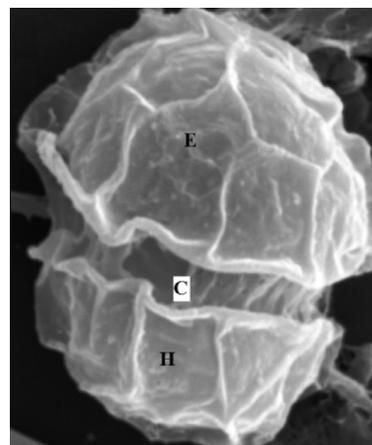


Figure 8 SEM showing the cingulum denoted as C. Letter E denotes epitheca and H denotes hypotheca.

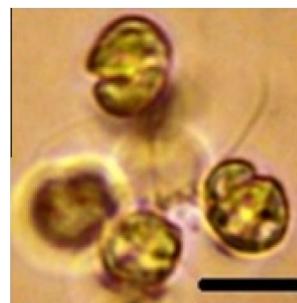


Figure 9 Dynamic aggregation of *Katodinium fungiforme* (scale bar 10 μm).

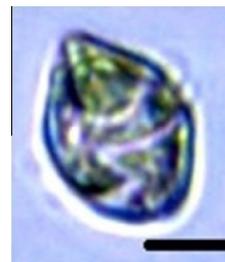


Figure 10 Light micrograph showing the episome and hyposome of *Gyrodinium cf. dominans* (scale bar 10 μm).

in length and 30 μm in width. The cingulum is clear with a minimal or no displacement. Pustule-like structures are present. This naked heterotrophic dorsoventrally-flattened dinoflagellate was identified as *Gymnodinium* sp. (Fig. 28).

Discussion

There is an ongoing debate about the taxonomy of dinoflagellates. Several taxonomic revisions have either already taken place or are underway (Hoppenrath et al., 2014). The main reason behind this is the emergence of new data sets of previously misidentified taxa. For example, the revelation of the



Figure 11 Light micrograph showing the descending cingulum of *Gyrodinium cf. dominans* (scale bar 10 μm). The photo was taken by Dr. Hoppenrath.



Figure 12 Light micrograph showing the striations and the descending cingulum of *Gyrodinium cf. dominans* (scale bar 10 μm). Photo number 12 was taken by Dr. Hoppenrath.

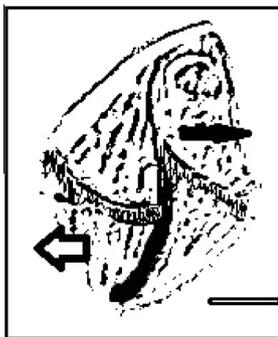


Figure 13 Line drawing showing the descending cingulum (denoted as short stripes) whereas the sulcus (denoted as solid dark line extending slightly in the episome but deeply until the end of hyposome). Episome is denoted by solid dark arrow whereas hyposome is denoted by white arrow.

presence of delicate theca (Hoppenrath, 2000) in taxa that were previously reported to be naked as in the case of *Katodinium* (Calado, 2011) and the appearance of new molecular data necessitate those taxonomic revisions (Thessen et al., 2012). Bearing that in mind, we attempted to collect more information about the taxa involved. We used a combined approach to describe the most frequently-encountered benthic species in which we integrated several data to allow accurate characterization. The data included size range, morphology supported by micrographs. Light microscopy confirmed that the isolate under study was *K. fungiforme* (Anissinowa) Loeblich (1965) as the description of our isolate fits well with the



Figure 14 Light micrograph showing the large intermediate nucleus (denoted as N by an arrow) of *Gyrodinium cf. dominans* (scale bar 5 μm). The photo was taken by Dr. Hoppenrath.



Figure 15 Light micrograph of *Gyrodinium*-like heterotrophic dinophyte (scale bar 5 μm).



Figure 16 Light micrograph showing the nucleus denoted as N of *Gyrodinium*-like heterotrophic dinophyte (scale bar 5 μm). The photo was taken by Dr. Hoppenrath.



Figure 17 Line drawing showing episome (denoted by dark arrow) being smaller than hyposome (denoted by white arrow).

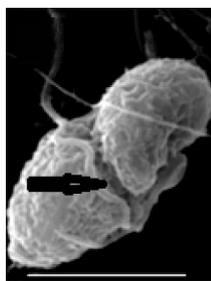


Figure 18 SEM showing naked heterotrophic *Gyrodinium*-like dinophyte with displaced cingulum (scale bar 10 μm).

description of the latter. According to Murray et al. (2007), *Katodinium* is a relatively underexplored genus comprising both heterotrophic and autotrophic, marine and freshwater forms and it needs thorough taxonomic investigation. It was mistakenly identified as naked *Gymnodinium* genus but later was modified into thecate *Katodinium* genus (Murray et al., 2007). Consistently, the *K. fungiforme* was previously known as *Gymnodinium fungiforme* (Spero and Morée, 1981) as it was mistakenly reported to be naked. However, using scanning electron microscopy, *K. fungiforme* has now been found to possess thecal plates apparently arranged in a peridinioid-like pattern as multiple plate series (Hoppenrath, 2000; Murray, 2003). We attempted to reveal the tabulation pattern using calcofluor epifluorescence method but we obtained negative results. According to Dr. Wayne Coates (personal communication), the thecal plates of *Pfisteria*-like dinoflagellates, including *Katodinium* genus do not stain with calcofluor. We also observed the dynamic aggregation of that species around the prey which was previously described by Spero and Morée (1981). According to those authors, this phagotrophic dinophyte feeds by means of feeding tube (peduncle) on its prey and tends to gather in large numbers around it. This only supports the taxonomic identification of our isolate as *K. fungiforme*. Nevertheless, it seems that the taxonomy of *Katodinium* genus itself awaits even more investigations as Murray et al. (2007) recommended the revision of the taxonomic feature of *Katodinium* as having an epitheca larger than hypotheca. They argued that this is not always a stable diagnostic taxonomic character. Therefore, this genus taxonomy is still in a state of flux and more studies need to be performed on a large scale to provide the accurate taxonomic circumscription. However, in our case we consistently found that the epitheca was larger than the hypotheca in accordance with original description. There was also a rare appearance of mushroom-like dinophyte with a bigger conical episome than hyposome. We also recorded the presence of photosynthetic



Figure 19 Light micrograph showing the first stage of the oblique binary fission of *Gyrodinium*-like dinophyte (scale bar 5 μm).

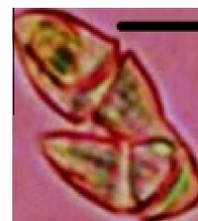


Figure 20 Light micrograph showing the second stage of the oblique binary fission of *Gyrodinium*-like dinophyte (scale bar 5 μm).



Figure 21 Light micrograph showing the third stage of the oblique binary fission of *Gyrodinium*-like dinophyte (scale bar 5 μm).



Figure 22 Light micrograph showing the fourth stage of the oblique binary fission of *Gyrodinium*-like dinophyte (scale bar 5 μm).

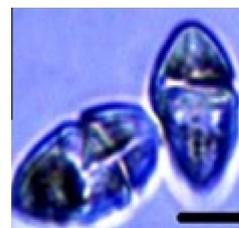


Figure 23 Light micrograph showing the final stage of the oblique binary fission of *Gyrodinium*-like dinophyte (scale bar 5 μm).

Katodinium species with larger episome than hyposome. Similarly, the presence of photosynthetic *Katodinium* species has also been reported, e.g. by Murray et al. (2007). In all of those mushroom-like dinophytes, the episome was larger than the hyposome, therefore this character cannot be considered as irrelevant in the taxonomic treatment of that genus. No similar records have been found on all of those taxa from Red Sea. The second frequently observed *Gyrodinium* sp. was closely matched to that described by Hulburt (1957) as *Gyrodinium cf. dominans* in USA. Interestingly, no contemporary records

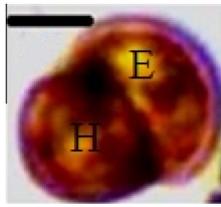


Figure 24 Light micrograph of photosynthetic *Katodinium* sp. (scale bar 5 μm). E stands for episome and H stands for hyposome.

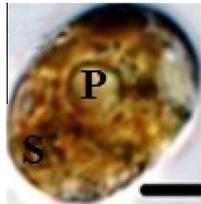


Figure 25 Light micrograph of photosynthetic *Katodinium* sp., showing the central globular pyrenoid (denoted by P) and stigma (denoted by S) (scale bar 3 μm).



Figure 26 Light micrograph showing the mushroom-like heterotrophic dinophyte with large conical episome (scale bar 2 μm).

were ever made since on that taxon from anywhere else which only confirms the novelty of our record. The third species possessed *Gyrodinium*-like morphology where it is athecate, the epicone being much smaller than hypocone and the nucleus is intermediate. The oblique binary fission of that species resulted in daughter cell nearly similar in size to parental cell (Hoppenrath et al., 2009). Again, we could not find similar record on that type of dinophyte from Red Sea or elsewhere. The second rarely-observed photosynthetic dinoflagellate species had stigma similar to that of “dinotoms” which is a term describing dinophyte with an endosymbiotic diatom arising from tertiary endosymbiosis (Imanian et al., 2012). This might indicate the possible capture of photosynthetic chloroplast from diatom as in some phototrophic dinophytes (Moestrup and Daugbjerg, 2007) which are sometimes called kleptochloroplasts. It is noteworthy that the mode of nutrition varies among dinoflagellates and includes heterotrophy, phototrophy and mixotrophy. Interestingly, heterotrophic dinoflagellates can acquire chloroplasts from other algae such as diatoms and perform photosynthesis thus becoming mixotrophic in a process presumably involving transfer of endosymbiotic genes to host nucleus (Burki et al., 2014). The presence of *Gymnodinium* sp. with its naked dorsoventrally-flattened structure has long been recorded in Egypt but not from Red Sea (Schmarda LK (1854) Zur Naturgeschichte Ägyptens.

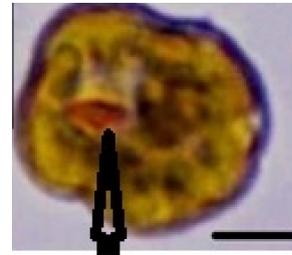


Figure 27 Light micrograph showing a conspicuous stigma, similar to type B eye spot (upward arrow) observed in “dinotoms”. This photosynthetic dinophyte has apparently larger episome than hyposome (scale bar 15 μm).

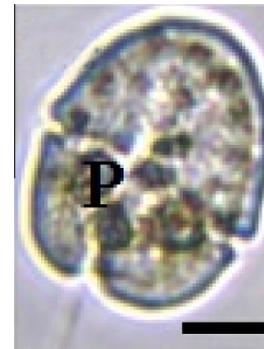


Figure 28 Light micrograph showing a naked dorsoventrally-flattened heterotrophic *Gymnodinium* sp. with slightly bigger episome than hyposome and with conspicuous sulcus extending slightly in the episome but extending to the antapical end in the hyposome and the longitudinal flagella beating posteriorly (scale bar 10 μm). Pusule-like structure is denoted as P.

Denkschr Akad Wiss Wien 7: 1–2; cited in Thessen et al., 2012). Also, Labib (1998) reported that *Gymnodinium catenatum* was present in the Mediterranean Sea along the coast of Alexandria. *Gymnodinium* genus presence can be quite alarming as it encompasses several toxic species which produce the saxitoxins, reported from planktonic *Gymnodinium* which are heterocyclic neurotoxic Guanidine. Those toxins cause Paralytic Shellfish Poisoning with symptoms for those who have eaten seafood contaminated with those toxins ranging from tingling and numbness of the perioral area and extremities to loss of motor control and drowsiness and in extreme cases respiratory paralysis (Zaccaroni and Scaravelli, 2008). No toxicity test could be performed from our side as the dinophyte was rarely observed and not present in large numbers during the sampling period. Nevertheless, the presence of such genus with reported toxicity should be monitored especially during summer months when proliferation occurs. Finally, the early records reported in this study have not been reported from Red Sea, Egypt. Further thorough studies need to be conducted to unveil the extent of dinophyte biodiversity, their distribution and their toxicity along the coast of Red Sea.

Conflict of interest

The author confirms that there is no conflict of interest.

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