New form taxa of non-pollen palynomorphs (NPP) from southern Red Sea coastal sediments of Saudi Arabia

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ABSTRACT

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Palynological slides of Quaternary-Recent marine and brackish water sediments invariably comprise a variety of vase, urn, flask, funnel, tube and spherical palynomorphs. They are of variable sizes, could be hyaline or agglutinated and their colour ranges between yellowish to dark brown, and sometimes greyish. Biological affinities of such palynomorphs are debatable, often few palynologists relate them to tintinnid loricae and cysts, thus known as tintinnomorphs. However, similar forms are known from lacustrine sediments as well and considered to be oocytes or resting eggs (6–200 µm) of *Neorhabdocoela*, a small, soft-bodied flatworm belonging to class *Turbellaria*, phylum *Platyhelminthes*, found in freshwater environments all over the world. Sometimes morphologically similar microfossils have also been related to testate amoebae. Identification of such forms are confusing because there is no standard nomenclature to describe them. Informal descriptions of various morphological groups have been made. However, there is confusion about their identifications since they do not have any formal taxonomic identity as genus and species. This study addresses this issue by proposing new form genera and form species from a large morphologically diverse population of tintinnomorphs described from the southern Red Sea coastal environments of Saudi Arabia. Two new form genera *Katora,* and *Mangrovia,* and six new form species *Katora arabica, K. elongata, K. oblonga, K. twinmorpha, Mangrovia redseaensis* and *M. hallii* are proposed.

Keywords: Red Sea coastal environments, Tintinnids, Tintinnomorphs, *Turbellaria,* Rotifers, Non-pollen palynomorphs.

INTRODUCTION

Tintinnids are unicellular, ciliate, planktic, heterotrophic protists, their size ranges from 20 to 200 µm. They belong to the Phylum *Ciliophora*, Class *Spirotrichea*, Subclass *Choreotrichida*, and Order *Tintinnida* (Dolan 2013). Their cell is surrounded by a test or lorica, that defines their morphological character, is secreted by the organism. Their wall is organic which could be hyaline transparent or agglutinated with biogenic and abiogenic particles. Generally, they are bell-shaped oligotrichs, that dominate ciliate microzooplankton in coastal marine waters (Mudie et al. 2021a). The loricate forms are typically oblong, vase-, tube- or bell-shaped, and their length varies between 15–400 µm (Dolan 2013).

Van Waveren (1994) introduced the term tintinnomorphs for organic remains that included loricae, cysts, and the stalked pouches in which cysts were

originally encapsulated. Wide morphological variability has been observed among the loricae and the cysts. She described, illustrated, and categorized tintinnomorphs in an informal morphological system and emphasized that palynomorphs resembling tintinnids cannot always be separated into loricae or cysts and may even represent cysts of other protozoans. da Silva et al. (2017) expanded the concept of tintinnomorphs for the group of palynomorphs resembling organic remains of tintinnids, which are not always identifiable as true lorica, cysts or pouch, and may correspond to other metazoans such as rotifers and even the soft-bodied flatworms belonging to the class *Turbellaria*.

Palynological literature reports a variety of vase, urn, flask, funnel, tube, and spherical palynomorphs. Their identifications are confusing since there is no standard nomenclature to describe them. Although attempts to informally describe them in various morphological groups were made, yet confusion prevails and there is a need for formal taxonomic identifications. Thirty-four types of tintinnomorphs were informally described from the recent sediments belonging to various coastal environments of the southern Red Sea coast of Saudi Arabia (Kumar 2020, 2021). Formal taxonomic names are proposed as new form genera and form species from these thirty-four tintinnomorphs. A form genus is defined as "a genus unassignable to a family, but it may be referable to a taxon of higher rank… Form genera are artificial in varying degree." (Tschudy & Scott 1969, p. 60). The objective of this study is to conceptualize and categorize such morphological groups under formal names. Since their biological affinities are debatable, thus form genera and form species are proposed. Because of its general shape the form genus *Katora* is described by using morphological terminology of van Waveren (1994) and Matsuoka and Ando (2021).

A survey of palynological literature reporting or describing vase or urn-shaped non-pollen palynomorphs is carried out to relate them to the proposed form genera and form species of tintinnomorphs and rotifer palynomorphs. There are several Holocene records of subfossil rotifers from peat bogs and other deposits,

for example, *Bdelloidea* rotifers (Warner & Chengalath 1988, 1991) and *Monogononta* rotifers (e.g., Swadling et al. 2001, Turton & McAndrews 2006). Since the form genus *Mangrovia* has morphological affinity with rotifers, thus morphological terminology of Warner and Chengalath (1988) and Swadling et al. (2001) is used to describe this form genus.

RED SEA AND ITS COASTAL ENVIRONMENTS

Basic information about the geography, climate, and oceanography of the Red Sea was provided in Kumar (2020, 2021). Red Sea surface water temperatures remain constant year-round at 21–25°C (Jado & Zölt 1984), and the salinity ranges between ~36% (3.6% on the Practical Salinity Scale or PSU meaning actual dissolved salts) in the southern region and ~41% (4.0% PSU) in the northern region, where as the world average is ~35% or 3.5% PSU (Hanauer 1988). The climate of this region is controlled by two monsoon seasons: a northeasterly monsoon and a southwesterly monsoon, however the rainfall is extremely low averaging 0.06 m/year; mostly in the form of showers of short duration often associated with thunderstorms. During winter months there is inflow of water from the Gulf of Aden into the Red Sea resulting in an overall drift to the northern end of the Red Sea. Thus, north and northeastern winds influence the movement of water in the coastal inlets to the adjacent sabkhas (saltpans), especially during storms. Winter mean sea level is 0.5 m higher than the mean sea level in the summer (Kumar et al. 2010). Red Sea, being a semi-enclosed basin in the arid region, is affected by high temperatures, high evaporation rate and high salinities impacting the composition of flora and fauna along its coastal environments.

Red Sea coastal marine ecosystem comprises of coral reefs, mangroves, seagrasses, coastal vegetation, and associated flora. There is an increase of mangroves, seagrasses, and coastal flora towards the southern region (Price et al. 1998). Mangrove swamps and wadis (dry riverbeds) are scattered all along the coast. Location of the study site lies on southern Red Sea
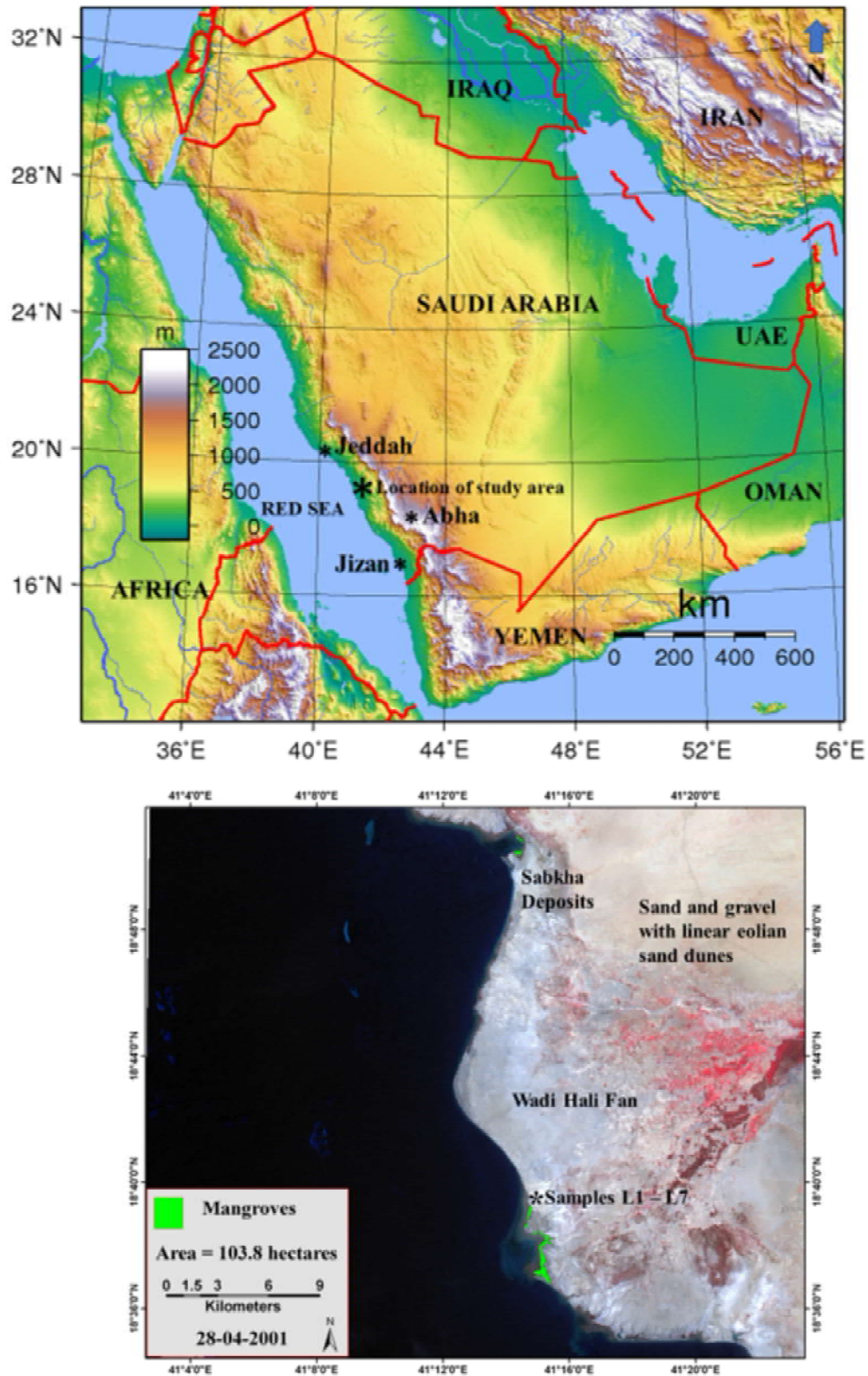
Figure 1. A. Topographical map of the Arabian Peninsula showing various countries and Red Sea coast indicating the location (the star) of area of study (Modified after https://commons.wikimedia.org/wiki/File:Saudi_Arabia_Topography.png). **B.** Coastal and terrestrial environments around the area of study showing Wadi Hali Fan and locations of samples L1– L7. Satellite image of the area showing marine and coastal environments. Mangroves shown in green colour. (Modified after Khan et al. 2010)

coast of Saudi Arabia (Figure 1.A). Wadi Hali Fan is a significant geomorphological setting of this region (Figures 1.B, 2.A) that covers an area of around 50 km N-S and 40 km E-W. This region has aeolian, fluvial, coastal, intertidal, brackish-water ponds with mangrove swamps and saline lagoons (Figures 1.B, 2.A). Estuarine clastic sediments have been depositing in this region since Quaternary (Jado et al. 1990). Massive flooding events are common in the SW regions of the Arabian Peninsula due to periodic intense cloud bursts. Wadi Hali has been eroding the Arabian Shield and transporting sediments to the Red Sea (Jado et al. 1990).

MANGROVE SWAMPS AND MICROBIAL MATS

Scattered patches of mangrove swamps occur along the southern Red Sea coast of Saudi Arabia (Khan et al. 2010). This patchy distribution of mangroves is mainly due to the following four factors, there are wider continental shelf, more protected and gently inclining coastline, greater availability of freshwater, and finally greater availability of suitable substrate in the region (Price et al. 1987). These are estuarine soft-bottom environments characterized by brackish water areas with freshwater inflow, where mangrove sediments become finer and deeper (Zahran 1974, 1980).

The mangrove species *Avicennia marina* Forssk. is the only species that occurs on the mainland and shows its tolerance for extreme conditions (MacNae 1968) however, another mangrove species *Rhizophora mucronata* Lam. occurs only in the Farasan Archipelago in the southern Red Sea (Mandura et al.

1987, Vasey-Fitzgerald 1955). Flora of these mangrove swamps includes abundant blue-green algae (*Cyanophyta*), and algal taxa like, *Sargassum, Cladophora* and *Enteromorpha*. The common faunal elements include mollusks (gastropods and bivalves), crabs (crab burrows), barnacles, polychaetes, coelenterates, sponges, and less commonly echinoderms. Dead leaves of sea grasses occur in these swamps as well (Price et al. 1987, Saifullah 1996).

The mangrove swamps of southern Red Sea coast of Saudi Arabia form the landward limit of lagoons that survive in most unfavorable conditions and grow along the margins of shallow lagoons which are sheltered and have favorable depositional environment. These mangroves grow in high salinity environments, where rivers are non-existent, has minimum rainfall, and an oligotrophic sea. However, the factors for mangrove growth include thick and soft, muddy bottom with nutrient input from decomposition of organic matter, and rainfall and runoff conditions evident from several wadis in the region that form a network of shallow drainage channels collecting rainwater along with alluvium and drain them into the lagoons or directly into the sea (Morley 1975). They are characterized by tropical climate and form fringe type of forest, classified as dwarf forest because of a narrow tidal zone, oligotrophic waters, high salinity values and small size of plants (Snedaker 1989). The southern Red Sea mangrove growth and diversity is poor because of very low nutrient levels (Saifullah 1996).

Microbial mats are formed over tidal flats where water reaches only few times a year, that too during winter months when mean sea level is higher. Such areas,

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Figure 2. A. A part of the geological map of the Wadi Hali Quadrangle, sheet 18E, Kingdom of Saudi Arabia (Prinz 1984). The map shows offshore islands, coral reefs and surficial deposits that include two fans that were formed by ancient streams now wadis (dry riverbeds). The region is covered with Holocene-Recent flood plain deposits, sabkhas (saltpans), scattered patches of mangrove swamps and eolian sand fields. Sample locations (1 through 5) are as follows. Mangrove Swamp Environment: Location 1; Location 2A; and Location 2B. Algal Mat Environment: Location 5; Sabia Island Coral Reef Environment: Location 4: and Intertidal Environment: Location 3 (after Kumar, 2021). **B.** Various localities of samples collected for this study. a. Two clay samples (M1 and M2) from the mangrove swamp (Figure 3, Location 1). b. Two clay samples (M3 and M4) from the mangrove swamp (Figure 3, Location 2A). c. Three clay samples (M5, M6 and M7) from the mangrove swamp (Figure 3, Location 2B). d. One sample (AM1) from algal mat (water depth 50 cm or less; Figure 3, Location 5) E. One sample (AM2) from dried part of the algal mat (Figure 3, Location 5) (after Kumar, 2021).
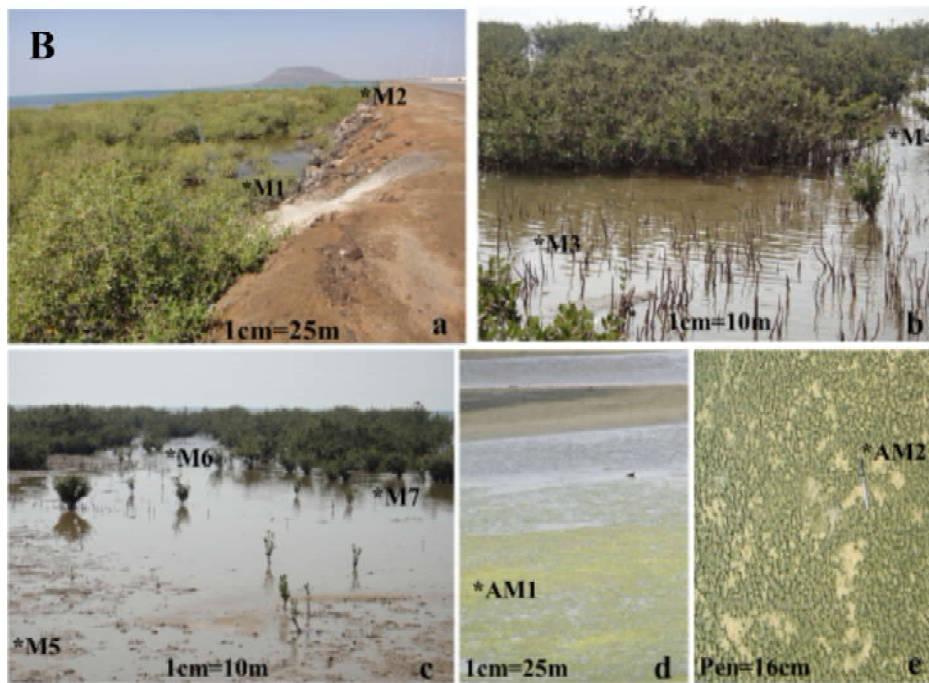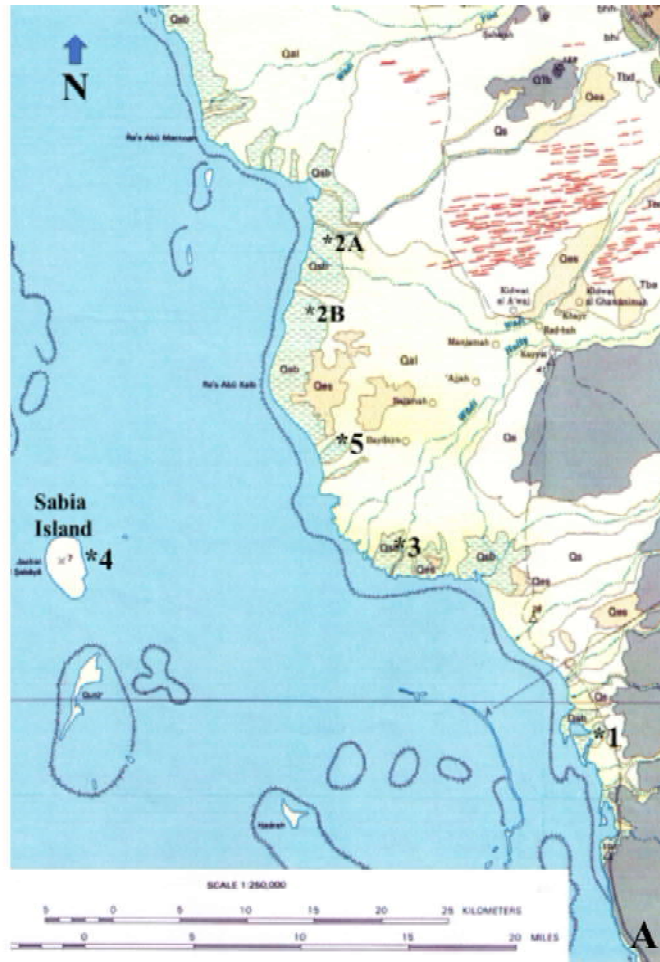
Figure 2

when wet, allow a very thick growth of filamentous Cyanobacteria, but when dry, as they are for most of the year, they die out leaving black sheaths that persist in the area (Saifullah 1996).

AN OVERVIEW OF TINTINNIDS, TINTINNOMORPHS, TURBELLARIAN EGG CAPSULES AND ROTIFER PALYNOMORPHS

A. Tintinnids, tintinnomorphs and turbellarian egg capsules

Tintinnids are protists of complex eukaryotic organisms, are part of the microzooplankton (size ranges between 20–200 µm) that inhabit primarily marine, but brackish and freshwaters as well (da Silva et al. 2017). They are heterotrophic organisms, feeding on photosynthetic algae and bacteria. Tintinnids produce chitinous shell, known as lorica which has an oral opening at the anterior end. The posterior end of the lorica is closed and may be conical, globular, or tubular. Most loricae are transparent thus hyaline. However, few loricae agglomerate mineral or biogenic particles forming a hard shell. A hard bowl lorica is formed when the particles only stick to the posterior end (Agatha et al. 2013). Shape of the lorica is species specific, however, there is considerable intraspecific morphological variations related to the life cycle stages of the ciliates (Agatha et al. 2013). Such morphological variations also depend on the environmental conditions such as temperature, salinity, and particle availability during its construction, thus influencing its size, shape, and structure (Agatha & Strüder-Kypke 2012). They primarily inhabit marine and brackish environments (Dolan 2013) but may occur in freshwater environments as well (Mudie et al. 2021a).

Reid and John (1978) reviewed morphology of tintinnid cysts and established simple terminology of loricae and semi-enclosed flask-shaped cysts. They recorded flask-shaped tintinnid loricae in plankton recorder around the British Isles and found similar forms in the palynological slides of the British intertidal sediments. Abu Zaid and Hellal (2012) described an assemblage of 92 species belonging to 30 genera and 13 families of Tintinnids from the plankton samples of the Hurghada coast of Egypt, northern Red Sea. They commented that Tintinnid taxonomy is poorly understood and is based on the morphology of their loricae. There is a high intraspecific morphological variability among the tintinnid loricae, thus, many species may be invalid.

In palynological preparations of marine and brackish water sediments flask, bulb, funnel, urn, vase, spherical, bell, fusiform, pitcher or cup-shaped palynomorphs are often observed. Although they have distinct morphology, but their biological affinities remain uncertain and debatable. They were considered by various authors to be tintinnid loricae and cysts (Reid & John 1978, van Waveren 1994, Meckler et al. 2008, Hardy & Wrenn 2009, Mudie et al. 2010, 2011, Pieńkowski et al. 2011, 2013, Matsuoka et al. 2017) and were classified as zoomorphs (Traverse 1994). Matsuoka and Ando (2021) consider similar funnel, bell, pitcher or cup-shaped palynomorphs to be remains of organisms of different origin, that may include ciliate lorica, resting cysts, and turbellarian egg capsules.

According to van Waveren (1994) tintinnomorphs resemble organic remains of tintinnids, but are not necessarily identifiable as true lorica, cysts or pouch. She proposed an informal morphological system, with descriptions and illustrations of the cysts, loricae and the pouches of seventy-six morphological types from the Banda Sea, Indonesia. However, Canudo (2004) considers tintinnoids and tintinnomorphs to represent true tintinnid loricae and similar forms, minimizing the mistaken designations. da Silva et al. (2017) considered that morphological studies of the organic remains attributed to tintinnids are needed and considered that tintinnomorphs may have biological affinities with other protozoans or other organisms, such as rotifers and turbellarians. Many loricae and cysts have been observed in palynological slides of recent marine and marginal marine sediments (Reid & John 1978, Meckler et al. 2008, Mudie et al. 2010, 2011, Price & Pospelova, 2011, Pieńkowski et al., 2011, 2013). Also,

large numbers of tintinnid loricae and cysts of diverse morphologies are known from Holocene marine sediments as well (van Waveren 1994, van Waveren & Visscher 1994, Grill et al. 2002, Borromei & Quattrocchio 2001, 2007, Kawamura 2004, Hardy & Wrenn 2009, Lipps et al. 2013, Matsuoka et al. 2017). Mudie et al. (2021a) extensively discussed possible relationship between tintinnomorphs with tintinnid loricae and cysts and with other groups of organisms. Paranjape (1980) considered true tintinnid cysts to be typically thick-walled, round, or oblong (flask-shaped).

Certain microscopic forms are morphologically akin to tintinnomorphs occur in the lacustrine sediments. For example, Haas (1996) described dark brown oocytes from recent sediments of a Swiss lake, which are elliptical to spherical, occasionally with operculum, and some with a basal stalk for attachment to the substrate. He considered these oocytes to be resting eggs (6–200 µm, up to 600 µm) of *Neorhabdocoela,* a small (< 5 mm), soft-bodied flatworm belonging to class *Turbellaria,* phylum *Platyhelminthes* found in freshwater environments worldwide.

Microfossils that appear like tintinnomorphs were reported from nearshore and continental margin sediments of Atlantic Canada and were described as organic, hyaline, and agglutinated tintinnid palynomorphs (spores and lorica) by de Vernal (2009). Mudie et al. (2010) found common presence of *Polyasterias problematica* and *Radiosperma* type cysts and tintinnid loricae in the Black Sea corridor sediments.

Tintinnomorphs were described as cylindrical and inverted frustum type loricae and spherical, elliptical, egg-shaped resting cysts from tropical shallow marine sediments in Oman, Malaysia, and Japan (Matsuoka et al. 2017). In a similar study Matsuoka and Ishii (2018) reported two types of loricae and nine types of resting spores of ciliata from the surface sediments of Osaka Bay, Japan that were termed as tintinnomorphs. Hartman et al. (2018) studied Holocene marine palynomorphs from IODP core (East Antarctica) and described many types of tintinnomorphs, that included

tintinnid loricae having an oral opening, their posterior ends were either conical, globular, or tubular. Loricae were both hyaline and agglutinated. They found shapes of loricae to be species specific, although intraspecific variability was commonly observed. According to Belmonte and Rubino (2019) a loricate oligotrichs mostly produce flask-shaped resting cysts in marine and brackish waters.

Pieńkowski et al. (2020) described six types of tintinnomorphs from Baffin Bay, Arctic Canada. A detailed palynological study of the recent sediments from various coastal environments along the southern Red Sea coast of Saudi Arabia was published by Kumar (2020, 2021). Using the terminology of informal morphological system proposed by van Waveren (1994) he informally described 17 types of tintinnomorphs from the recent intertidal sediments (Kumar 2020) and additional 17 tintinnomorph types were described from various other coastal environments from the same region as well (Kumar 2021).

Mudie et al. (2021a) carried out a comprehensive examination of non-pollen palynomorph groups that primarily occur in Quaternary marine and brackish-water sediments represented by various planktic and micro- to macro benthic organisms, for example, dinoflagellates, prasinophytes, tintinnids and other ciliates, copepod eggs and their skeletal remains, foraminiferal organic linings, ostracod mandibles and carapace linings, various worm egg capsules and mouthparts. This study emphasized NPP groups' distribution in modern environments, their trophic relationships and commented on the biological affinities of certain NPP groups. Microzooplanktic NPP were considered to be in the size range of 20–200 µm representing 'the resting cysts of unicellular organisms, primarily tintinnids and other ciliophoran, but they also include the resting (diapause) eggs of marine copepods.' These authors described morphology and size ranges of tintinnid loricae produced by various taxonomic groups and illustrated their morphological features using the terminology provided by Reid and John (1978), van Waveren (1994) and Agatha (2010). They

illustrated several types of tintinnid cysts and loricae and other vase-shaped marine tintinnomorphs. According to them there is a probable affinity between tintinnid cyst type P and benthic red algal genus *Beringiella* as suggested by new micro-Fourier Transform Infrared spectroscopy spectra.

Mudie et al. (2021b) studied palynology of 43 surface sediment samples of the northwestern Black Sea shelf region from the depth ranging between 71–905 mbsl. The palynomorph assemblages demonstrated environmental differences within the area of study. They found organic remains of ciliate protists throughout the study area, the most common and widespread ciliates were small cysts or loricae of tintinnids including the smooth-walled Cyst-type P, and very small spiny Cyst-type O taxa of Reid and John (1987). They reported several flask-shaped cysts and vase-shaped tintinnid loricae and flatworm egg capsules in their study (see figures 9/21–24; 11/1,5,7–9,11,12) and egg capsules of *Turbellaria* flatworms (see figures 11/ 5, 7–9, 12). They observed that relatively thick chitinous walls along with the common presence of long thin stalks with spreading bases rooted within cellular tissue denote a trematode-like or parasitic life-form which is characteristic of platyhelminthes and not tintinnids or another ciliate Protista.

Matsuoka and Ando (2021) while considering tintinnomorphs to be remains of organisms of different origin, that may include ciliate lorica, resting cysts, and turbellarian egg capsules, however, they demonstrated that such cup and vase-shaped non-pollen palynomorphs are actually turbellarian egg capsules by comparing the morphology of modern turbellarian capsules with similar forms preserved in sediments.

B. Rotifer palynomorphs

Phylum *Rotifera* is characterized by the presence of a ciliated corona and a muscular pharynx called mastax (Wallace et al. 2006). Rotifers are small (~ 50–2000 mm), bilaterally symmetrical metazoans grouped within the pseudocoelomates. They are saccate to cylindrically shaped animals and possess three prominent regions which are corona, trunk, and foot.

Morphology, taxonomy, ecology, and reproduction process of rotifers are described by Wallace (2002). Phylum *Rotifera* primarily is a freshwater Metazoa containing two major groups: the heterogonic *Monogononta* and the exclusively parthenogenetic *Bdelloidea*. *Monogononta* are free-living freshwater taxa while *Bdelloidea* are predominantly limnoterrestrial. Monogononts inhabit in all types of water bodies around the world and are particularly diverse in the littoral zone of stagnant water bodies with soft, slightly acidic water and under oligo- to mesotrophic conditions (Segers 2008). In a subsequent paper Segers (2019) briefly discussed biology, life cycle, and suggested an identification key for all extant families of monogonont rotifers, except the North American endemic Birgeidae and a few other genera. Fontaneto and De Smet (2015) also provided a comprehensive account of biology, systematics, and distribution of rotifers.

These animals occupy all habitats where water is available, even for a short period, due to their ability to produce dormant stages that resist absence of water (Gilbert 1974, Ricci 2001). Thus, they become significant components of the aquatic biocoenoses in fresh, brackish, and to a lesser degree in marine environments. Most rotifer species occur in freshwater environments; however, few others inhabit brackish, and marine environments as well (Fontaneto et al. 2006, 2008). Benthic rotifers live at the water-sediment interface or in the top one cm of substrate. Saline rotifers occupy a diverse range of habitats, behaviors, and trophic levels at all latitudes and their species richness decreases with increasing salinity (Ruttner-Kolisko 1980a, Egborge 1994).

There are few reports of rotifer occurrences in and around the Arabian Peninsula. Van Damme and Segers (2004) reported presence of epizoic rotifer *Anomopus telphusae* Piovanelli, 1903 from the Socotran endemic crab *Socotra potamon socotrensis* Hilgendorf, 1883. This Rotifer species was earlier known only from freshwater crabs in Italy and Bulgaria; however, present report indicates its presence in the island of Socotra

offshore Yemen. Hammadi and Bielañska-Grajner (2012) discussed the biodiversity of rotifers in the Shatt Al-Arab region which is a large brackish water river formed by the confluence of the Tigris and the Euphrates Rivers in southern Iraq. Another report on rotifers from Iraq is by Ahmed and Ghazi (2014) who also studied rotifers from Shatt Al-Arab River and found that rotifer species composition varied between regions and ecological structures of the aquatic environments. A report from Iran by Reihan Reshteh and Rahimian (2014) described freshwater rotifer fauna from Khuzestan Province in Southwestern Iran. They found considerable similarities between Khuzestan's fauna with those of the Afro-tropical and Oriental regions.

Few other significant studies on rotifers in the Asian region include studies by Sa-Ardrit et al. (2013) who provided a checklist of 398 species of freshwater rotifers (*Monogononta* and *Bdelloidea*) from Thailand. These species are mostly cosmopolitan; however, a few are endemic to Thailand and southeast Asia. There are not many studies on littoral rotifers, especially from the estuarine environments. A long-term study of the littoral rotifers in a mangrove swamp and a tidal creek of Qi'ao Island in the Pearl River estuary of southern China revealed significant differences in the community structure at different sites and in different seasons. This study also revealed higher rotifer diversity and abundance at the mangrove wetlands which had more marine species with higher abundance mostly in the winter season (Wei and Xu 2014).

Due to lack of mineralization rotifers have very little preservation potential and therefore have a sparse fossil record. However, some rotifer species build external thecae which may be preserved in the fossil record. Rotifer thecae, eggs and body fossils have been reported from Quaternary bog sediments of Europe and North America (Warner & Chengalath 1988, van Geel 1978). Analysis of non-pollen palynomorphs may result in useful additional palaeoenvironmental information, for example, rotifer eggs are significant because of their potential palaeoenvironmental indicator value (van Geel 2001).

There are very few fossil records of rotifers (Poinar & Ricci 1992). Waggoner and Poinar (1993) described fossil habrotrochid rotifer from Eocene-Oligocene ambers from Dominican Republic and suggested that these microfossils are identical with the thecae of living moss-dwelling rotifers in the genus *Habrotrocha* (*Bdelloidea*). These amber fossils are bulbous, flask-shaped, dark brown to translucent, 95–135 µm long, somewhat bent having a slightly constricted neck, and with smooth surface. Mostly these are empty, but one specimen had egg like structure inside. *Habrotrocha* is the only genus in the *Habrotrochidae* in which smooth transparent theca are found, and *H. angusticollis* is the most common, widespread, and best known thecate habrotrochid species with wide morphological variations. Modern *Habrotrocha* is most common in wet mosses where moisture content is above 90%. The absence of rotifers suggests drying out of moss just before its fossilization (Waggoner & Poinar 1993). Similar forms have also been reported from pre-Quaternary peats that are almost identical to extant *Habrotrocha angusticollis* (Habrotrochidae; *Bdelloidea*) (van Geel 1978, Poinar & Ricci 1992). Thus, Habrotrochid rotifers seem to have persisted for 35 M yr BP with little change in their morphology or ecology (Waggoner & Poinar 1993).

Numerous records of subfossil rotifers are known from the Holocene peat bogs and other deposits, for example, *Bdelloidea* rotifers (Warner & Chengalath 1988, 1991) and *Monogononta* rotifers (e.g., Swadling et al. 2001, Turton & McAndrews 2006). Resting eggs of rotifers are also known as subfossils in different types of Holocene sediments (van Geel 2001). It has been suggested that some records of unidentified palynomorphs may be rotifer resting eggs (van Geel 1998). Warner and Chengalath (1988) reported on the occurrence of fossil rotifer shells of *Habrotrocha angusticollus* (*Bdelloidea*: *Rotifera*) from the Holocene peatlands in northern Ontario, Canada. The dark, proteinaceous protective shells of the order *Bdelloidea*, specifically of *Habrotrocha angusticollis* were reported from European fossil peat deposits

(Steinecke 1927, Frey 1964). Fossils of the whole rotifer species were also reported by van Geel (1985). In addition to the shells and the whole body, rotifer resting eggs are also known as fossils and regularly occur in lake deposits (Frey 1964), but according to van Geel (2001) normally their records are ignored. Many rotifer taxa pass the winter as resting eggs. Some rotifers live in shallow puddles, for such species the resting egg is a stage which can survive when the puddle dries up (van Geel, 2001). Merkt and Müller (1999) showed that Late-Glacial climate changes, as evident from the pollen record of Hämelsee (Germany), were also reflected in the oscillating frequencies of rotifer remains.

STUDY AREA

The study site is located west of the town of Abha on the southern Red Sea coast of Saudi Arabia between Jeddah in the north and Jizan in the south (Figure 1.A). The area under the study covers mainly a mixture of marginal marine and non-marine environments that include upper intertidal and supratidal flats (Figure 1.B). Microbial mats and mud flats, scattered patches of mangroves and their muddy environments, sand flats, both rippled and without ripples of the upper intertidal environments are covered under this study (Figures 2.A, 2.B). The samples were collected from the following environments: mangrove swamp environment, Middle Holocene paleochannel section, algal mat environment, Sabia Island coral reef environment, and intertidal environment.

MATERIALS AND METHODS

This study is based on 18 samples collected from five different localities representing five different coastal environments around the Wadi Hali area (18°49'35.27" N: 41°22'44.23" E) and its surroundings in the southern Red Sea coast of Saudi Arabia (Figures 1.B, 2.A, 2.B, 3.A, 3.B). These samples were collected during a geological field trip to the southern Red Sea coast of Saudi Arabia in the first week of March 2011. The surface samples represent top one cm of the sediments; their numbers and respective localities are given below.

1. Mangrove Swamp Environment (Figures 2.A, 3.A)**: Locality 1:** Two surface mud samples (M1 and M2); **Locality 2A:** Two surface mud samples (M3 and M4); **Locality 2B:** Three surface mud samples (M5, M6 and M7).

2. Intertidal Flat Environment (Figures 1.B, 3.B): **Locality 3:** A close-up of the area where samples L1– L7 were collected.

3. Coral Reef Environment (Figure 5): **Locality 4 (Sabia Island):** Two surface calcareous sand samples (SI1 and SI2) from the coral reefs around the island. These were grab samples collected by diving in the shallow water. Close to the shore in 1 m water depth (SI1) and further offshore in 2 m water depth (SI2).

4. Algal Mat Environment (Figure 2.B): **Locality 5:** Two surface mud samples (AM1 and AM2) from the algal mats of the hypersaline pools on the tidal flats.

Seven samples (L1 through L7) are surface semi consolidated sediments from the tidal flats, a small pond on the tidal flats and the subtidal environment. Four clay to fine sand samples (L1 through L4) are from different areas of tidal flats close to the shoreline. Two clay samples (L6 and L7) are from a small pond with abundant algae located 150 m away from the shoreline making samples L6 and L7 as farthest inland from the coastline. The sample L5 is subtidal mud collected 100 m away from the coastline under 1.5 m water depth (Figures 1.B, 3.B).

Sample lithology and locations are as follows: L1 is black mud from a small pond on the tidal flat; L2 is from a tidal channel that connects the pond with the sea; L3 is from a tidal flat surface full of fecal pellets and bioturbation; L4 is from a tidal flat along the shoreline; L5 is from subtidal mud, 100 m from the coast in 1.5 m water depth; L6 is mud and fine sand from middle of the pond, and L7 is silty to sandy laminated sediment on the edge of the pond (Kumar 2020).

Sediment samples were macerated following the techniques described in Kumar (2020). One cubic centimeter (cm^3) of dry sample was used in the
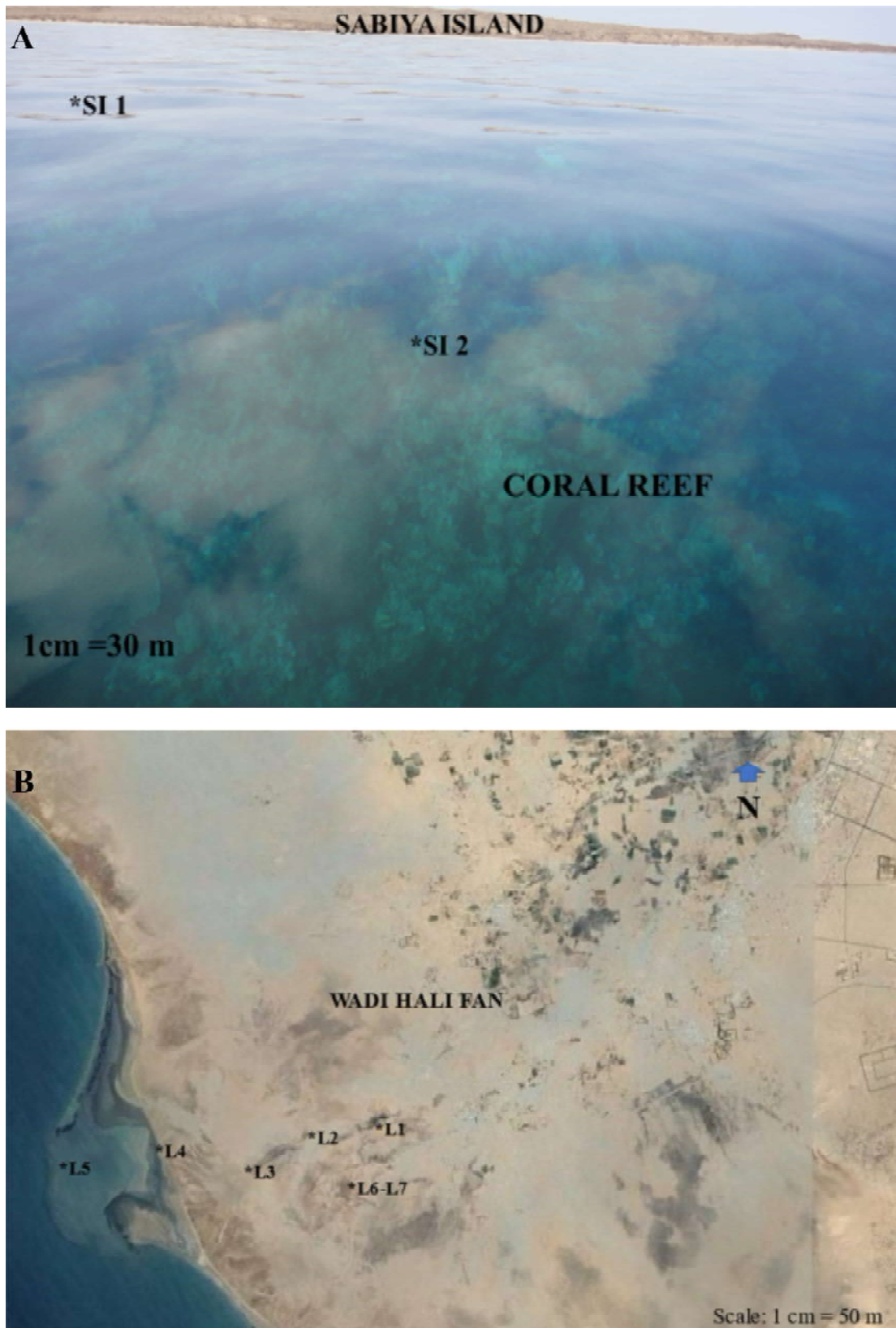
Figure 3. A. Localities of samples collected from offshore Sabia Island (Location 4). Two fine sand samples SI1 and SI2 (after Kumar 2021). **B.** A close-up of the intertidal flat where samples L1 through L7 (Location 3) were collected (after Kumar 2020).

maceration process using following method. (1) 10% HCl treatment for 15 minutes to remove carbonates. (2) Overnight cold HF (40%) treatment to remove silicate minerals. (3) Commercial grade HNO3 (sp. gr. 1.35) treatment for two hours at 80°C for oxidation of organic matter to remove unwanted organic debris. (4) 10% KOH treatment for 15 minutes followed by rotation at 1000 rpm for 5 minutes to remove humic matter. (5) Treatment of solution with 5% HCl to neutralize pH. (6) Residue sieved through10 μm mesh size sieve to remove clay minerals. (7) Residue with fraction larger than 10 μm fraction mixed with 3 drops of polyvinyl alcohol, mixed thoroughly, and smeared over coverslip and dried at 60°C over hot plate. (8) Mounted with Canada Balsam and kept for 20 minutes over hot plate at 80°C. (9) Four slides of each sample were made.

The slides were studied under an OMAX Optical Microscope (MD827S30L Series) using transmitted light. Each slide was scanned under x400 magnification and palynomorphs were photographed at ×400 and ×1000 (oil immersion) using an inbuilt camera system in the microscope. Few large palynomorphs were photographed at ×100 as well. Since palynomorph numbers are usually low, all palynomorphs in each slide were counted. All the palynological slides are stored in the palynology laboratory of Carleton Climate and Environment Research Group (CCERG), Department of Earth Sciences, Carleton University, Ottawa, Canada.

SYSTEMATIC PALYNOLOGY

The terms used in morphological description of form genus *Katora* and its four form species are primarily based on the tintinnomorph features described as lorica; pouch; and cyst, and their morphological organization described by van Waveren (1994). Additionally, morphological terms used to describe turbellarian egg capsules by Matsuoka and Ando (2021) have also been used to show alternative terms for the similar structures. The turbellarian egg capsules are described as one unit 'capsule' while a tintinnomorph is generally divisible into a corolla enclosing a chamber, an opening (sometimes with operculum), a calyx (a hollow appendix), a stem (a massive appendix), a horn (calyx plus stem), and a collar. The term chamber is combination of collar and corolla (van Waveren 1994, da Silva et al. 2017). The tintinnomorph term 'stem' is equivalent to turbellarian egg 'stalk'. The opening at the anterior end is described as an aperture by Matsuoka and Ando (2021).

Form Genus *Katora* A. Kumar, **gen. nov.**

Type species: *Katora arabica* A. Kumar, sp. nov.

Diagnosis: Corolla (capsule) grey, greyish yellow, yellow, and light brown, shape variable, could be oval, elliptical, spherical to subspherical, elongate, triangular, and rectangular. Aperture at the anterior end, diameter variable. Collar and operculum may or may not be present. Horn (calyx plus stem) may or may not be present, if present, its shape, and size is variable. A thread-like stem (stalk) of variable length and diameter is present at the posterior end. Wall generally opaque but rarely pale, almost translucent, surface generally psilate but sometimes ornamented. Size variable.

Etymology: Named after Hindi word Katora, which is a vase- or bowl-shaped metallic, earthen, or ceramic kitchen utensil commonly used in India.

Comments: Four new form species are described under this form genus *Katora* A. Kumar, gen. nov.

Katora arabica A. Kumar, **sp. nov.**

Figures 4.1–17

Synonymy: Plate 1g: *Gyratrix hermaphroditus* Ecotype 1-A (Haas 1996); Plate VIII/T1221: oocytes from Neorhabdocoela (flatworm) species (Gelorini et al. 2011); Figure 3(16): lorica type 1; cf. tintinnid loricae/turbellarian egg capsule (Mudie et al. 2011); Figure 9H: Polychaete egg capsule cove (Pieńkowski et al. 2012); Figure 4B: ELENO– 4 (da Silva et al. 2017); Figure 4C–4E: ESABNO– 6 (da Silva et al. 2017); Figure 4G – 4H: HEXANO– 2 (da Silva et al. 2017); Figure 2l: tintinnid resting cyst Elleno–13 of van Waveren, 1993 (Matsuoka et al. 2017); Figure 4a–b: Hexagonal, not ornamented type (Hexano–5) of van Wanveren 1993 (Matsuoka & Ishii 2018); Figure 4A, B, C: egg capsules

with stalks (Matsuoka & Ando 2021); Figure 5A, B, C: egg capsules possessing stalks basal attachment (Matsuoka & Ando 2021); Figure 8A, B: egg capsule of *Gieyztoria hermachreditus* (Matsuoka & Ando 2021); Figure 12A–12G: modern turbellarian egg capsules preserved in sediments (Matsuoka & Ando 2021); Figure 7o: trematode egg capsule with operculum (Mudie et al. 2021a); Figure 7p: ?lorica of *Ptychocylis* (Mudie et al. 2021a); Figure 7q, 7t: trematode egg capsule (Mudie et al. 2021a); Figure 7u, 7v: ? trematode egg capsule (Mudie et al. 2021a); Figure 7w: probable parasitic trematode egg capsule (Mudie et al. 2021a); Figure 11(5): flatworm egg capsule (Mudie et al. 2021b); Figure 11(12): flatworm egg capsule (Mudie et al. 2021b).

Diagnosis: Corolla (capsule) grey, yellow, and brown, of various shapes, predominantly cup-shaped with an aperture (opening) of variable diameter at the anterior end. Collar absent, but calyx may or may not be present. A thread-like stem (stalk) of variable length present at the posterior end. Wall generally opaque but rarely pale, almost translucent, surface generally psilate but sometimes ornamented. Size variable.

Holotype: slide L3a; 9.2 × 160.3; size 71 × 55 µm; stem length 35 µm (Figure 4.1).

Type locality: Recent intertidal sediments, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named owing to its occurrence on the margins of the Arabian Peninsula.

Description: Corolla (capsule) is predominantly of grey, yellow, and brown colour. It is primarily cup-shaped, without collar but calyx may be present in some specimens. Shape is variable, mainly egg-shaped orally blunt (Figures 4.1, 2, 6, 8,10,16), but could also be elongated elliptical (Figures 4.5, 15), spherical (Figure 4.11), triangular (Figures 4.3, 7, 12), and sub-tetragonal (Figure 4.17). Aperture (opening) at the anterior end and of variable diameter ranging between equatorial at 0° (Figures 4.6,7) to small, superior to 75° (Figures 4.5, 11, 17). Most aperture diameters range in between these ends and are either large (0°–30°) or medium (30°–75°). Operculum that covers the aperture of

capsule (see Matsuoka & Ando 2021, Figure 2) is rarely observed in this species (Figure 4.17). Calyx may be absent (Figure 4.11) and if present is short and triangular (Figures 4.1, 2, 3, 5, 9, 10, 15). A thread-like flagellar stem (stalk) is present at the posterior end. Stems may be long (Figures 4.4, 11, 12) or short (Figures 4.2, 13, 15, 17), may have a bulge (Figure 4.13, 16), or with rooted basal attachment (Figures 4.6, 7, 8, 10, 16). Calyx, if present, may be nodular (Figure 4.3), flagellar (Figures 4.1, 2, 5) or tailed (Figures 4.13, 14, 15). Wall generally opaque (Figures 4.1, 5, 12, 15, 17) but rarely pale almost translucent (Figure 4.7, 10), surface largely psilate but sometimes wrinkled and ornamented (Figures 4.3, 7, 14, 17).

Size Range (Based on 17 specimens): Length of Corolla (capsule): 37.8–117 µm, Width of Corolla (capsule): 32–85 µm, Stem (stalk) length: 18–126.8 µm.

Comments: The letter coding of van Waveren (1994) was used to informally describe various types of tintinnomorphs (Kumar 2020, 2021). The tintinnomorph type 1 (ESOBNO), type 6 (ESOBNO), type 8 (TRIANO–1), and type 15 (TRIA) from the intertidal sediments of the southern Red Sea coast of Saudi Arabia (Kumar 2020) conform to the description of this species. Similarly, tintinnomorph type 19 (ESOBNO–1), type 20 (AROBNO–1), type 23 (ESOBNO–4), type 24 (ESOBNO–4), type 25 (ESOBNO–4), type 27 (RECTNO), type 28 (ELLIPNO), type 31 (ESOBNO–4), type 32 (ESABNO), and type 34 (RECTNO) from various other southern Red Sea coastal environments (Kumar 2021) conform to the description of this species as well.

Such forms are widely reported as tintinnomorphs having biological affinity with Tintinnids (van Waveren 1994, da Silva et al. 2017). Some of the oocytes (egg capsules) of the aquatic flatworms of the Order *Neorhabdocoela* have certain morphological resemblance with a few tintinnomorph morphotypes (Haas 1996, Matsuoka & Ando 2021). However, *Neorhabdocoela* oocytes are typically elliptical to spherical and dark brown and are relatively larger in

size (60–600 μm), whereas shapes of tintinnomorphs are much more diverse, light grey, pale yellow and light brown, and relatively smaller in size (Kumar 2020). *Neorhabdocoela* oocytes occur predominantly in freshwater environments, while the present population of tintinnomorphs belonging to *Katora arabica* A. Kumar, sp. nov. occur in the marginal marine sediments.

Katora oblonga A. Kumar, sp. nov.

Figures 4.18–32

Synonymy: Plate 1h: *Gyratrix hermaphroditus* Ecotype 1-C (Haas 1996); Plate VIII/T1221, T1222, T1223: oocytes from Neorhabdocoela (flatworm) species (Gelorini et al. 2011); Figure 3(17): lorica type 2; cf. tintinnid loricae/turbellarian egg capsule (Mudie et al. 2011); Figure 9B: *Palaeostomocystis fritilla* (Pieńkowski et al. 2012); Figure 4A: SPHERO–1 (da Silva et al. 2017); Figure 4F: RECTNO–1 (da Silva et al. 2017); Figure 2b: tintinnid resting cyst, Spherno–1 of van Waveren 1993 (Matsuoka et al. 2017); Plate 5/10,11,12: *Palaeostomocystis* cf. *fritilla* (Hartman et al. 2018); Figure 4c–e: Asymmetrically rhombic, orally blunt, not ornamented type of van Wanveren, 1993 (Matsuoka & Ishii 2018); Figure 12H – 12L: modern turbellarian egg capsules preserved in sediments (Matsuoka & Ando 2021); Figure 7r and 7s: Trematode egg capsule (Mudie et al. 2021a); Figure 4d: *Palaeostomocystis fritilla* (Pieńkowski et al. 2020)

Diagnosis: Corolla (capsule) mainly light grey, yellow, and light brown, shape oval, ovoidal and oblong with an aperture of variable diameter at the anterior end. The posterior end is mainly rounded to subrounded and without horn (calyx plus stem). Wall opaque, sometimes pale, and translucent, surface psilate but rarely scabrate. Size variable.

Holotype: Slide L5c; 20 × 152.2; size 77 × 71 μm; opening 60 μm (O = operculum) (Figure 4.18).

Type locality: Recent intertidal sediments, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named owing to its oblong-oval shape.

Description: Corolla (capsule) is mainly light grey, sometimes of yellow or light brown colour. Its shape is variable, mostly oval-ovoidal or spherical (Figures 4.19, 21, 25, 26), but could also be elliptical-oblong (Figures 4.18, 20, 22, 27, 28, 32), and elongated-elliptical (Figures 4.23, 29, 30). Aperture (opening) is situated at the anterior end, is of variable diameter ranging between equatorial at 0º (Figures 4.24, 31) to small, superior to 75º (Figures 4.19, 21, 23, 29). Most aperture diameters range in between these two ends and are either large (0–30º) or medium (between 3º–75º). Operculum covers the aperture of the capsule is frequently observed in this species (Figures 4.18, 19, 21, 24). Horn (calyx plus stem) is absent. Wall generally opaque (Figures 4.18, 19, 21, 23, 24, 25, 30, 31) but may also be pale almost translucent (Figures 4.20, 22, 27, 28, 32), surface generally psilate but sometimes wrinkled and ornamented (Figures 4.22, 23, 26, 27, 32).

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Figure 4. 1-17. *Katora arabica* A. Kumar, **sp. nov. 1.** Slide L3a; 9.2 × 160.3; size 71 × 55 μm; stem length 35 μm. **2.** Slide L3a; 10.5 × 146.3; size 73 × 62 μm; stem length 19 μm. **3.** Slide L2b; 10.4 × 162.2; size 86 × 68 μm. **4.** Slide M5b; 4.7 × 134.5; size 43.5 × 38, length of stem 85 μm. **5.** Slide M7b; 16.5 × 133; size 96.5 × 60.8, length of stem 55 μm. **6.** Slide M5a; 19 × 132.5; size 99.5 × 81 μm. **7.** Slide M5d; 19 × 144; size 57 × 41.5 μm. **8.** Slide M5a; 19.4 × 135; size 104.2 × 79.7 μm. **9.** Slide AM1c; 5.5 × 134; size 74.8 × 49.4 μm. **10.** Slide SI 1d; 21 × 146; size 98 × 72; stem length 37.5 μm. **11.** Slide SI 2a; 17.5 × 145.8; size 37.8 × 32; stem length 126.8 μm. **12.** Slide SI 2a; 20.5 × 151; size 57 × 47.3; stem length 55.3 μm. **13.** Slide SI 1b; 18 × 155; size 78 × 61; stem length 25 μm. **14.** Slide SI 1d; 8 × 159.5; size 88 × 62 μm. **15.** Slide SI 1d; 13 × 133.5; size 130.9 × 98; stem length 26.6 μm. **16.** Slide M1a; 149 × 6.2; size 117 × 85 μm (×100). **17.** Slide L3d; 5 × 131.6; size 51 × 49 μm; stem 18 μm (O=Operculum). **18-32.** *Katora oblonga* A. Kumar, **sp. nov. 18.** Slide L5c; 20 × 152.2; size 77 × 71 μm; aperture diameter 60 μm (O=Operculum). **19.** Slide L3d; 6.8 × 149; size 42 × 40 μm (O=Operculum). **20.** Slide L3b; 7 × 146; size 72 × 46 μm. **21.** Slide L3c; 7 × 141.5; size 310 μm (×100) (O=Operculum). **22.** Slide L3c; 2.2 × 131.7; size 76 × 59 μm. **23.** Slide M2b; 6.5 × 154; size 160.4 × 56 μm. **24.** Slide AM2a; 13 × 130.3; size 96.2 × 76.6 μm. **25.** Slide M2a; 7 × 140.5; size 35.5 × 31 μm. **26.** Slide M6d; 4 × 137.5; size 58 × 48.7 μm; aperture diameter 16 μm. **27.** Slide AM2b; 4 × 150.4; size 73.2 × 62.2 μm. **28.** Slide AM2b; 4 × 150.4; size 73.2 × 62.2 μm. **29.** Slide SI 2a; 17 × 133.5; size 58.3 × 37.2 μm. **30.** Slide M2b; 151.2 × 13; size 58 μm, 56 × 27.6 μm. **31.** Slide M6d; 134.5 × 13.3; size 124.5 × 94.8 μm. **32.** Slide SI2b. 158 × 16.5; size 118 × 91 μm
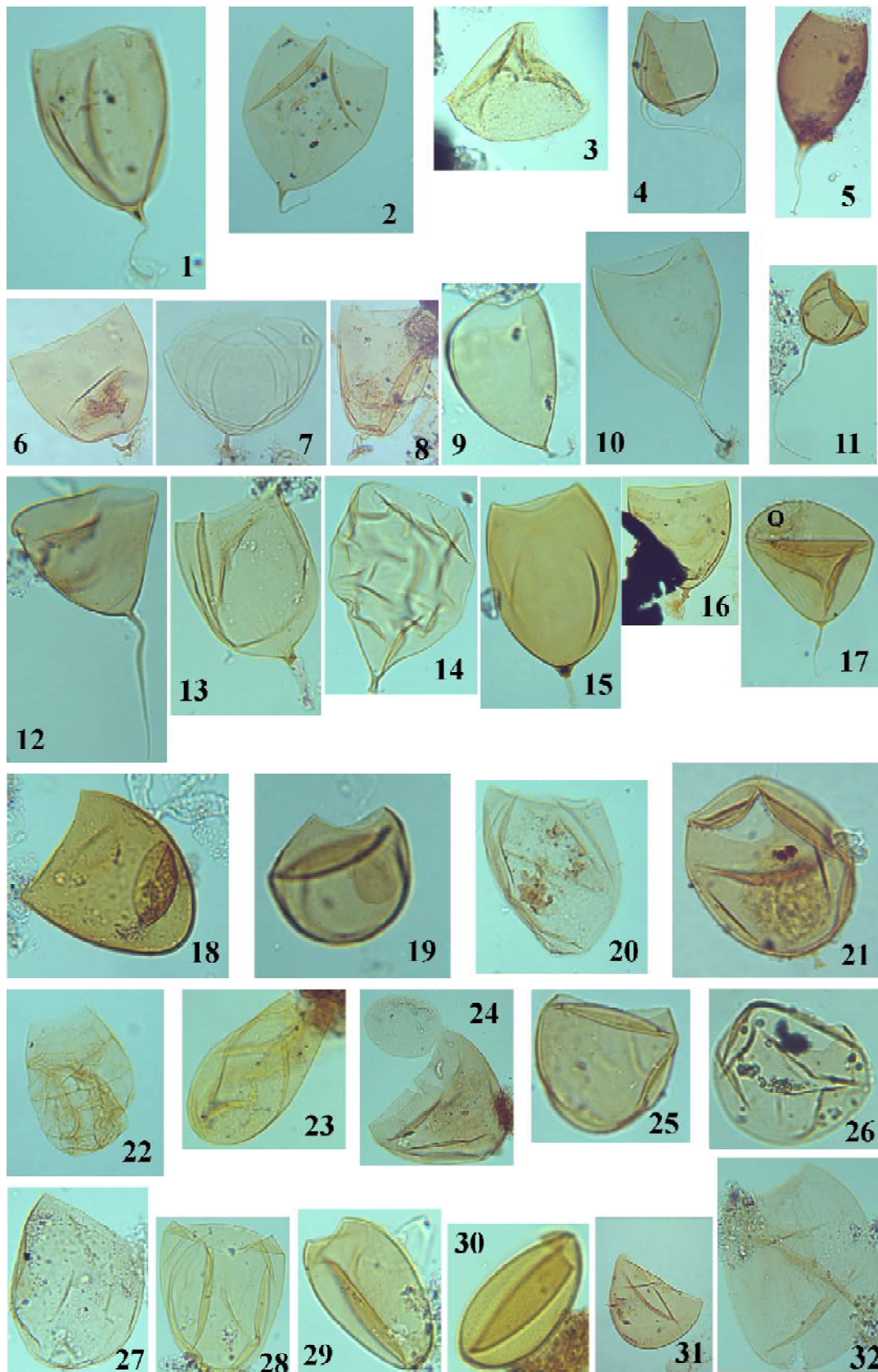
Figure 4

Size Range (Based on 15 specimens): Length of Corolla (capsule): 35–160.4 μm, Width of Corolla (capsule): 31–94.8 μm.

Comments: Informally described tintinnomorph type 2 (ELLIPNO), type 3 (SPHERNO), type 5 (ELLIPNO–1), type 7 (SPHERNO), and type 17 (ESABNO–1) from the intertidal sediments of the southern Red Sea coast of Saudi Arabia (Kumar 2020) and informally described tintinnomorph type 22 (ELLENO–2), type 29 (ESOBNO) and type 33 (RECTNO) from various other southern Red Sea coastal environments (Kumar 2021) conform to the description of *Katora oblonga* A. Kumar, sp. nov. The morphology of this species appears similar to the three basic morphological types D, E and F of turbellarian egg capsules found preserved in Holocene sediments (Matsuoka & Ando 2021, Figures 3, 4).

Katora twinmorpha A. Kumar, **sp. nov.**

Figures 5.1–7

Synonymy: Figure 11A: modern egg capsule of *Aegla serrana* Amato et al. 2003 (Matsuoka & Ando 2021)

Diagnosis: Twin corollas (capsules), greyish brown or light yellow colour. Two cup-shaped corollas (capsules) joined by their stems (stalks) and basal attachments. Collar and calyx absent. Aperture (opening) diameter equatorial at 0º. Wall generally opaque sometimes pale and translucent, surface psilate. Size variable.

Holotype: Slide M7c; 161 × 18; corolla (capsule) size 61.3 × 60.7 μm (Figure 5.7).

Type locality: Recent intertidal sediments, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named for two almost identical corollas (capsules) attached by their stem (stalk) and basal attachment.

Description: Twin corollas (capsules), predominantly of greyish brown and light yellow colour. They are cup-shaped with aperture (opening) at the anterior end, is equatorial at 0º (Figures 5.1–7). Corollas (capsules) may be attached (Figures 5.1, 3, 6) or widely separated (Figure 5.7). Collar, calyx, and operculum are absent. Stem (stalk) short, may be fused (Figures 5.1, 4, 5, 6) or separated having rooted basal attachment which is normally joined but sometimes appear to be disjointed, however, always in close proximity (Figures 5.2, 3, 7). Sometimes these capsules may contain cysts inside them (Figures 5.4, 6). Wall generally opaque (Figures 5.1, 2) but rarely pale almost translucent (Figure 5.4, 6, 7), surface psilate and sometimes wrinkled (Figures 5.1, 5, 7).

Size Range (Based on seven specimens): Length of Corolla (capsule): 48–98 μm, Width of Corolla (capsule): 40–67 μm.

Comments: The illustration of fungal genus *Glomus* sp. (Kumar 2020, plate 3, figure 22) was misidentified, this specimen conforms to the description of *Katora twinmorpha* A. Kumar, sp. nov. Informally described tintinnomorph type 21 (ESOBNO–4) from various other southern Red Sea coastal environments (Kumar 2021) conform to the description of this species as well. Basal attachment developed in modern turbellarian capsule of *Aegla serrana* (Amato et al. 2003, figure 4) is illustrated by Matsuoka and Ando (2021, Figure 11-A) is similar to *Katora twinmorpha* A. Kumar, sp. nov.

Katora elongata A. Kumar, **sp. nov.**

Figures 5.8–14

Synonymy: Figure 4I: AROBNO–3 (da Silva et al. 2017)

Diagnosis: Corolla (capsule) generally grey, greyish yellow, yellow, and brown, shape elongated elliptical, rectangular, and width to length ratio is 1: >2.5. Aperture is of variable diameter at the anterior end without collar. The posterior end may be angular, subrounded or flat and with a short horn (calyx plus stem). Wall opaque, surface psilate but sometimes reticulate. Size variable.

Holotype: Slide M2c; 12.2 × 156; size 102 × 33.5 μm (Figure 5.12).

Type locality: Recent intertidal sediments, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named owing to its elongate shape.

Description: Corolla (capsule) is of grey, greyish yellow, yellow, and brown colour. Shape is elongated elliptical (Figures 5.9, 11, 13) and rectangular (Figures 5.10, 12, 14), ratio of width to length is 1: >2.5. Aperture (opening) is situated at the anterior end, is of variable diameter ranging from medium, between 30º–75º (Figures 5.8, 9, 12, 14) to small, superior to 75º (Figures 5.10, 11). Operculum is rarely observed in this species (Figure 5.10). Posterior end is generally rounded (Figures 5.8, 11, 12), but sometimes flat (Figure 5.10) or angular (Figures 5.9, 13, 14). There are forms whose posterior ends may have short triangular calyx (Figure 5.9) or elongated triangular calyx (Figure 5.13), or a short tubular stem (Figures 5.8, 12, 14) or a nodule (Figure 5.11). Wall opaque, surface generally psilate but could be reticulate (Figure 5.9, 13).

Size Range (Based on 7 specimens): Length of Corolla (capsule): 57–262 µm, Width of Corolla (capsule): 24–74.2 µm.

Comments: Informally described tintinnomorph type 4 (ELELNO) and type 10 (RECTNO–1) from the intertidal sediments of the southern Red Sea coast of Saudi Arabia (Kumar 2020) and informally described tintinnomorph type 18 (RECTNO–2), type 26 (ELELNO–2), type 30 (ELELNO–4), and type D from various other southern Red Sea coastal environments (Kumar 2021) conform to the description of *Katora elongata* A. Kumar, sp. nov.

Form Genus **Mangrovia** A. Kumar, **gen. nov.**

Type species: *Mangrovia redseaensis* A. Kumar, sp. nov.

Diagnosis: Shells grey, dark grey, greyish brown to light brown, shapes variable, may vary between oval-elongated, elliptical-elongated, or flask shaped. Neck length and width variable that may or may not have swelling. Aperture small, circular to subcircular, ovoidal with or without a ring. Posterior end generally rounded, sometimes flat, angular, or rarely bifurcated. Occasionally a cyst may be present inside a shell. Wall opaque, surface smooth but sometimes finely granular. Size variable.

Etymology: This genus is named owing to its occurrence in the mangrove swamp environment.

Comments: Morphologically almost identical forms were described as fossil Rotifer shells by Warner and Chengalath (1988, 1991) and Waggoner and Poinar(1993). Therefore, *Mangrovia* A. Kumar, genus nov. is described using their morphological terms (Warner & Chengalath 1988, 1991, Waggoner & Poinar 1993). Two new form species belonging to *Mangrovia* A. Kumar, gen. nov. are being described.

Similar forms were also described as tintinnomorphs by van Waveren (1994), for example, SPHERNO–8 (spherical not ornamented), and ESABNO–l, ESABNO-2 (Egg-shaped aborally blunt not ornamented). A tintinnomorph was described as AROBNO–3 (orally blunt, not ornamented) by da Silva et al. (2017) is also similar to certain forms in this genus.

Fairly similar forms were also described as testate amoebae, for example, *Difflugia oblonga* Ehrenberg 1832. This species varies considerably in its shape and size, however commonly they are flask shaped and their tests are made of sand particles and diatom frustules. Their fundus is rounded, neck subcylindrical, aperture terminal, circular to subcircular (Ellison & Ogden, 1987, Kumar & Dalby 1998). This species is morphologically very similar to certain forms belonging to *Mangrovia* A. Kumar, gen. nov. However, the main difference is that *Difflugia oblonga* Ehrenberg 1832 inhabits freshwater environments and their tests are agglutinated, whereas *Mangrovia* A. Kumar, gen. nov. has a smooth organic wall and inhabits marginal marine, brackish water environments. Several vase- or urn-shaped testate amoebae, similar in shape and size to certain tintinnomorphs were reported from the peatland mosses as well (Swindle & Roe 2007, Mudie et al. 2011).

Mangrovia redseaensis A. Kumar, **sp. nov.**

Figures 5.15–27

Synonymy: Plate 1D: cyst-type K (Reid & John 1978); Plate 1E: smooth-walled *Sphaeropsis* tintinnid

cyst (Reid & John 1978); Plate 1F: elongate *Sphaeropsis* tintinnid cyst (Reid & John 1978); Figure 3, 4A, 4B, 5, 7: SEM image of vase-shaped microfossil (VSM) (Porter & Knoll 2000); Figure 4s: *Strombidium*? Cyst A (Pieńkowski et al. 2020); Figure 4u: Cyst K sensu Reid and John 1978 (Pieńkowski et al. 2020).

Diagnosis: Shell grey to dark grey, shape oval-elongated, flask shaped. Neck length and width variable, characterized by annular swelling. Aperture small, circular to subcircular or ovoidal with a distinct ring. Posterior end generally rounded but occasionally flat or angular. A cyst may sometimes be present inside the shell. Wall opaque, surface smooth, occasionally finely granular. Thin membranous sheath may fully or partly cover the shell. Size variable.

Holotype: Slide M2c; 8 × 143; size 104 × 54 μm, aperture 22 × 17 μm (Figure 5.15).

Type locality: Mangrove swamps, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named after the Red Sea.

Description: These shells are light to dark grey, their shapes are variable, may be oval-elongated (Figures 5.15, 19, 25, 27), elliptical-elongated (Figures 5.17, 20), and flask shaped (Figures 5.22, 23, 27). Neck length and width variable, generally characterized by swelling (Figures 5.15, 19, 22, 23, 27). Aperture small, circular to subcircular (Figures 5.15, 18, 19, 20),

ovoidal (Figure 5.16) with a distinct ring (Figures 5.15, 18, 20, 25). Posterior end generally rounded but may be flat (Figures 5.16, 23), angular (Figures 5.18, 19) or rarely bifurcated (Figure 5.21). A cyst may sometimes be present inside the shell (Figures 5.20, 23). Thin membranous sheath may almost fully (Figures 5.16, 21, 24) or partly (Figures 5.15, 16, 27) cover the shell, whereas few specimens do not have such covering (Figures 5.18, 23, 26). Wall opaque, surface generally smooth but sometimes finely granular (Figures 5.26, 27).

This species occurs in sediments of mangrove swamps of southern Red Sea coast of Saudi Arabia. Size variable.

Size Range (based on 13 specimens): Length of shell: 91–132.6 μm, Width of shell: 43.5–76 μm, Aperture diameter: 11.9–26.9 μm.

Comments: Warner and Chengalath (1988) described fossil shells of the rotifer *Habrotrocha angusticollus* (*Bdelloidea*: *Rotifera*) from Holocene peat deposits in northern Ontario, Canada, a common microfaunal element of *Sphagnum* peat deposits and other wet mossy habitats. *Bdelloidea* are solely freshwater organisms, have a contractile body, and some of them are protected in a shell. The dark, proteinaceous protective shells are secreted by the body of the animal that allows them to occupy a wide range of ecological conditions in mossy habitats that may be submerged, emergent, or terrestrial and only occasionally wet. The

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Figure 5. 1–7. *Katora twinmorpha* A. Kumar, **sp. nov. 1.** Slide L6a; 15 × 132.3; size 58 × 48 μm (Kumar 2020, pl. 3/22). **2.** Slide M1b; 11.8 × 129; size 95 × 67 μm and 98 × 65 μm. **3.** Slide AM2b; 4.4 × 150; size 64.7 × 47 and 54 × 50 μm. **4.** Slide L6a; 132 × 19; size 48 × 47 μm. **5.** Slide M3a; 140 × 8; size 65 × 45.2 μm. **6.** Slide M6a; 160.5 × 11.5; size 49.2 × 40 and 54.7 × 52.4 μm. **7.** Slide M7c; 161 × 18; size 61.3 × 60.7 μm. **8–14. *Katora elongata*** A. Kumar, **sp. nov. 8.** Slide M6b; 21 × 146.5; size 137 × 65.8 μm. **9.** Slide L5b; 9 × 148.2; size 78 × 29 μm (Lorica parts are labelled as shown in Figure 2 in van Waveren, 1994). **10.** Slide L6c; 9 × 169; size 262 × 61 μm (×100). **11.** Slide SI 1b; 17.8 × 146; size 58.5 × 24 μm. **12.** Slide M2c; 12.2 × 156; size 102 × 33.5 μm. **13.** Slide M7d; 610.5 × 148.5; size 57 × 26 μm. **14.** Slide SI2d. 137.5 × 18.2; size 133 × 74.2 μm. **15–27. *Mangrovia redseaensis*** A. Kumar, **sp. nov. 15.** Slide M2c; 8 × 143; size 104 × 54 μm, aperture 22 × 17 μm. **16.** Slide M5d; 10.5 × 136; size 127.7 × 61.5 μm. **17.** Slide M6a; 8.5 × 153.5; size 89.5 × 43.5 μm. **18.** Slide M3a; 165 × 5.5; size 100 × 60 μm. **19.** Slide M6a; 154 × 5; size 132.6 × 60 μm; aperture 26 × 17 μm **20.** Slide M6a; 159 × 12.4; size 123.6 × 46 μm. **21.** Slide M6a; 159.8 × 3.6; size 132 × 76 μm. **22.** Slide M6b; 134.4 × 5.4; size 120.9 × 61 μm; aperture 26.9 × 15 μm. **23.** Slide M6a; 135.5 × 5; size 126 × 53 μm; aperture 27 × 15 μm. **24.** Slide M3c; 141.2 × 4.4; size 91 × 51 μm. **25.** Slide M5c; 147.5 × 10; size 132 × 67 μm; aperture 25.8 × 11.9. **26.** Slide M2d; 162.8 × 16; size 94 × 54.5 μm, aperture 24.7 × 14 μm. **27.** Slide M6b; 155 × 15.2; size 117.8 × 60.8 μm; aperture 26.9 × 14 μm. **28–33. *Mangrovia hallii*** A. Kumar, **sp. nov. 28.** Slide M6d; 150 × 14,8; size 83 × 33 μm. **29.** Slide M6c; 155.5 × 2; size 92 × 38.4 μm; aperture 24.4 × 4 μm. **30.** slide M6a; 131.6 × 6.6; size 90 × 47 μm; aperture 13 × 4.5 μm. **31.** Slide M7c; 146 × 11; size 125.9 × 36.8 μm. **32.** Slide AM2b; 142 × 20.4; size 270.6 × 80.4 μm. **33.** Slide AM2a; 145.5 × 10; size 127.6 × 87.4 μm (×100).
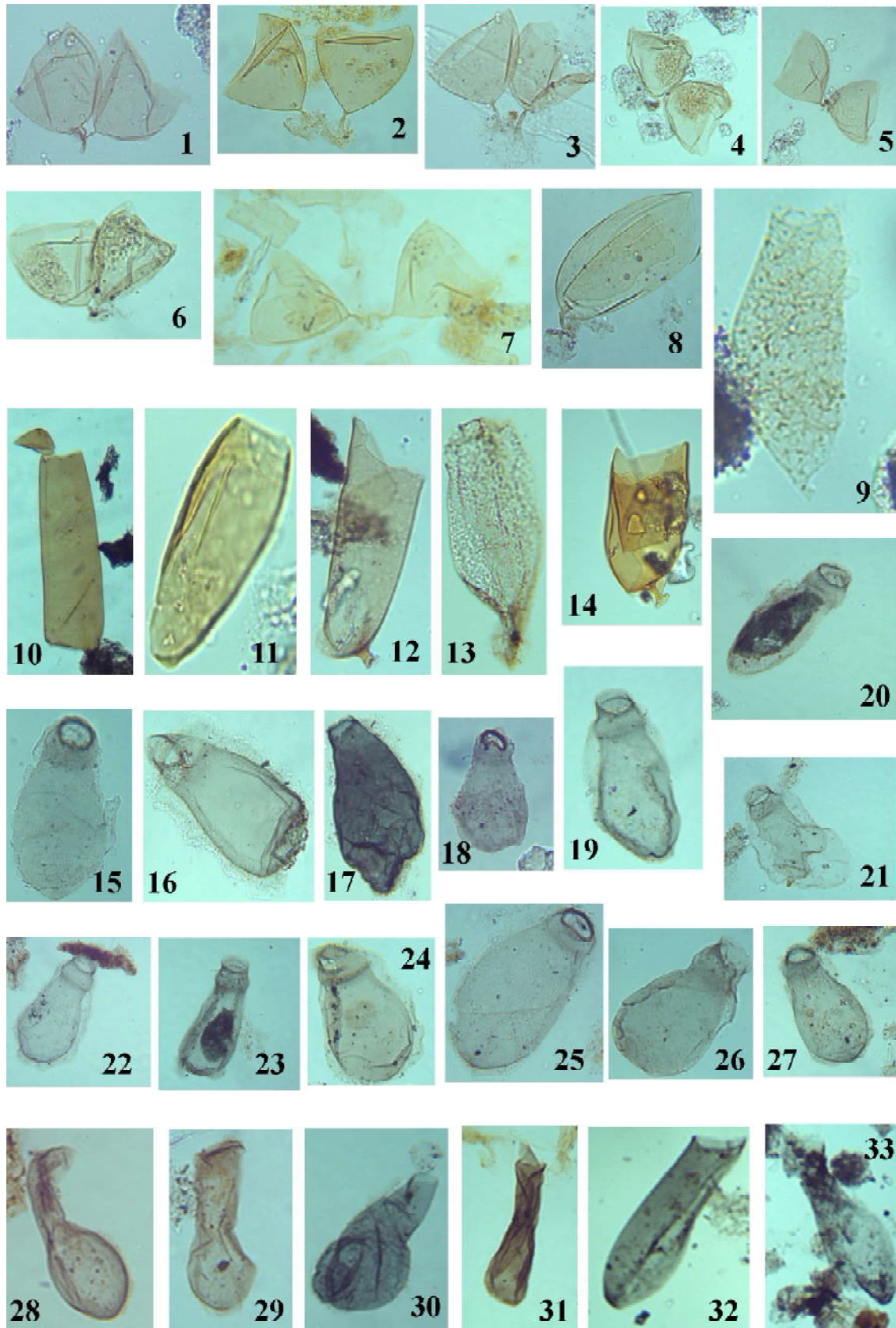
Figure 5

shells of *Habrotrocha angusticollis* are favorable to preservation in fossil peat deposits. The shells of this species were observed in Europe and North America as well (Warner & Chengalath 1988). The description and illustrations of *H. angusticollis* shells by Warner and Chengalath (1988, figures 6–8) show very close morphological resemblance to this species; thus, have biological affinity with *Habrotrocha angusticollis* (*Bdelloidea*: *Rotifera*).

Thecamoebian type C informally described from mangrove swamps in the southern Red Sea coast of Saudi Arabia (Kumar 2021) is assigned to this species. Porter and Knoll (2000) described vase-shaped microfossils (VSMs) from the Neoproterozoic Chuar Group of Grand Canyon, Arizona. Based on the morphology and taphonomy, they suggested their biological affinity with testate amoebae. The VSMs illustrated by them (Figures 3, 4, 5, 7) have close morphological similarity with *M. redseaensis* A. Kumar, sp. nov. In a further study of these VSMs Porter et al. (2003) used the taxonomy of modern testate amoebae as a guide to describe nine new species and eight new genera. Their new VSM species *Cycliocyrillium simplex* (Figure 6:1–9); *Cycliocyrillium torquata* (Figure 6:12–23); *Bonniea dacruchares* (Figure 9:1–15) and *Bonniea pytinaia* (Figure 9:16–23) show morphological resemblance with *M. redseaensis* A. Kumar, sp. nov.

Additionally, forms similar to *M. redseaensis* A. Kumar, sp. nov were described as tintinnomorphs by van Waveren (1994), they are SPHERNO–8 (spherical not ornamented), and ESABNO–l, ESABNO–2 (Egg-shaped aborally blunt not ornamented). Another tintinnomorph described as AROBNO–3 (Figure 4-I; orally blunt, not ornamented) by da Silva et al. (2017) is also similar to certain forms as rotifer shells.

Mangrovia hallii A. Kumar, **sp. nov.**

Figures 5.28–33

Synonymy: Plate 1c: cyst-type P (Reid & John 1978); Figure 4q: Tintinnid J (Pieńkowski et al. 2020); Figure 7d: cyst-type P of Reid & John 1978 (Mudie et al. 2021a).

Diagnosis: Shell grey to dark grey, greyish brown to light brown, shape elongated elliptical, rectangular or flask shaped. Neck long, length and width variable. Aperture circular to subcircular, diameter small or large, generally larger than *Mangrovia redseaensis*. Posterior end rounded but may be flat or angular. Wall opaque, surface smooth sometimes finely granulate. Size variable.

Holotype: Slide M6c; 155.5 × 2; size 92 × 38.4 μm; aperture 24.4 × 4 μm (Figure 5.29).

Type locality: Mangrove swamps, southern Red Sea coast of Saudi Arabia.

Etymology: This species is named after Wadi Hali, the area from where it is described.

Description: Shell grey to dark grey (Figures 5.30, 33), and greyish brown to light brown (Figures 5.28, 29, 31). Shape elongated elliptical (Figures 5.32, 33), rectangular (Figure 5.31), and flask shaped (Figures 5.28, 29). Neck long straight (Figures 5.29, 30, 31) and sometimes curved (Figure 5.28). Aperture circular to subcircular (Figures 5.29, 30, 32). Posterior end generally rounded but may be flat (Figure 5.31), and angular (Figures 5.32, 33). Wall opaque, surface generally smooth but sometimes finely granular (Figures 5.28, 30, 32). Size variable.

Size Range (based on 6 specimens): Length of shell: 83–270 μm, Width of shell: 33–87.4 μm, Aperture diameter: 13–24.4 μm.

Comments: This species occurs in mangrove swamps and algal mat environments in the southern Red Sea coast of Saudi Arabia. It differs from *M. redseaensis* in being elongated, occasionally of light brown colour, wider aperture and lack of swelling around the neck. Waggoner and Poinar (1993) described fossil Habrotrochid rotifers from Eocene-Oligocene amber from Dominican Republic. These are flask-shaped microfossils almost identical with thecae of extant rotifer *H. angusticollis* (*Bdelloidea*: *Rotifera*). Some of their illustrations closely resemble *Mangrovia* species described here. Figure 8 of Waggoner and Poinar (1993) shows thecae of various extant *Habrotrocha* species. Figure 8A *Habrotrocha*

angusticollis is like *Mangrovia hallii*, figure 8B *Habrotrocha angusticollis reversa* is like *Mangrovia redseaensis* and figure 8C *Habrotrocha angusticollis attenuata* is similar to *Mangrovia hallii*. Thus, *Mangrovia hallii* has biological affinity with various extant *Habrotrocha* species.

DISCUSSION AND CONCLUSIONS

Palynomorphs of various shapes such as vase, urn or related forms are often observed in the palynological studies of Quaternary-Recent marine and brackish water sediments. Generally, they are of yellowish, brownish, and greyish colour with smooth wall but rarely may be agglutinated as well. Their biological affinities are debatable. Some authors relate them to tintinnid loricae and cysts naming them as tintinnomorphs (van Waveren 1994). Da Silva et al. (2017) considered tintinnomorphs not be always identifiable as true tintinnid lorica, cysts or pouch, they may also be related to other metazoans such as rotifers and even the soft-bodied flatworms belonging to class *Turbellaria*. A few similar forms were reported from lacustrine sediments and were oocytes or resting eggs in the size range of 6–200 µm of *Neorhabdocoela*, a small, soft-bodied flatworm found in freshwater environments all over the world (Hass 1996).

The tintinnomorphs recovered from brackish-water sediments are not reliable indicators of paleoenvironments since they are thought to be derived from a wide array of micro-organisms and meiobenthos. However, Canudo (2004) considered tintinnoids and tintinnomorphs to represent true tintinnid loricae and similar forms, minimizing the mistaken designations. Further discussion on this subject emphasized that actual biological links between tintinnomorphs and tintinnids needs confirmation (Mudie et al. 2011). Tintinnids are a less well-studied group of NPP thus more taxonomic and source-linkage studies are needed (Miola 2012). This problem becomes more difficult since widespread occurrence of vase- or urn-shaped testate amoebae, very similar in shape and size to certain tintinnomorphs, are known from the peatland mosses (Swindle & Roe 2007, Mudie et al. 2011).

Thirty-four types of tintinnomorphs were informally described from the recent sediments belonging to various coastal environments of the southern Red Sea coast of Saudi Arabia (Kumar 2020, 2021). With an idea to provide formal taxonomic names to such microfossils; two new form genera and six new form species are being proposed from these thirty-four tintinnomorphs. A form genus is defined as "a genus unassignable to a family, but it may be referable to a taxon of higher rank… Form genera are artificial in varying degree." (Tschudy & Scott, 1969, p. 60). The objective of this study was to conceptualize and categorize such morphological groups under formal names. Since their true biological affinities are debatable, thus form genera and form species are proposed.

Bdelloidea rotifers are supposedly solely freshwater organisms, however, occurrence of their shells in the mangrove swamps and algal mats reported here indicate their occurrence in brackish environments as well. Wei and Xu (2014) reported occurrence of Bdelloid spp. from mangrove swamps from Qi'ao Island, Pearl River estuary, China, but did not report the occurrence of Habrotrochid rotifers.

Such forms are described by their shape and size using varied terminologies. Identifying such forms become confusing since there is no standard nomenclature to describe them. There is confusion about their identifications in the absence of any formal taxonomic identity as genus and species. This study proposes form genera *Katora,* and *Mangrovia,* and form species *K. arabiaca, K. elongata, K. oblonga, K. twinmorpha, M. redseaensis* and *M. hallii*.

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