Diversity and distribution of benthic foraminifera in the Al-Kharrar Lagoon, eastern Red Sea coast, Saudi Arabia

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ABSTRACT: High-resolution benthic foraminiferal study was carried out on the surficial bottom sediments of the Al-Kharrar Lagoon (KL), north of Rabigh City, eastern Red Sea coast, Saudi Arabia. One hundred thirty surface sediments samples were collected from the lagoon during March 2014 to investigate the benthic foraminiferal diversity, abundance, distribution and controlling factors. The lagoon's water environmental parameters such as temperature, salinity, dissolved oxygen and pH, water depth, sediment grain size, organic matter and carbonate were also studied. Statistical techniques were applied to test the reliability of collected data and to facilitate the interpretation. The results showed that faunal density and diversity were with averages of 135±300 dead tests/g and 23±10 displaying the highest values (3000 and 44) only in some intertidal areas, respectively. The Q-mode cluster analysis as well as the spatial distribution of the benthic foraminifera allowed the division of KL into five environmental biotopes such as the southern tip, the mid-eastern side, the inlet, the whole intertidal-subtidal and, the deeper area. These biotopes were dominated by five major assemblages such as an intertidal assemblage (*Quinqueloculina seminula-Q. laevigata* and *Affinetrina quadrilateralis-Neorotalia calcar*), an inlet *Amphistegina lessonii* assemblage, an intertidal-subtidal assemblage (*Peneroplis planatus-Coscinospira hemprichii-Sorites orbiculus*) and deep-water assemblage (*Spiroloculina communis-Triloculina serrulata-T. trigonula*). The canonical correspondence analysis indicated that the intertidal-subtidal assemblage is positively correlated with high salinity, temperature, and bioclastic sandy substrates with algal mats, sea-grasses and macro-algae, reflecting their preferences to warm, dry climatic conditions. The deep-water assemblage showed positive relationships with pH, deep muddy substrates enriched in organic matter, and negatively correlated with high temperature and salinity. The inlet assemblage is also correlated with the deeper waters where hard to coarse-grained substrates predominate.

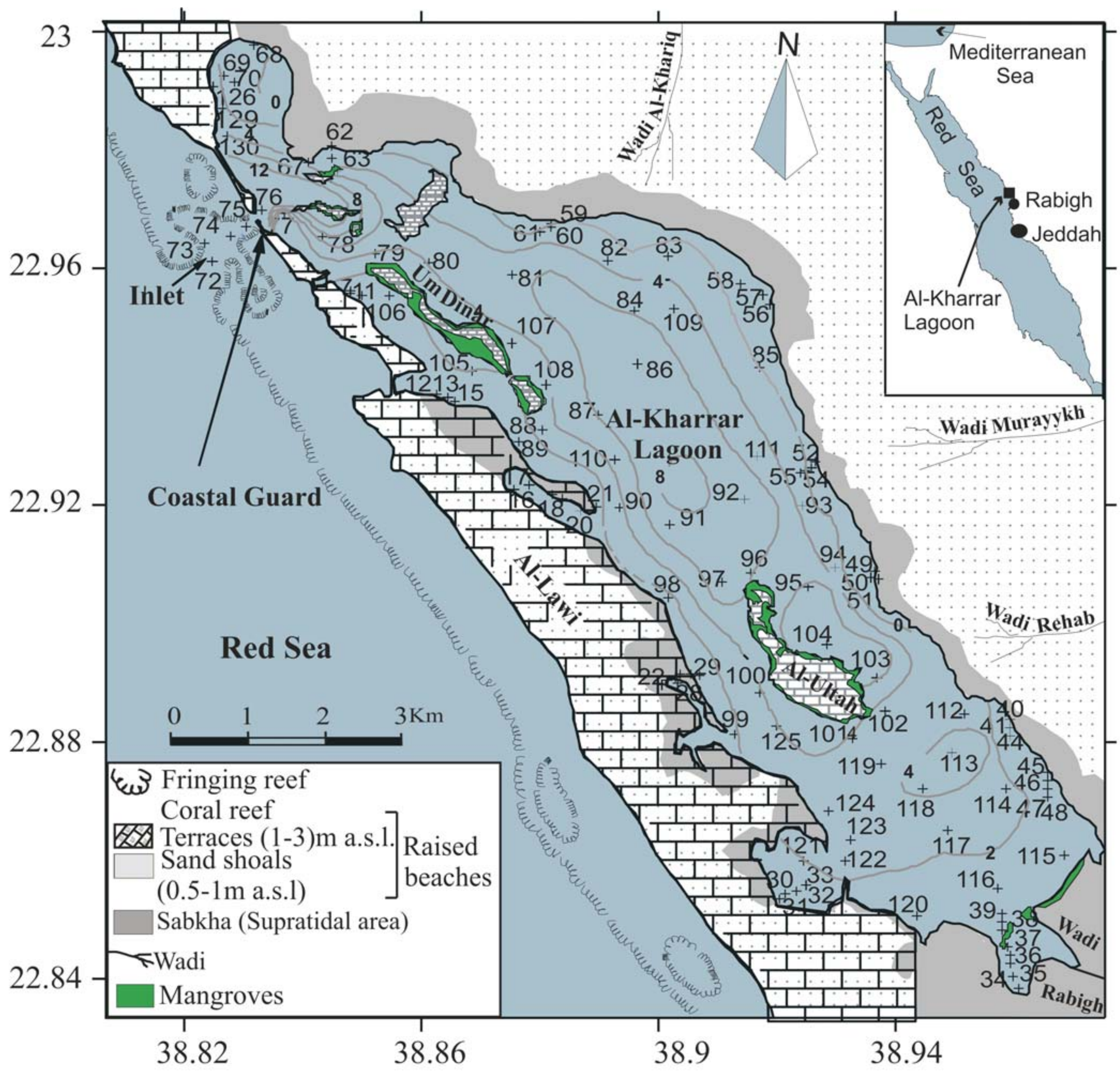
Key words: Biotopes, Foraminifera, Al-Kharrar Lagoon, Intertidal, Subtidal, Red Sea

INTRODUCTION

The benthic foraminifera of coastal lagoons have commonly been used by many authors (e.g., Albani and Johnson 1975; Albani and Barbero 1982; Albani et al. 1984, 1991, 1998; Bernhard 1987; Hayward et al. 1996; Abu-Zied et al. 2007, 2016; Al-Dubai 2011; Strotz 2012; Frontalini et al. 2013) to subdivide these areas into ecological biotopes based on the composition and spatial distribution of these fauna. For example, Albani and Barbero (1982) studied foraminiferal fauna in a selected portion of the Lagoon of Venice (Italy) to define biotopes, based on them, they found that their geographic extent subdivided the Lagoon into areas of similar hydrological conditions. Also, Frontalini et al. (2013) investigated benthic foraminiferal assemblages in Lake Varano (southern Italy) to identify biotopes and their spatial distribution within the lake. They recognized the existence of two main biotopes and five sub-biotopes that are separated from one another by salinity gradients, grain-size substrates and organic matter content in sediments.

Over the last few decades, the Al-Kharrar Lagoon (KL) has been studied by many authors, who focused on the hydrographic features, sedimentological, mineralogical, geochemical aspects, and microfossils of the sediments (Behairy et al. 1991; El-Abd and Awad 1991; Abou-Ouf 1996; Al-Washmi 1999; Basaham 2008; Basaham et al. 2015; Hariri 2008; Al- Barakati 2010; Al-Barakati and Ahmad 2012; Mandurah 2010; Manaa 2011; Youssef and El-Sorogy 2016; Abu-Zied and Hariri 2016). Abou-Ouf and El-Shater (1993), Abou-Ouf (1996), Hariri (2008) and Abu-Zied and Hariri (2016) have only discussed the distribution of benthic foraminifera in the lagoon sediments and its surrounding area. For example, Abou-Ouf (1996) studied the abundance and distribution of benthic foraminifera and indicated that Rotaliina (*Calcarina*, *Amphistegina* and *Ammonia*) dominate in the coarse sediments of the KL. Hariri (2008) investigated the benthic foraminifera of the KL and assumed that they were mainly controlled by environmental factors such as salinity, sediment texture, light and water depth. Abu-Zied and Hariri (2016) studied the geochemistry and benthic foraminifera of the nearshore sediments from Yanbu to Al-Lith and reported that *Coscinospira hemprichii-Varidentella neostriatula* assemblage increased northwards, indicating the increase of salinity northward; whereas, the *Neorotalia calcar-Neoeponides bradyi* assemblage increased southward, indicating the profusion of seagrasses and filamentous algae.

The previously published works on the KL have not attempted to study the benthic foraminifera. Therefore, the present study aims to investigate the diversity, abundance, distribution of benthic foraminiferal species in the surface sediments of the KL

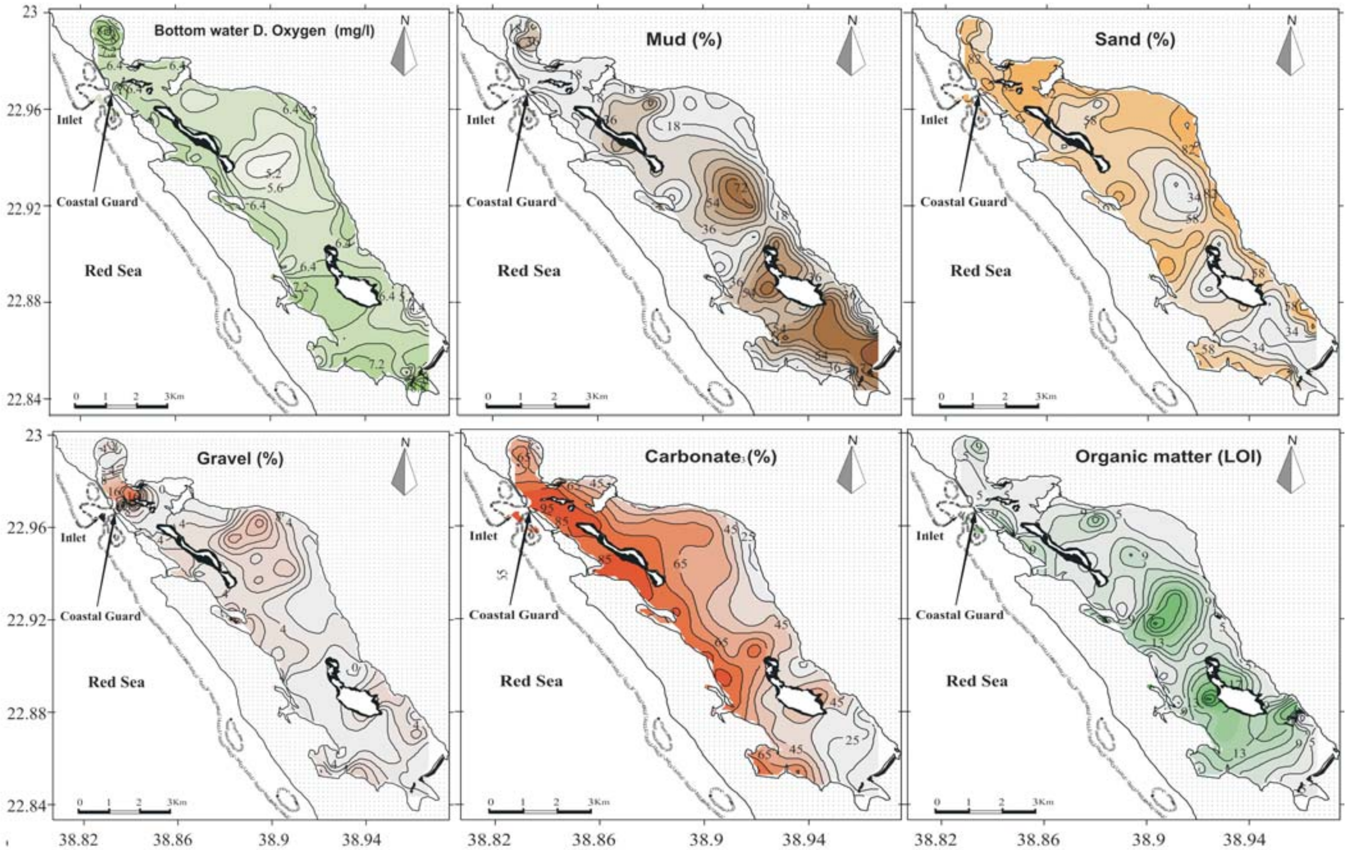


TEXT-FIGURE 1
Location map of the KL, bathymetry, the surrounding area and wadis, and sample sites. Modified after Al-Dubai et al. (2017).

and correlate them with environmental conditions in order to use them as a modern model for paleoenvironmental interpretation, and as a base-line for future monitoring of the lagoon.

THE STUDY AREA

The KL is situated on the central Red Sea coast, 10 km north of Rabigh City, Saudi Arabia, between latitudes 22.83° and 23°N and longitudes 38.81° and 38.97°E (text-fig. 1). It is locally known as Sharm Al-Kharrar, and thought to have originated by erosion during the late Pleistocene and drowned by the post-glacial sea-level rise, especially during the early Holocene transgression (Braithwaite 1987; Brown et al. 1989; Al-Washmi 1999). The KL is an elongated-shaped basin with its long axis (20 km long) parallel to the Red Sea coast and a maximum width of 5 km, having shallow bathymetry with a mean depth of 5 m, whereas the deepest part (8 m) occurs in the central-northern part of the lagoon (Al-Dubai et al. 2017). It is connected with the Red Sea via a narrow, shallow inlet (about 120 m wide and 14 m deep) located at the northwestern corner of the lagoon (text-fig. 1). The KL is subjected to a warm, dry tropical climate with episodic rainfall (50–100 mm/year, mostly in November–May) and sporadic influx of freshwater during the winter across four intermittent wadis such as the Rabigh, Rehab, Murayykh, and Al-Khariq (Ramsay 1986). The freshwater of



TEXT-FIGURE 2
Distribution maps illustrating: bottom dissolved oxygen (DO, mg/l) and grain size: mud (%), sand (%), gravel (%), carbonate content (%), and organic matter (LOI) in the KL during March 2014.

Wadi Rabigh no longer reaches the KL due to the construction of the Rabigh Dam in 2009.

The lagoon water exchange with the Red Sea is restricted to a narrow inlet where two water layers pass through. One layer enters the lagoon as a surface inflow with temperatures of 25 and 30 ºC and the same salinity of 39‰ in both winter and summer, respectively. The other layer exits the lagoon inlet as a subsurface outflow with temperatures of 24.5 and 30 ºC and salinities of 39.8 and 40.5‰ during winter and summer, respectively (Al-Dubai et al. 2017). This water exchange with the Red Sea is mainly governed by the tidal force and local wind (NNE) dominated the area throughout the year, and thermohaline circulation (Al-Barakati 2010; Al-Dubai et al. 2017). The environmental parameters of the KL such as bathymetry, water temperature, salinity, dissolved oxygen (DO) and pH were measured during March 2014 and discussed in detail by Al-Dubai et al. (2017).

The southern and eastern parts of the KL are surrounded by extensive intertidal and sabkha/supratidal flats (approximately 4 km wide), which are mainly composed of sand alluvium, and by a sandy berm in the northeastern part (El-Abd and Awad 1991). They are low-lying areas, flooded during spring tide and storms, and are mostly covered with thin sheets of salts and algal mats. On the other hand, the western side of the KL is bordered by old, raised reefal limestone terraces of Pleistocene age (Al-Washmi 1999; Manaa 2011; Abu-Zied and Hariri 2016). These terraces are known as the Al-Lawi Coast (about 18 km long), separating the main lagoonal body from the open sea by heights ranging between 1–3 m above sea level, protecting the lagoon from strong waves. Inside the lagoon, there are a number of small reefal limestone islets such as Al-Ultah and Um Dinar, which rose as a result of late Pleistocene sea level fluctuations (Al-Washmi 1999; Basaham 2008), and are mostly covered by mangroves. The mangroves cover the southern side and some parts of the western and northeastern sides of the lagoon. The decayed mangrove litters are considered as one of the important sources to supply the lagoonal systems with nutrients (Al-Dubai et al. 2017).

MATERIALS AND METHODS

Field sampling

One hundred and thirty superficial (upper 2 cm) sediment samples were collected from different environmental niches in the KL, during March 2014 (text-fig. 1). The coordinates of each sample were determined by GPS (Garmin II) (Table 1). At each sampling site, water depth was measured by using a UWTEC Eco-sounder; and other environmental factors such as salinity, temperature, dissolved oxygen (DO), and pH were measured in situ by using a YSI 556 MPS parameter Meter (Table 1).

TABLE 1
Sample sites and measurements of environmental variables (depth, temperature, salinity, DO, pH, grain size, LOI, carbonate content, and substrate characters) in the KL during March 2014.

S. no	lat. N	Long. E	Depth (m)	Surface Temperature (°C)	Surface Salinity (‰)	Surface D. oxygen (mg/l)	Bottom D. oxygen (mg/l)	Surface pH	Gravel (%)	Sand (%)	Mud (%)	CaCO3 (%)	LOI-organic matter (%)	Substrate Macro-fauna and flora
KHA 1	22.9657	38.8358	0.1	32.16	38.89	6.67	6.67	8.27	0.54	35.67	63.78	57.8	17.96	Firm, algal-mat & coastal shrubs
KHA 2	22.9661	38.8361	0.24	29.37	38.69	7.38	7.38	8.21	12.30	67.32	20.37	92.5	6.11	Firm, algal-mat & mangrove
KHA 3	22.9672	38.8365	0.36	28.59	37.64	7.38	7.38	8.23	7.10	75.02	17.89	90.1	7.24	Hard & Filamentous algae
KHA 4	22.9681	38.8366	0.32	28.61	38.54	6.98	6.98	8.23	4.75	85.79	9.45	91.4	4.51	Hard & Filamentous algae
KHA 5	22.969	38.8367	0.37	28.89	38.40	7.57	7.57	8.26	0.65	89.67	9.68	92	4.18	Hard & Filamentous algae
KHA 6	22.9694	38.8365	0.52	28.93	38.71	7.91	7.91	8.28	2.89	86.33	10.78	90.4	4.93	Hard
KHA 7	22.955	38.8491	0.01	29.99	40.53	6.22	6.22	8.26	7.46	80.75	11.78	63.4	23.03	Firm & coastal shrubs
KHA 8	22.9552	38.8492	0.25	30.35	40.12	7.52	7.52	8.2	3.75	81.38	14.87	86.1	5.09	Firm & algal
KHA 9	22.9558	38.8499	0.5	28.98	40.48	6.33	6.33	8.11	0.03	92.97	7.00	86	3.58	Soft
KHA 10	22.9564	38.8504	0.8	28.41	40.47	6.24	6.24	8.1	0.23	81.54	18.23	88.5	3.43	Soft
KHA 11	22.9568	38.8511	0.85	27.81	40.38	5.93	5.93	8.07	4.30	72.01	23.70	91.9	5.41	Soft
KHA 12	22.9368	38.8656	0.04	29.92	41.10	7.73	7.73	8.29	11.88	77.64	10.47	89.7	5.63	Soft
KHA 13	22.9378	38.8663	0.28	29.12	41.11	6.51	6.51	8.22	6.32	81.23	12.45	93.1	8.38	Soft
KHA 14	22.9388	38.867	0.3	29.17	41.10	6.29	6.29	8.11	3.10	85.07	11.84	95.5	5.42	Soft & mucous algal-mats
KHA 15	22.9395	38.8678	0.76	28.68	40.80	6.09	6.09	8.11	0.42	77.12	22.47	86.6	7.53	Soft
KHA 16	22.918	38.8817	0.01	26.29	53.11	7.12	7.12	8.82	2.47	66.61	30.92	66	15.51	Soft & algal-mats
KHA 17	22.9188	38.8828	0.04	28.59	45.91	7.61	7.61	9.04	3.18	31.99	64.82	71.5	25.35	Algal-mats & coastal shrubs
KHA 18	22.92	38.8843	0.26	27.55	43.96	6.86	6.86	8.84	23.97	48.06	27.97	72.2	10.03	Soft & mucous algal-mats
KHA 19	22.9221	38.8867	0.02	23.68	53.64	5.28	5.28	8.96	4.18	34.56	61.26	73.7	27.23	Soft & mucous algal-mats
KHA 20	22.9228	38.8877	0.23	25.85	41.41	6.13	6.13	8.2	2.24	93.27	4.49	81.5	7.53	Hard
KHA 21	22.923	38.8884	0.45	27.20	40.61	5.93	5.93	8.14	3.82	92.38	3.80	89.9	3.70	Firm
KHA 22	22.8901	38.8991	0.02	26.54	45.28	7.21	7.21	8.67	9.47	18.46	72.07	64	24.39	Algal-mats (Supratidal)
KHA 23	22.8909	38.9008	0.14	25.03	43.24	5.99	5.99	8.75	25.84	33.63	40.53	90.1	4.40	Algal-mats (Supratidal)
KHA 24	22.8922	38.9031	0.01	28.98	42.79	8.56	8.56	8.55	3.25	76.18	20.57	65.7	22.85	Algal-mats (Supratidal)
KHA 25	22.8934	38.9042	0.18	26.10	40.84	6.18	6.18	8.14	19.73	73.04	7.23	82.6	8.65	Firm (Supratidal)
KHA 26	22.8935	38.9047	0.45	25.76	40.42	5.11	5.11	8.14	2.07	88.12	9.80	88	4.50	Hard (Supratidal)
KHA 27	22.8937	38.9054	0.57	26.30	40.17	5.57	5.57	8.16	0.28	97.16	2.57	91.6	3.63	Firm & seagrasses (Supratidal)
KHA 28	22.894	38.9063	0.72	26.76	40.11	5.5	5.50	8.15	4.55	90.44	5.01	87.2	4.06	Firm & seagrasses (Supratidal)
KHA 29	22.8939	38.9066	0.94	26.60	40.09	5.67	5.67	8.14	0.47	96.48	3.05	94.8	4.70	Firm & seagrasses (Supratidal)
KHA 30	22.854	38.9187	0.2	29.31	41.72	7.24	7.24	8.17	11.41	63.85	24.75	79.4	15.25	Algal-mats & shrubs (Supratidal)
KHA 31	22.8545	38.9192	0.38	27.70	41.56	5.64	5.64	8.1	3.46	85.20	11.34	86.1	7.36	Soft
KHA 32	22.8552	38.9202	0.59	27.07	41.47	5.8	5.80	8.13	3.05	90.95	6.01	92.6	4.77	Hard
KHA 33	22.8555	38.9207	0.94	27.12	41.41	5.61	5.61	8.12	9.42	81.42	9.17	85.6	7.20	Soft
KHA 34	22.8383	38.9603	0.04	30.98	51.64	6.1	6.1	8.93	8.79	69.85	21.36	16.9	7.38	Thick algal-mats
KHA 35	22.8436	38.9598	0.1	31.26	44.19	8.92	8.92	8.82	3.22	47.99	48.79	28.9	8.06	Soft & algal-mats (Supratidal)
KHA 36	22.8457	38.9595	0.25	31.00	45.23	9.62	9.62	8.9	2.78	47.12	50.10	11.4	5.13	Soft in tidal creek
KHA 37	22.8492	38.959	0.4	29.19	42.18	5.91	5.91	8.23	1.19	44.92	53.89	8.7	3.13	Firm
KHA 38	22.8502	38.9581	0.52	28.62	42.23	5.75	5.75	8.21	0.37	33.55	66.09	12.9	3.00	Firm
KHA 39	22.8516	38.9564	0.65	28.57	41.93	5.98	5.98	8.12	1.13	90.09	8.78	9.3	2.69	Firm
KHA 40	22.8803	38.9596	-0.3	24.26	53.51	2.33	2.33	7.73	2.85	81.92	15.24	20.4	21.87	Algal-mats (supratidal)
KHA 41	22.8797	38.9597	0.03	24.32	45.76	4.76	4.76	7.91	0.91	95.74	3.35	6.7	3.01	Algal-mats (supratidal)
KHA 42	22.8783	38.9599	0.4	26.20	41.36	4.66	4.66	8.12	0.46	94.97	4.58	9.8	1.85	Firm
KHA 43	22.8777	38.9598	0.54	27.20	41.41	4.38	4.38	8.16	1.84	91.14	7.02	13.4	2.20	Firm & seagrasses
KHA 44	22.8762	38.96	0.85	26.84	41.39	4.38	4.38	8.16	2.32	92.29	5.39	16.5	2.68	Firm & seagrasses
KHA 45	22.8702	38.9667	0.09	26.85	41.81	5.75	5.75	8.2	0.79	78.38	20.83	9.6	4.86	Soft
KHA 46	22.8697	38.9659	0.43	26.64	41.63	5.16	5.16	8.2	11.83	83.54	4.63	14.7	1.94	Firm & small mollusks
KHA 47	22.8694	38.9653	0.69	26.86	41.39	5.79	5.79	8.2	1.81	91.95	6.24	13.4	1.87	Firm & algae
KHA 48	22.8692	38.9651	0.83	27.02	41.23	5.97	5.97	8.19	2.79	93.90	3.30	13.4	2.92	Firm & seagrasses
KHA 49	22.9018	38.9385	0.07	28.54	39.69	5.62	5.62	8.17	5.22	94.68	0.09	35.8	2.43	Firm
KHA 50	22.9016	38.9384	0.56	27.58	40.78	6.08	6.08	8.17	0.27	74.72	25.01	18.8	6.06	Soft
KHA 51	22.9014	38.9383	1	27.25	40.67	5.87	5.87	8.15	0.00	77.52	22.48	17.6	3.42	Firm
KHA 52	22.9217	38.9292	0.01	30.22	41.05	7.25	7.25	8.23	1.09	98.55	0.36	42.1	2.10	Sand & beach-rock
KHA 53	22.9213	38.9286	0.6	27.81	40.41	5.75	5.75	8.14	3.07	68.42	28.51	32.3	4.15	Sand & beach-rock
KHA 54	22.9212	38.9283	0.56	28.11	40.35	6.21	6.21	8.17	2.61	79.33	18.06	33.6	16.88	Soft
KHA 55	22.9208	38.9276	0.9	27.53	40.29	5.81	5.81	8.15	3.47	93.97	2.56	49.9	3.54	Hard & *Turbinaria*
KHA 56	22.9549	38.9189	0.05	34.57	46.14	7.98	7.98	8.77	4.03	81.31	14.66	11.6	4.93	Algal-mat
KHA 57	22.9542	38.9182	0.07	30.57	40.40	6.19	6.19	8.15	2.79	76.79	20.42	21.4	3.61	Algal-mat
KHA 58	22.9537	38.9165	0.5	28.54	40.16	6.19	6.19	8.14	0.00	98.53	1.47	26.9	3.72	Firm to hard
KHA 59	22.9685	38.8785	0.05	31.83	38.32	6.18	6.18	8.18	0.72	97.21	2.07	30	2.68	Beachrock
KHA 60	22.9679	38.8784	0.65	28.69	39.87	6.31	6.31	8.15	0.03	93.06	6.92	32.8	2.72	Firm
KHA 61	22.9671	38.878	0.7	27.87	39.79	6.02	6.02	8.16	1.00	96.37	2.63	43.2	4.06	Firm to hard
KHA 62	22.9805	38.8445	0.02	30.85	40.87	7.1	7.10	8.64	3.11	82.83	14.05	26.6	4.40	Firm & algal-mat
KHA 63	22.9802	38.8445	0.3	30.44	39.84	6.65	6.65	8.22	3.76	77.16	19.08	48.6	5.42	Soft & mangrove
KHA 64	22.9796	38.8444	0.4	29.56	39.75	6.2	6.20	8.2	7.72	57.01	35.28	70.8	6.56	Soft & mangrove
KHA 65	22.9792	38.8443	0.45	29.53	39.71	6.25	6.25	8.2	1.53	84.49	13.98	73.5	7.42	Soft & mucous algal-mats

Superficial sediment samples were recovered by means of a Van Veen grab sampler in deeper water and with a spatula in shallower waters less than 1 m depth. Immediately on board, the grab was carefully opened in a container where the surface sediments were deposited in their initial position without distortion (Debenay et al. 2001). After substrate sediments description, the uppermost layer (upper 2 cm) of the surface sediments was scraped off and partitioned into two aliquots: one set of sediment subsamples was stored in numbered polyethylene jars, treated with buffered rose Bengal solution (1.5 g of Rose Ben-

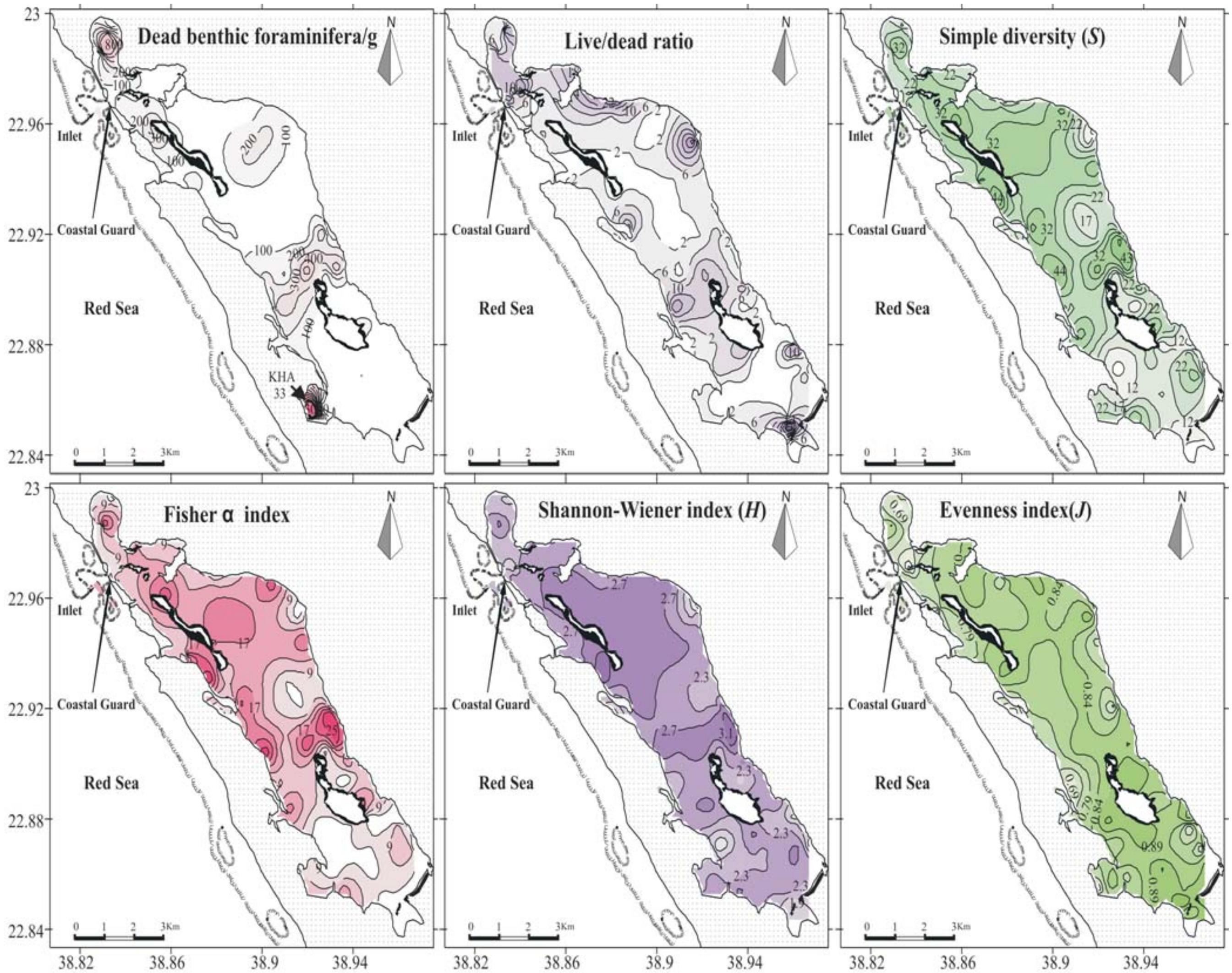
TABLE 1
Continued.

S. no	lat. N	Long. E	Depth (m)	Surface Temperature (°C)	Surface Salinity (‰)	Surface D. oxygen (mg/l)	Bottom D. oxygen (mg/l)	Surface pH	Gravel (%)	Sand (%)	Mud (%)	$CaCO_3$ (%)	LOI-organic matter (%)	Substrate Macro-fauna and flora
KHA 66	22.9789	38.8444	0.9	29.12	39.63	6.35	6.35	8.22	0.26	86.67	13.07	73.1	6.31	Soft
KHA 67	22.9789	38.8433	0.4	29.33	39.72	6.02	6.02	8.21	15.06	62.41	22.53	77.6	7.35	Soft & mangrove
KHA 68	22.9971	38.8346	-0.05	27.93	44.80	6.47	6.47	9.26	4.00	69.61	26.40	21.3	7.33	Thick algal-mat
KHA 69	22.9957	38.8341	0.1	29.17	42.73	7.15	7.15	8.44	0.94	54.81	44.25	57.3	12.29	Soft
KHA 70	22.9946	38.8334	0.17	29.23	41.96	7.03	7.03	8.34	13.31	57.80	28.89	52.9	6.99	Soft
KHA 71	22.9935	38.8328	0.6	28.47	41.61	5.83	5.83	8.27	11.43	57.96	30.61	52	14.83	Soft
KHA 72	22.9607	38.8245	20	25.2	38.89	6.23	6.01	8.2	2.43	85.28	12.29	90.6	5.55	Fine sediments
KHA 73	22.9638	38.8259	30	24.74	39.39	6.01	6.03	8.21	28.20	69.44	2.36	90.5	2.64	Coarse sediments & small mollusks
KHA 74	22.965	38.8287	12	24.57	39.6	6.29	6.14	8.25	0.00	97.78	2.22	94.4	9.93	Coarse sediments & small mollusks
KHA 75	22.968	38.8335	18	24.82	40.12	6.16	6.10	8.38	31.27	66.93	1.80	92.5	4.85	Coarse & coral reef
KHA 76	22.9703	38.837	11	24.86	40.17	6.18	5.99	8.38	0.66	98.64	0.70	94.2	3.99	Fine sediments
KHA 77	22.9719	38.8403	14.5	24.88	40.13	5.94	6.07	8.39	43.89	55.94	0.17	94.1	5.92	Hard & coarse sediments
KHA 78	22.9691	38.8446	13.5	25.12	40.3	5.99	6.08	8.4	5.63	91.61	2.76	94.4	4.38	Hard & coarse sediments
KHA 79	22.9611	38.8579	3.5	25.12	40.19	6.29	6.24	8.4	4.12	82.59	13.29	92.9	5.25	Median sediments
KHA 80	22.9619	38.8659	5.3	25.44	40.55	6.17	5.82	8.37	4.01	55.30	40.69	65.6	7.87	Soft
KHA 81	22.9627	38.8802	5.3	25.45	40.5	6.05	6.03	8.35	1.31	34.97	63.72	66.5	15.24	Soft
KHA 82	22.9623	38.895	2	25.22	40.53	6.2	6.03	8.37	15.48	80.27	4.26	64.1	3.21	Coarse sediments & small mollusks
KHA 83	22.9644	38.9044	2	24.36	40.4	6.73	6.42	8.37	3.84	70.61	25.55	52.4	4.68	Soft
KHA 84	22.957	38.902	4.5	25.5	40.48	6.06	5.84	8.35	8.84	77.83	13.32	69.3	4.02	Soft
KHA 85	22.9444	38.9182	1.4	24.98	40.55	6.69	6.52	8.36	0.16	94.87	4.97	22.1	3.88	Soft & seagrasses
KHA 86	22.9414	38.9082	5.2	25.47	40.51	6.18	5.16	8.34	9.82	49.78	40.40	63.7	8.40	Soft
KHA 87	22.9367	38.8936	7.5	25.25	40.53	6.09	4.87	8.32	8.69	56.65	34.66	61.4	6.33	Soft
KHA 88	22.9331	38.8825	4	24.99	40.46	6.43	5.70	8.35	4.05	56.85	39.10	79.1	8.80	Soft & seagrasses
KHA 89	22.9309	38.8771	1	23.5	39.69	7.22	7.28	8.34	3.37	65.98	30.65	92.2	5.48	Soft
KHA 90	22.9207	38.8907	2	24.81	40.43	6.88	6.46	8.33	8.49	71.08	20.43	85.3	4.83	Soft & seagrasses
KHA 91	22.918	38.9027	8.4	25.24	40.49	6.89	6.12	8.35	4.41	43.90	51.69	57.1	24.16	Soft
KHA 92	22.9192	38.9189	6.9	25.07	40.69	6.29	5.97	8.32	0.08	25.97	73.95	36.2	13.28	Soft
KHA 93	22.9181	38.9292	2.1	25.02	40.45	6.54	6.55	8.34	3.38	86.44	10.18	44	4.99	Soft
KHA 94	22.9077	38.9324	1	26.17	40.5	7.26	7.22	8.38	2.82	60.77	36.41	46.4	7.03	Soft
KHA 95	22.9049	38.9278	7.7	24.97	40.73	6.42	6.19	8.35	0.38	29.73	69.89	45.6	9.32	Soft
KHA 96	22.9068	38.9198	4.5	24.88	40.6	6.22	6.34	8.32	3.23	82.89	13.88	85	5.46	Soft & seagrasses
KHA 97	22.9053	38.9102	7	25.1	40.66	6.08	6.15	8.3	5.88	62.01	32.11	56.9	12.34	Soft
KHA 98	22.904	38.9018	1.2	25.72	40.5	7.16	7.12	8.37	2.74	75.46	21.80	90.1	4.59	Soft
KHA 99	22.884	38.9124	1.7	24.9	40.51	7.65	7.73	8.38	3.07	56.30	40.63	79.6	4.44	Soft, *Coralia* sp & *Hydroclathrus*
KHA 100	22.8849	38.9239	5.3	24.71	40.64	6.71	7.17	8.33	0.73	16.74	82.53	36.3	26.90	Soft & seagrasses
KHA 101	22.8772	38.939	2.3	24.9	41.03	7.35	7.07	8.37	5.12	62.26	32.62	50.2	14.62	Soft & seagrasses
KHA 102	22.8806	38.9471	5.7	24.31	41.35	6.22	5.98	8.33	0.00	19.48	80.52	28.1	12.55	Soft
KHA 103	22.8842	38.9431	0.6	24.96	41.44	7.61	7.42	8.39	10.20	65.28	24.52	75.8	5.98	Soft & seagrasses
KHA 104	22.8947	38.9371	8.1	24.76	41.11	6.45	6.39	8.33	0.25	42.01	57.74	35.3	13.17	Soft
KHA 105	22.9431	38.8669	2.3	23.72	40.2	7.06	6.85	8.35	6.13	42.47	51.40	88.4	5.77	Soft
KHA 106	22.9582	38.8533	1.1	25.13	40.14	6.71	6.90	8.37	0.26	86.13	13.61	84.6	3.37	Soft
KHA 107	22.9554	38.8827	7	24.5	40.51	6.21	6.16	8.31	13.80	75.87	10.34	74.2	5.30	Soft (black color)
KHA 108	22.9441	38.8777	2.3	24.15	40.26	6.22	6.54	8.34	3.06	63.22	33.72	84.4	3.78	Soft (Black color)
KHA 109	22.9475	38.8935	7.2	24.59	40.59	6.13	6.04	8.31	4.74	63.60	31.66	59.8	11.56	Soft (Gray color)
KHA 110	22.9246	38.8996	7.7	24.4	40.64	6.18	5.87	8.3	2.36	62.05	35.60	56.7	9.71	Soft (Gray color)
KHA 111	22.9294	38.9113	6.3	24.47	40.52	6.09	5.66	8.3	0.28	19.33	80.39	43.4	21.04	Soft (Gray color)
KHA 112	22.8858	38.9524	3.4	23.54	41.39	6.49	6.37	8.35	7.59	49.87	42.55	47.6	6.96	Soft (Black color)
KHA 113	22.8784	38.9553	3.3	23.55	41.3	6.12	6.48	8.34	6.41	46.09	47.49	35.8	20.00	Soft & seagrasses (Black color)
KHA 114	22.8706	38.9621	2.2	23.52	41.37	6.26	6.26	8.34	8.27	41.22	50.51	31	10.65	Soft
KHA 115	22.8644	38.9665	0.7	22.59	41.65	6.92	6.69	8.34	0.24	11.00	88.76	11.9	3.90	Soft (Black color)
KHA 116	22.8542	38.9574	1.2	22.57	41.51	6.86	6.86	8.38	2.17	30.32	67.52	14.4	6.50	Soft (Black color)
KHA 117	22.8619	38.948	2	22.49	41.36	6.85	6.89	8.36	0.43	20.66	78.91	23.2	10.02	Soft (Black color)
KHA 118	22.8687	38.9464	4.3	23.52	41.2	6.28	6.43	8.36	1.37	17.59	81.04	26.6	13.73	Soft
KHA 119	22.8746	38.9427	3.4	24.26	41.19	6.33	6.18	8.29	0.40	32.17	67.44	35.1	10.52	Soft (Black color)
KHA 120	22.8549	38.9361	1.2	23.1	40.69	7.63	7.57	8.38	10.23	71.42	18.35	76.6	9.14	Soft & seagrasses
KHA 121	22.8574	38.9256	1.5	20.99	41.34	6.65	6.85	8.33	0.00	56.62	43.38	64.7	11.31	Soft (Black color)
KHA 122	22.8597	38.932	3	23	40.68	6.49	6.73	8.35	0.49	60.68	38.83	53.9	13.75	Soft (Black color)
KHA 123	22.8656	38.931	3.7	23.47	40.72	6.16	6.37	8.29	0.00	22.19	77.81	46.4	14.54	Soft (Black color)
KHA 124	22.8709	38.9285	3.6	23.68	40.69	6.65	7.06	8.32	1.60	53.15	45.25	39.5	16.54	Soft & seagrasses
KHA 125	22.8789	38.924	4	23.64	40.58	6.23	6.82	8.31	0.16	54.22	45.62	48.9	11.91	Soft & seagrasses
KHA 126	22.9945	38.8336	0.01	29.26	45.37	5.98	5.98	8.42	8.00	37.69	54.31	27.1	10.92	Soft, *Avrainvillea* & *Caulerpa*
KHA 127	22.9938	38.8332	0.1	26.66	42.97	10.03	10.03	8.63	3.85	77.89	18.25	62.3	8.50	Soft & *Avrainvillea* algae
KHA 128	22.9931	38.8324	0.15	26.92	42.26	8.96	8.96	8.65	1.03	77.16	21.82	67.5	8.70	Soft & *Avrainvillea* algae
KHA 129	22.9862	38.8295	0.35	26.33	42.23	7.08	7.08	8.42	0.00	88.12	11.88	51	5.02	Soft & seagrasses
KHA 130	22.9866	38.8301	0.45	25.83	40.56	7.57	7.57	8.4	0.07	37.69	62.23	74.4	3.89	Soft

gal powder per liter of 95% ethyl alcohol), transported to the laboratory and then kept in the stain for a week before the micropaleontological analysis. The Rose Bengal stain was used to distinguish living (stained) from dead foraminiferal tests. Only tests containing dense, brightly rose-stained protoplasm in all but the last chambers were counted as alive, whereas colorless empty tests were counted as dead (Walton 1952; Murray 1991; Barras et al. 2014). The second set of sediment sub-samples was kept for geochemical analyses such as organic matter and carbonate contents.

Foraminifera and sediment grain size analyses

Part of the stained sediments was oven-dried at 50 ºC for 24 h, then weighed to determine their total dry weight. Dried sediments were soaked in distilled water overnight in order to disintegrate solidified aggregates. Wet sediments were gently

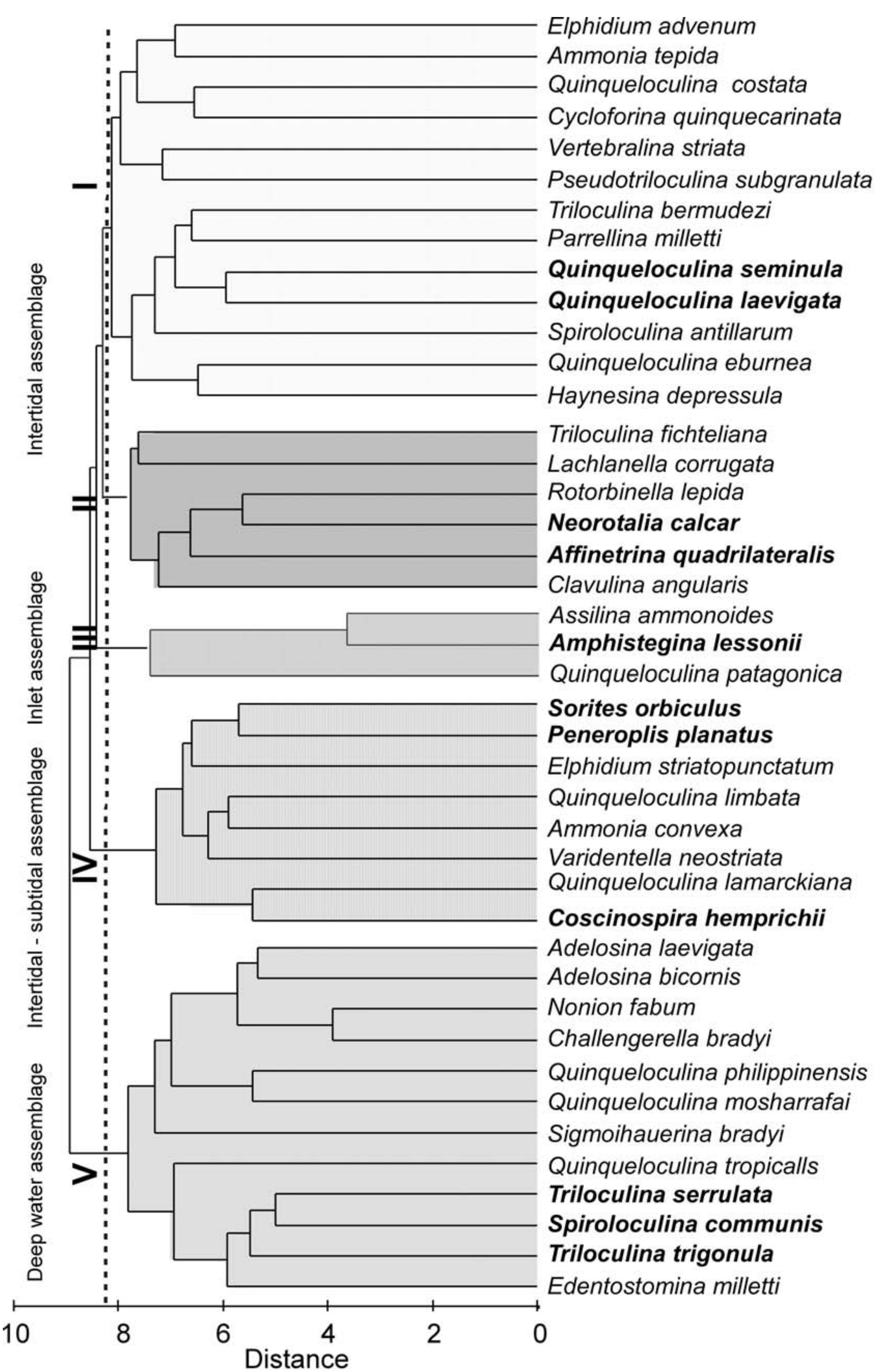


TEXT-FIGURE 3
Relative abundance distribution maps for: A Dead benthic foraminiferal density (per gram), Live/dead ratio, Simple diversity (S), Fisher diversity (α), Shannon-Wiener diversity (H) and Equitability (evenness) index (J) at the KL during March 2014.

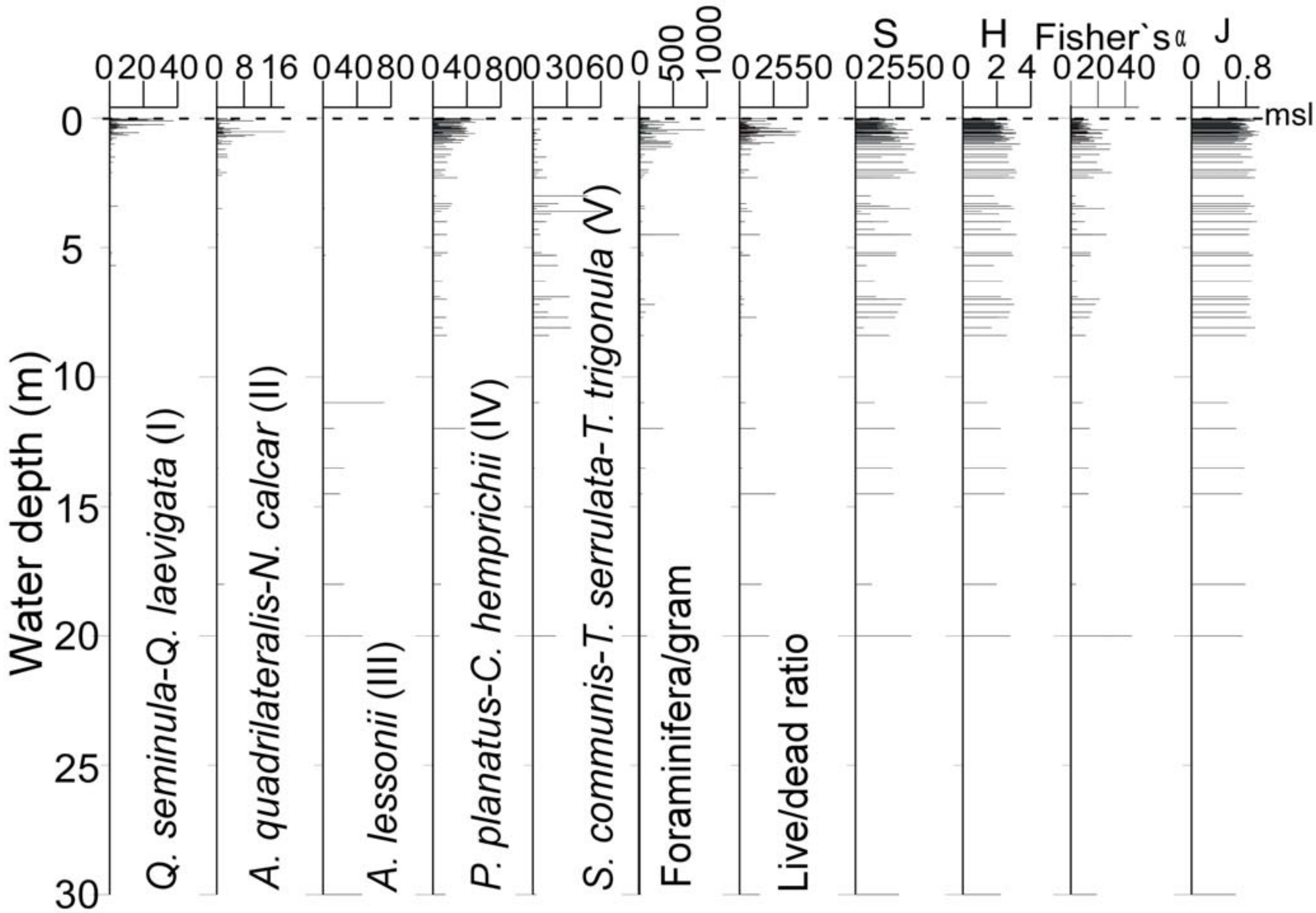
washed over sieves with 2 and 0.063 mm openings to remove any excess stain and separate gravel (>2 mm), sand (0.063–2 mm) and mud (<0.063 mm) fractions. The residual fractions obtained in each sieve were re-dried at 50 ºC and weighed to determine the percentage of each sediment grain size (Abu-Zied et al. 2013) (Table 1). They are presented in distributional maps (Surfer software version 8). Quantitative analysis of benthic foraminifera was performed on the sand fraction (0.063–2 mm). It was split using a micro-splitter to reduce the amount of sediment and number of foraminifera to at least 200 individuals for accurate statistical analysis and to insure that no species was missed. Individuals were picked, identified, counted, and presented as total number of tests/gram of dry weight sediments (hereafter called faunal density) and percentages of the total dead assemblage. The recorded benthic foraminiferal species were taxonomically identified following Loeblich and Tappan (1987), Haig (1988), Hottinger et al. (1993), Cherif et al. (1997), Abu-Zied et al. (2011a), Abu-Zied and Bantan (2013), and Abu-Zied et al. (2016). Some of the dominant species were photographed using an OPTIKA digital camera attached to a Leica light microscope and displayed in Plates 1–5. The stained live tests were counted and were not lumped with the dead assemblage in any statistical analysis, because they cannot indicate yearly average environmental conditions that are needed for modelling paleoenvironmental conditions (Scott and Medioli 1980; Debenay et al. 2001; Abu-Zied and Bantan 2013). They were only used to determine live/dead ratio in the KL to see if there are any significant changes in faunal productivity and sedimentation rate.

Organic matter (LOI)

The Weight Loss on Ignition (LOI) technique is a common, widely-used method for approximating the organic matter content of sediment samples (Heiri et al. 2001). About 1g of each sediment sample was placed in a ceramic crucible and dried in an oven overnight at 105 °C and then weighed to determine the total dry weight (DW_{105} °C). After that, they were placed in the oven (Thermolyne-type 47900 furnace) for three hours at 550



TEXT-FIGURE 4
Hierarchical cluster analysis (R-mode) of total dead benthic foraminiferal species (of =10%) based on fourth-root transformed data and standardized, using Euclidean distance coefficients of group-average.



TEXT-FIGURE 5
Distribution frequency of benthic foraminiferal assemblages (I, II, III, IV and V), density, live/dead ratio, diversity indices (S, Fisher's α, H and J) against water depth (m) in the KL. Assemblages I, II, III, IV and V were represented as the total sum of species defined in each cluster in text-fig. 4. MSL= mean sea level.

°C to burn the organic matter by removing the CO_2. After this heat treatment, residue of each sediment sample (DW_{550} °C) was cooled in a moisture-free glass desiccator with $CaCl_2$, then weighed. The weight loss was considered as a total organic matter which were calculated using the following equation:

$LOI_{550°C} = (DW_{105°C}-DW_{550°C}/DW_{105°C})*100$.

Where DW_{105} is the weight of oven-dried sediment and DW_{550} is the weight of sediment after combustion at 550°C.

Carbonate content ($CaCO_3$)

Carbonate content ($CaCO_3$) was determined by treating each weighed sediment sample (0.5-1g dry wt) with 1 mol HCl for 4 hours at 60 °C to dissolve $CaCO_3$. The sample was filtered to remove the solution and the residue was oven-dried at 50 °C and weighed. Percent $CaCO_3$ was calculated as $CaCO_3$ % = dry sample wt – dry residue wt/ dry sample wt × 100 according to (El Sayed et al. 2002).

Statistical analysis

Statistical analyses were conducted on the dead benthic foraminiferal species recorded in 130 sediment samples. Faunal density (dead tests/gram dry wt), live/dead ratio, simple diversity (S), Shannon-Wiener diversity index (H'), Equitability (evenness) index (J'), Fisher's α index, and cluster analysis were achieved using Primer v. 5.0 (Clarke and Warwick 1994). Hierarchical Q- and R-mode cluster analysis were applied using group-average linking of Euclidean distance coefficients of the 2nd and 4th root transformed (respectively), standardized species data that contribute =10% of the total dead assemblages. The canonical correspondence analysis (CCA) was applied using the PAST software (Hammer et al. 2001). It is a multivariate technique that relates community composition to known environmental data to show the relationship among themselves and provide a succinct description for the different habitat preferences (biotopes) of the species via an ordination diagram (Ter Braak 1987; Ter Braak and Verdonschot 1995).

RESULTS

Environmental parameters

The water depth ranges from 0.5 m at the southern part of the KL to 18 m at the inlet (text-fig. 1), it then deepens gradually to reach about 30 m in the outer part of the lagoon inlet. The surface water temperature varied from 26 ºC in the inlet to 30 ºC in the far southern part, having a mean value of 26.7 ºC. It was highest (34 ºC) near the shoreline of the lagoon. The surface water salinity showed a reverse trend with the surface water temperature, ranging from 42.5‰ at the southern part to 38.9‰ at the northern part with a mean average of 40.5‰. It was the highest (45.4‰) in the sheltered areas of the lagoon. The dissolved oxygen (DO) of the surface water had a mean average of 6.5 mg/l (for further details see Al-Dubai et al. 2017), whereas the DO of the bottom water varied between 7.7 mg/l at the mid-western side and 5.2 mg/l at the center of the lagoon, having an average of 6.4 mg/l (text-fig. 2). The surface water pH had a mean value of 8.3, but it varied from 8.1 at the northwestern part of the lagoon to 9.1 at the shallower areas that were covered by the cyanobacterial algal mats (Al-Dubai et al. 2017).

Sediment organic matter, carbonate and grain size

The organic matter (LOI) displayed the lowest value (5%) in the superficial sediments of the eastern side of the KL (text-fig. 2). It increased to the highest value (17%) in the southwestern areas and central part of the lagoon, where muddy substrates, algal mat, and seagrasses were dominant (text-fig. 2).

The distribution of carbonate in the surface sediment of the lagoon is remarkable showing the highest values up to 85% in the northwestern part of the lagoon, where coral reef and bio-clastic fragments predominate (text-fig. 2). The southeastern part of the lagoon showed the lowest carbonate value (15%), where the clastic materials from eastern wadis and Wadi Rabigh predominate (text-fig. 2).

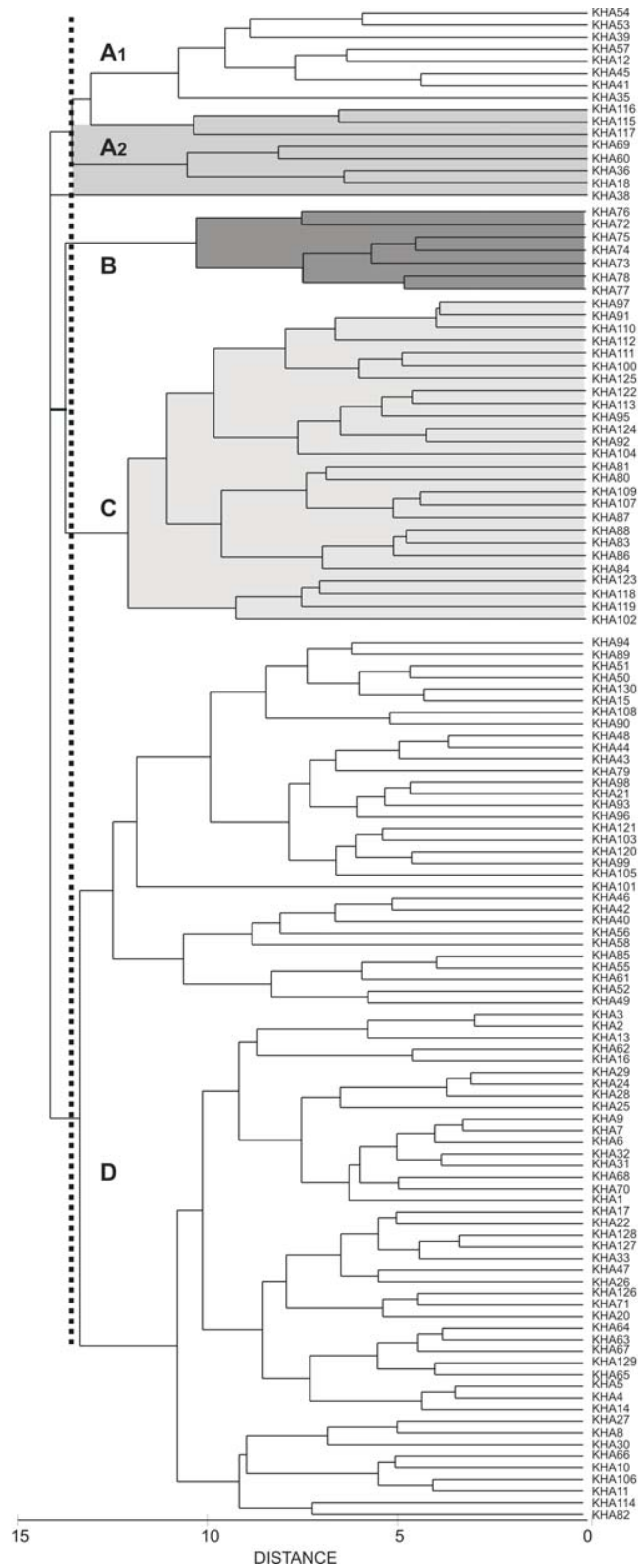
The mud fraction dominated the bottom sediments of the central and southern part of KL (text-fig. 2). It showed a similar distribution pattern to those of the organic matter, but it was reversely correlated with the distribution pattern of the sand fraction in the lagoon (text-fig. 2). The muddy substrates were the highest (up to 72%) in the central and southern parts of the lagoon and decreased to 18% in the inlet and northern part. Field observation showed that these muddy substrates varies from brown oxic-mud, flourished with seagrass *Cymodocea rotundata* and macro-algae *Turbinaria ornata* in the southern part, but in the central part of the lagoon, it turns to blackish gray, organic-rich mud flourishing with the seagrass *Halophila stipulacea* (Al-Dubai et al. 2017).

The sand fraction predominated the northern part and most of the nearshore areas of the KL, reaching a maximum value of 82% in the inlet of the lagoon (text-fig. 2). It showed the lowest value of 34% in the central and southern parts of the lagoon (text-fig. 2).

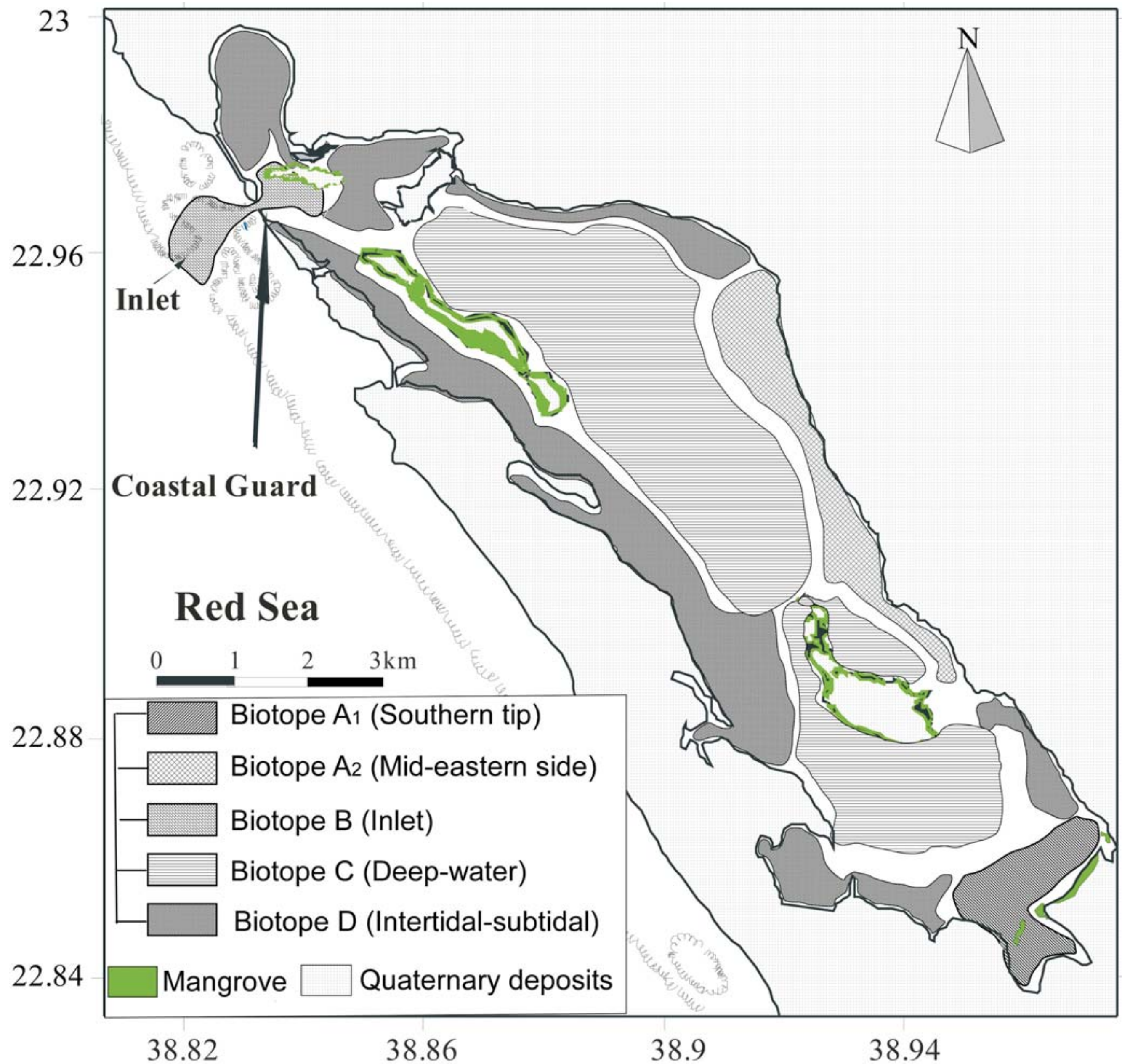
The gravel fraction was, in general, very low showing an average of 4% throughout the lagoon (text-fig. 2). In the northern area and inlet of the lagoon, gravelly substrates were abundant showing the highest value of 16%. These substrates disappeared at the southern tip of the lagoon (text-fig. 2). These coarse, gravelly substrates are composed mostly of bio-clastic materials such as foraminiferal tests, shells of pelecypods and gastropods, corals debris, and coralline algae.

Benthic foraminifera

A total of 111 dead species belong to 52 genera were recorded from the superficial sediments (the upper 2 cm) of the KL during March 2014. Their census data were used for the calculations of faunal density, diversity indices, and frequency



TEXT-FIGURE 6
Dendrogram of samples (Q-mode) based on square root transformed data, using group average linking of Euclidean distance coefficients.



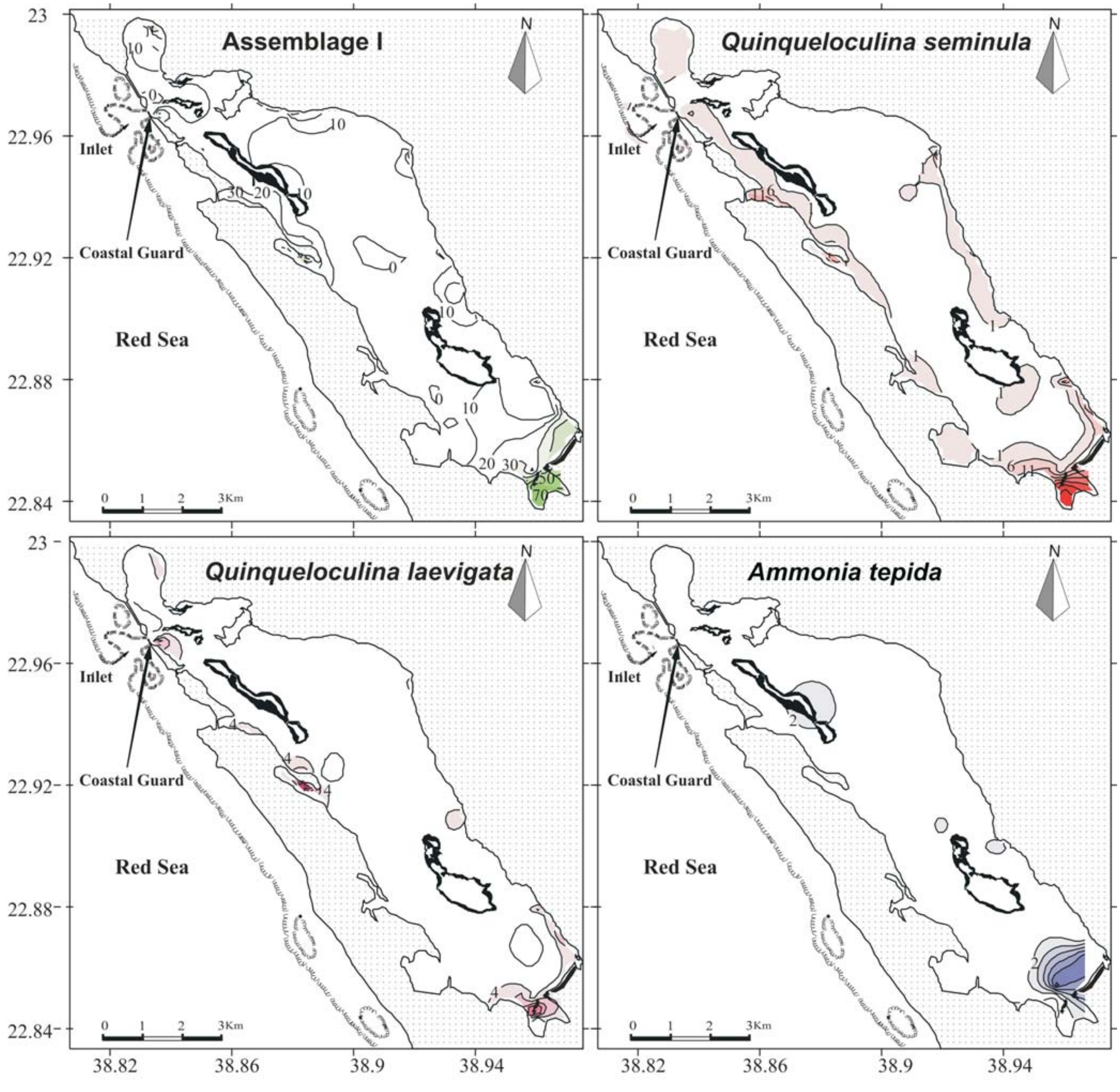
TEXT-FIGURE 7
Distribution of ecological biotopes in the KL based on sample groupings of TEXT-FIGURE 6.

abundance. The species =10% (only 42 species) of the dead assemblages were considered key species in this study, presented in distributional maps, discussed, and statistically tested by cluster and canonical correspondence analyses (CCA).

Faunal density and diversity

The faunal density of the surface sediments of the KL has a mean value of 135±300 tests/g (text-fig. 3). A high density (up to 500 tests/g) was recorded in the central part of the lagoon, immediately north of the Al-Ultah Islet (text-fig. 3). The northern tip of the lagoon showed the highest faunal density up to 900 tests/g. Sample KHA33 in the southwestern corner of the lagoon also showed a density up to 3000 tests/g (text-fig. 3). The lowest faunal density of 100 tests/g dominated the lagoon (text-fig. 3).

The live/dead ratio of benthic foraminifera in the surface sediments of KL showed a mean value of 10 (text-fig. 3). It was highest (up to 22%) at some localized areas near the shoreline (tidal area) of the lagoon, but in the central part of the lagoon live tests were almost absent (text-fig. 3). The most frequent species found alive in this study were *Peneroplis planatus* (15%), *Quinqueloculina lamarckiana* (6%), *Quinqueloculina laevigata* (5%), *Sorites orbiculus* (5%), *Varidentella neostriata* (5%), *Coscinospira hemprichii* (4%), *Ammonia convexa* (4%), and *Q. seminula* (4%).

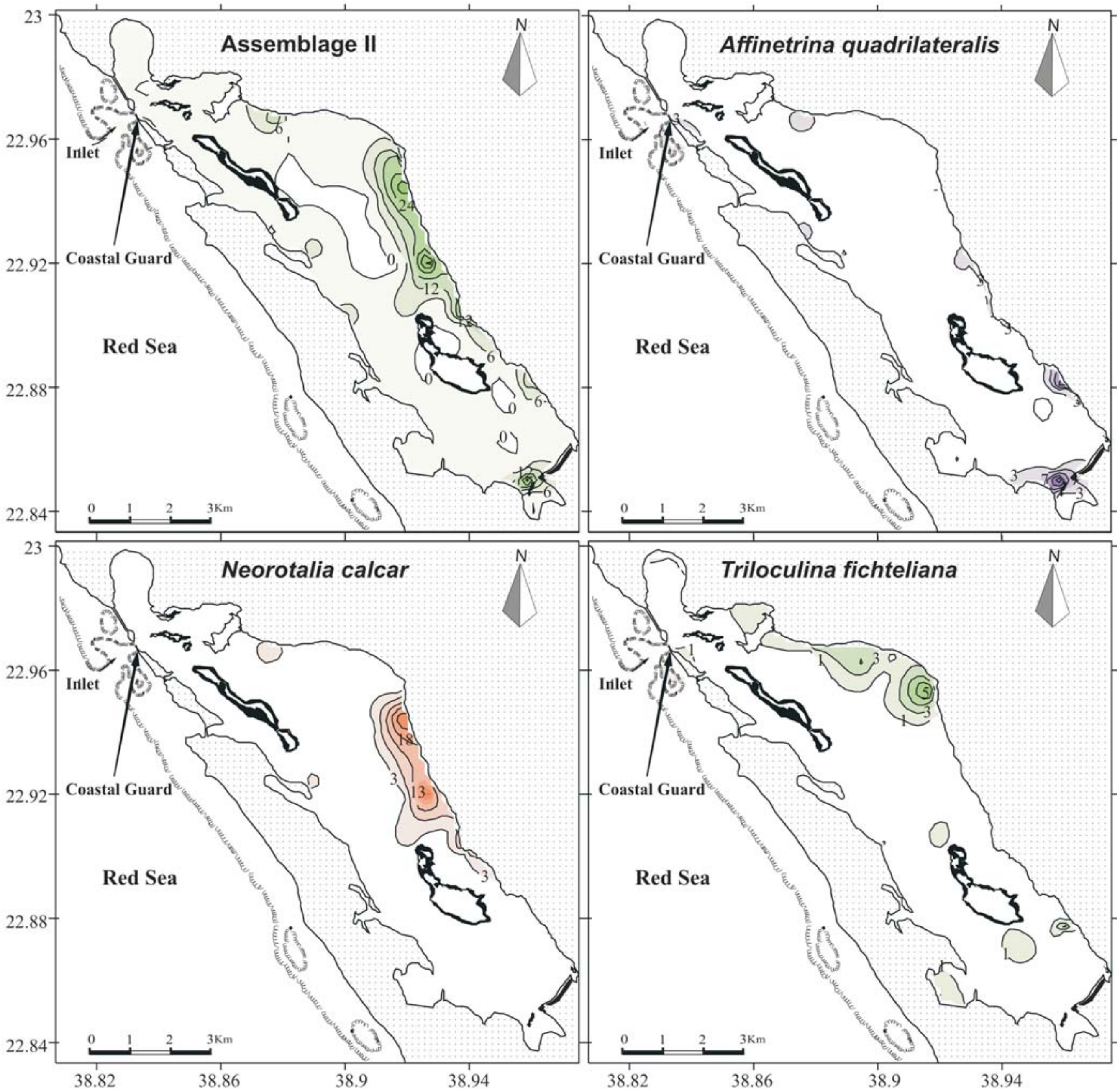


TEXT-FIGURE 8
Relative abundance distribution maps for: *Quinqueloculina seminula-Quinqueloculina laevigata* assemblage (I) and the key species *Quinqueloculina seminula*, *Quinqueloculina laevigata* and *Ammonia tepida* in the KL based on species grouping of text-fig. 4.

The faunal (dead assemblages) diversity indices S, H', J' and Fisher's α in the surface sediments of the KL showed mean values of 23±10, 2.3±0.5, 0.8±0.1 and 11±7, respectively (text-fig. 3). The S, H' and Fisher's α showed highest values (32, 2.7 and 17, respectively) in the central and the northern parts of the lagoon, whereas the southern and intertidal portions of the lagoon displayed the lowest values 12, 2.3 and 9, respectively (text-fig. 3). On the other hand, the J*'* showed the highest values (0.89) in the southern part of the lagoon, whereas the intertidal areas and the northern parts of the lagoon showed the lowest (0.69-0.84), see text-fig. 3.

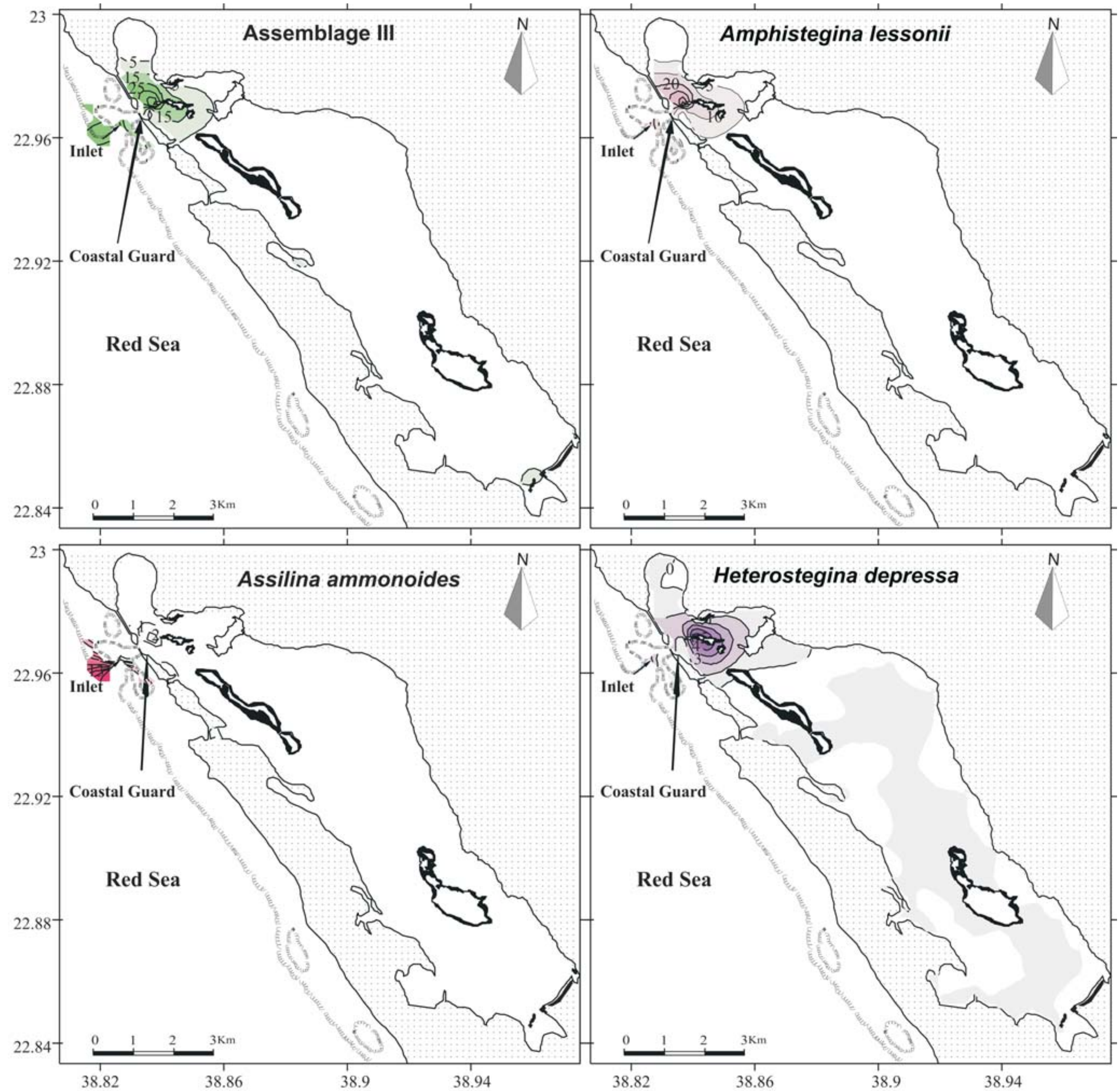
Distribution of benthic foraminiferal assemblages

R-mode cluster analysis as well as the spatial distribution of benthic foraminiferal species in the surface sediments of the KL allowed their subdivision into five assemblages (I-V) named according to the dominant species (text-fig. 4). Also, these assemblages were presented against water depths (text-fig. 5), and their Q-mode cluster analysis allowed the geography of the lagoon to be subdivided into five ecological biotopes (text-figs. 6-7).



TEXT-FIGURE 9
Relative abundance distribution maps for: *Affinetrina quadrilateralis-Neorotalia calcar* assemblage (II) and the key species *Affinetrina quadrilateralis*, *Neorotalia calcar* and *Triloculina fichteliana* in the KL based on species grouping of text-fig. 4.

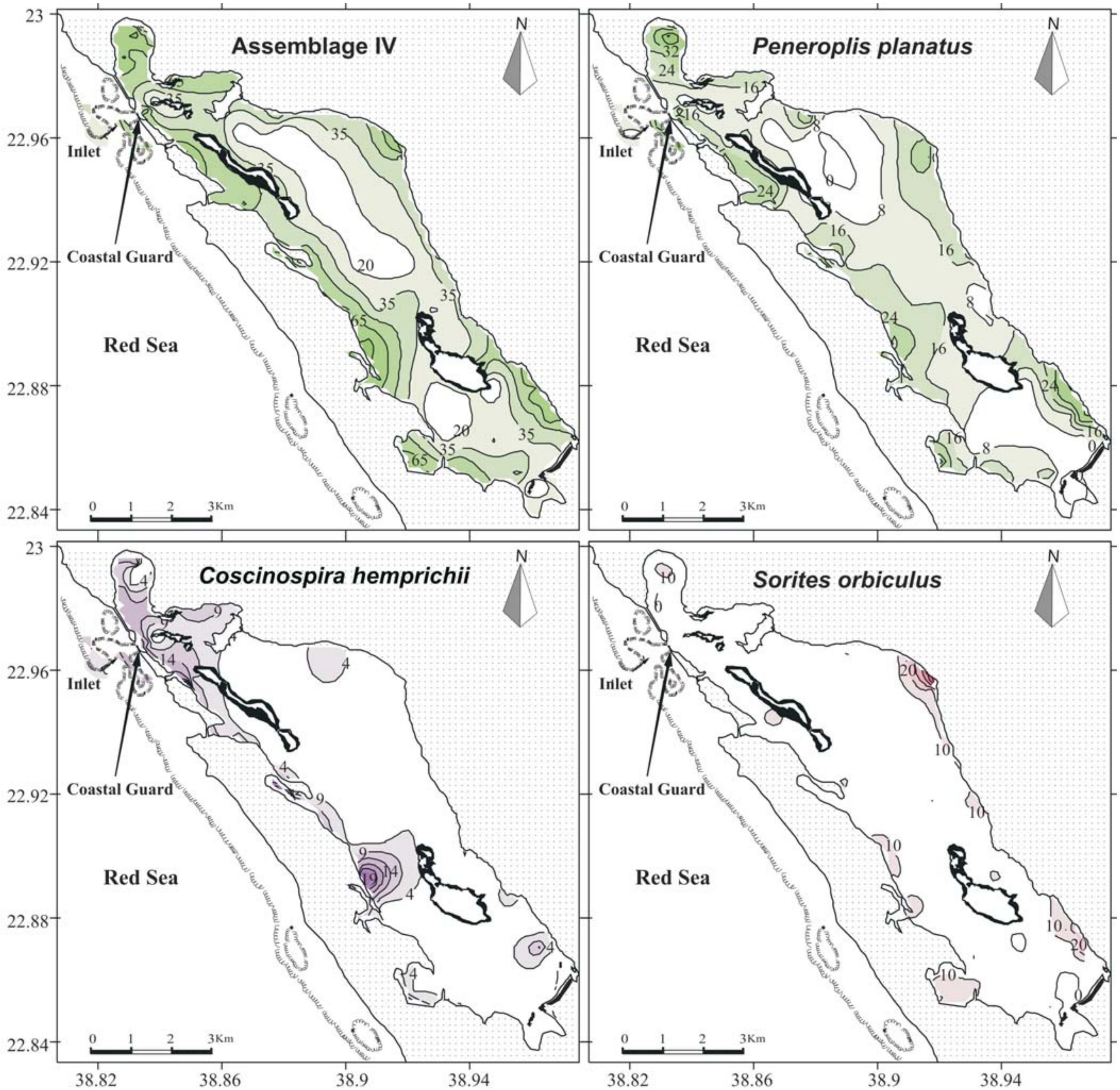
1- Intertidal assemblages *Quinqueloculina seminula-Q. laevigata* (I) and *Affinetrina quadrilateralis-Neorotalia calcar* (II): The *Q. seminula-Q. laevigata* assemblage dominated the intertidal sediments at southern part of the lagoon, representing >50% of the total dead benthic foraminiferal assemblages (text-fig. 8). Its frequency distribution decreases, in general, towards the central and northern parts of the lagoon and completely disappears in the deepest parts of the lagoon (text-fig. 8). *Quinqueloculina seminula* occurs mostly on the southern part of the lagoon, with a maximum frequency of 38% (text-fig. 5). It disappeared from the centre of the lagoon, showing only low abundance at the western and eastern sides of the lagoon. *Quinqueloculina laevigata* occurs also in the southern part and in the mid-western side of the lagoon with a mean abundance ~3%, showing the highest abundance (44%) on the southern intertidal sediments (text-fig. 8). *Ammonia tepida* occurs mainly on the southern part and around Um Dinar islet in the northern part of the lagoon, with a maximum frequency of 10%. It disappeared from the rest of the lagoon (text-fig. 8). Besides the key species of this assemblage, many species occur with low abun-



TEXT-FIGURE 10
Relative abundance distribution maps for: *Amphistegina lessonii* assemblage (III) and the key species *Amphistegina lessonii*, *Assilina ammonoides* and *Heterostegina depressa* in the KL based on species grouping of text-fig. 4.

dances such as *Elphidium advenum, Ammonia tepida, Quinqueloculina costata, Cycloforina quinquecarinata, Vertebralina striata, Pseudotriloculina subgranulata, Parrellina milletti, Spiroloculina antillarum, Quinqueloculina eburnea* and *Haynesina depressula* (text-fig. 4). This assemblage occupied depths ranging from 0 to 1m (text-fig. 5).

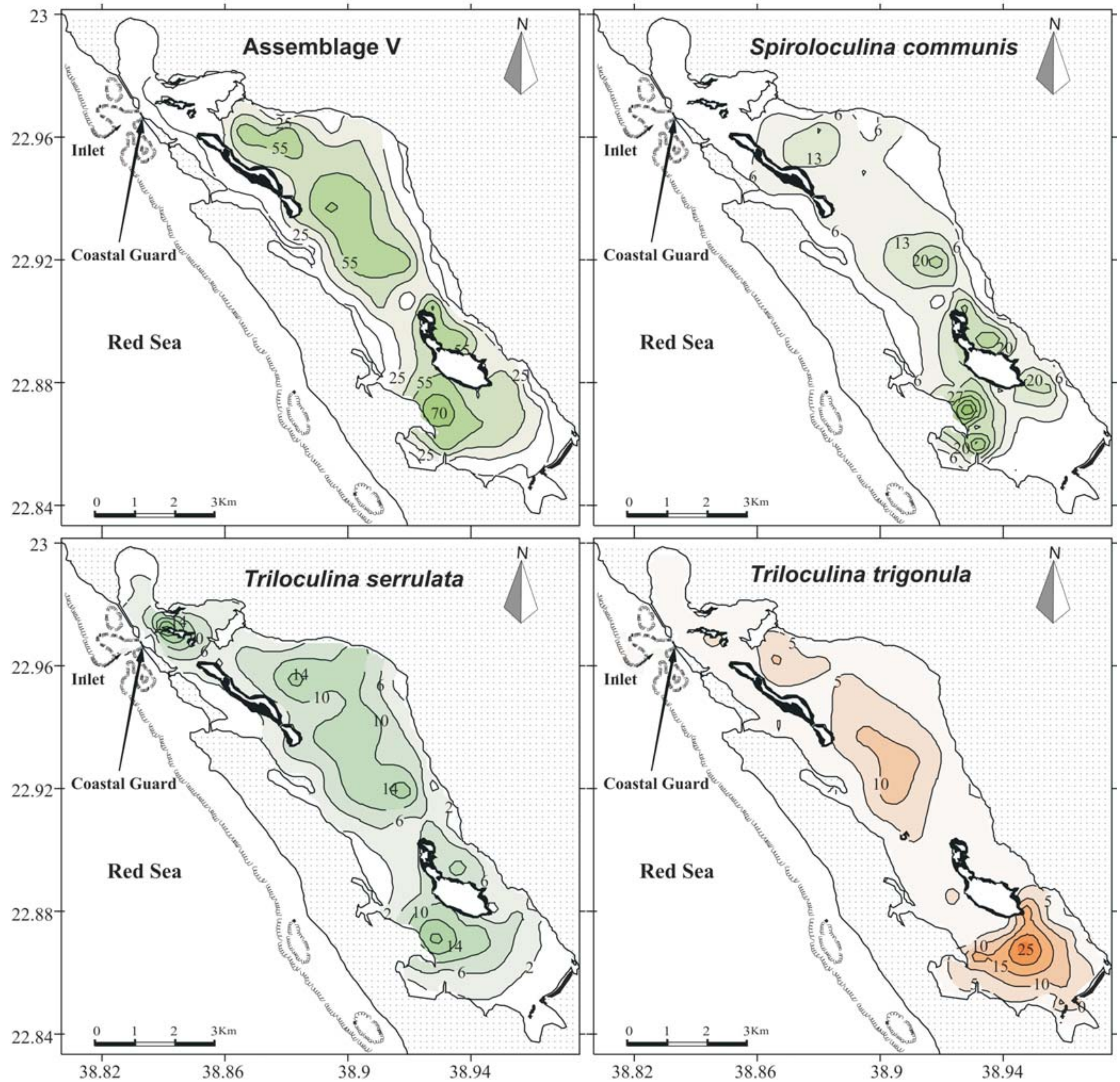
The *Affinetrina quadrilateralis-N. calcar* assemblage (II) was common (up to 36%) in the intertidal sediments, especially at the middle of the eastern side of the lagoon and at its southernmost part; it was absent from the centre and western parts of the lagoon (text-fig. 9). The species *A. quadrilateralis* and *N. calcar* constituted the major part (>60%) of this assemblage. *Affinetrina quadrilateralis* showed its highest abundance (25%) at the extreme southern part of the lagoon where algal mats (filamentous cyanobacteria) and mangroves trees dominate the area (text-fig. 9). It was totally absent from the rest of the lagoon, with only low abundances (~5%) along the eastern side of the lagoon. *Neorotalia calcar* dominated the middle of the eastern side of the lagoon with a maximum abundance of 39%, but it



TEXT-FIGURE 11
Relative abundance distribution maps for: *Peneroplis planatus-Coscinospira hemprichii-Sorites orbiculus* assemblage (IV) and the key species *Peneroplis planatus*, *Coscinospira hemprichii* and *Sorites orbiculus* in the KL based on species grouping of text-fig. 4.

was absent from the rest of the lagoon, displaying a very similar distributional pattern to this assemblage (text-fig. 9). Besides the key species of this assemblage, many species occur such as *Lachlanella corrugata*, *Clavulina angularis*, *Rotorbinella lepida* and *Triloculina fichteliana*. This assemblage dominated depths ranging from 0 to 2 m (text-fig. 5).

2- Inlet assemblage *Amphistegina lessonii* (III): The *Amphistegina lessonii* assemblage (and its associated species) occurred mostly in and around the lagoon's inlet, at the northwestern part of the lagoon, accounting for around 35% of the total dead assemblages (text-fig. 10). This assemblage was absent from surface sediments inside the lagoon (text-fig 10). The relative abundance of *A. lessonii* showed the highest frequency abundance up to 40% in the inlet, displaying a very similar distributional pattern to assemblage III (text-fig. 10). Its highest abundance occurred below 10m water depth (text-fig. 5). This assemblage consists mainly of photosymbiotic rotaliid species such as *Amphistegina lessonii* and *Assilina ammonoides* that represent approximately 6% of the total symbiont-bearing



TEXT-FIGURE 12
Relative abundance distribution maps for: *Spiroloculina communis-Triloculina serrulata-Triloculina trigonula* assemblage (V) in the KL based on species grouping of text-fig. 4.

species in the lagoon**.** *Quinqueloculina patagonica* was also found, but with low abundances.

3- Intertidal-subtidal assemblages *Peneroplis planatus-Coscinospira hemprichii-Sorites orbiculus* (IV): The *P. planatus-C. hemprichii-S. orbiculus* assemblage occurred throughout the KL, representing 65% of the total dead assemblages (text-fig. 11). The relative abundance of *P. planatus* reached 32%, with a mean value of 20%. Its highest abundance occurred in the intertidal-high subtidal areas of the lagoon and it decreased to the lowest values in the centre (deepest part) of the KL (text-fig. 11). *Coscinospira hemprichii* dominated the intertidal-high supratidal areas at the northern and western sides of the lagoon with a mean frequency of 7%, but showing its highest abundance (19%) of the total assemblage in the middle of the western side of the lagoon where algal mats (filamentous cyanobacteria) and coastal shrubs dominate the substrates, but it was absent from the rest of lagoon. *Sorites orbiculus* was found abundantly at some intertidal areas of the lagoon, showing the highest abundance (up to >50%) in the northeastern corner of the lagoon where coarse sand substrates with seagrasses dominate (text-fig. 11). Its abundance decreased throughout the rest of the lagoon, reaching the lowest values in the centre (deepest part) of the lagoon (text-fig. 11). These photosymbiotic miliolida (i.e., *P. planatus, C. hemprichii* and *S. orbiculus*) are a characteristic feature for this assemblage, representing >88% of the total symbiont-bearing species in the lagoon. Besides the key species of this assemblage, many other species occur such as *Elphidium striatopunctatum, Ammonia convexa, Quinqueloculina limbata*, *Q. lamarckiana* and *Varidentella neostriata,* accounting for >35% of the total assemblage (text-fig. 4).

4- Deep-water assemblage *Spiroloculina communis-Triloculina serrulata-T. trigonula* (V): The *S. communis- T. serrulata- T. trigonula* assemblage dominated the centre and southwestern side of the lagoon, representing 70% of the total dead benthic foraminiferal assemblages (text-fig. 12). Low abundances of this assemblage were recorded in the shallower areas (text-fig. 12). *Spiroloculina communis* occurs in the centre and southwestern parts of the lagoon with the highest percentages (>48%) at the southwestern side of the lagoon (text-fig. 12), displaying the same distributional pattern to that of total Assemblage V. It decreases or disappears from the shallower areas, near the shorelines of the lagoon (text-fig. 12). The species *T. serrulata* is widely distributed in the bottom sediments of the centre of the lagoon with an average abundance of 14% (text-fig. 12). Its abundance frequency decreases or disappears at the shallower areas, near the shorelines of the lagoon. *Triloculina trigonula* occurs on the southern and central parts of the lagoon, but with the highest abundance (25%) in the southern part of the lagoon (text-fig. 12). It is absent from the intertidal areas of the lagoon, with a very low abundance (<3%) along the eastern and western sides of the KL. The species comprising this assemblage include: *Quinqueloculina tropicalis, Sigmoihauerina bradyi, Challengerella bradyi, Nonion fabum*, *Edentostomina milletti*, *Adelosina bicornis, A. laevigata, Q. mosharrafai* and *Q. philippinensis*; they represent about 36% of the total benthic foraminifera assemblage (text-fig. 4).

Canonical correspondence analysis (CCA)

The CCA axes 1 and 2 yielded the best ordination, which explained 40 and 29% of the data, respectively. In the ordination of CCA, species such as *Ammonia tepida, A. convexa, Elphidium striatopunctatum, Haynesina depressula, Rotorbinella lepida* and *Quinqueloculina eburnea* showed positive relationships with LOI, pH and muddy substrate (text-fig. 13). In particular, *Ammonia tepida* is positively related with mud substrate and LOI; and inversely related with DO, and sandy substrates enriched in carbonate. *Amphistegina lessonii, Assilina ammonoides, Nonion fabum* and *Challengerella bradyi* are positively related with water depth (text-fig. 13). In contrast, they are inversely related with stressors such as temperature and salinity, but no clear relationship with LOI and pH is observed. *Coscinospira hemprichii*, *Q. costata* and *Varidentella neostriata* display positive relationships with temperature, salinity, DO and sandy substrates (text-fig. 13). However, they showed an inverse relationship with water depth. *Peneroplis planatus*, *Q. seminula, Sorites orbiculus, Q. limbata, Q. laevigata,* and *Triloculina bermudzi* show positive relationships with temperature, salinity, DO, and sandy substrates (text-fig. 13), and no relationship with muddy substrates and LOI. *Peneroplis planatus*, *Coscinospira hemprichii* and *Sorites orbiculus* are more influenced by factors such as temperature and salinity. Gravel and sand sediments are positively related with the carbonates.

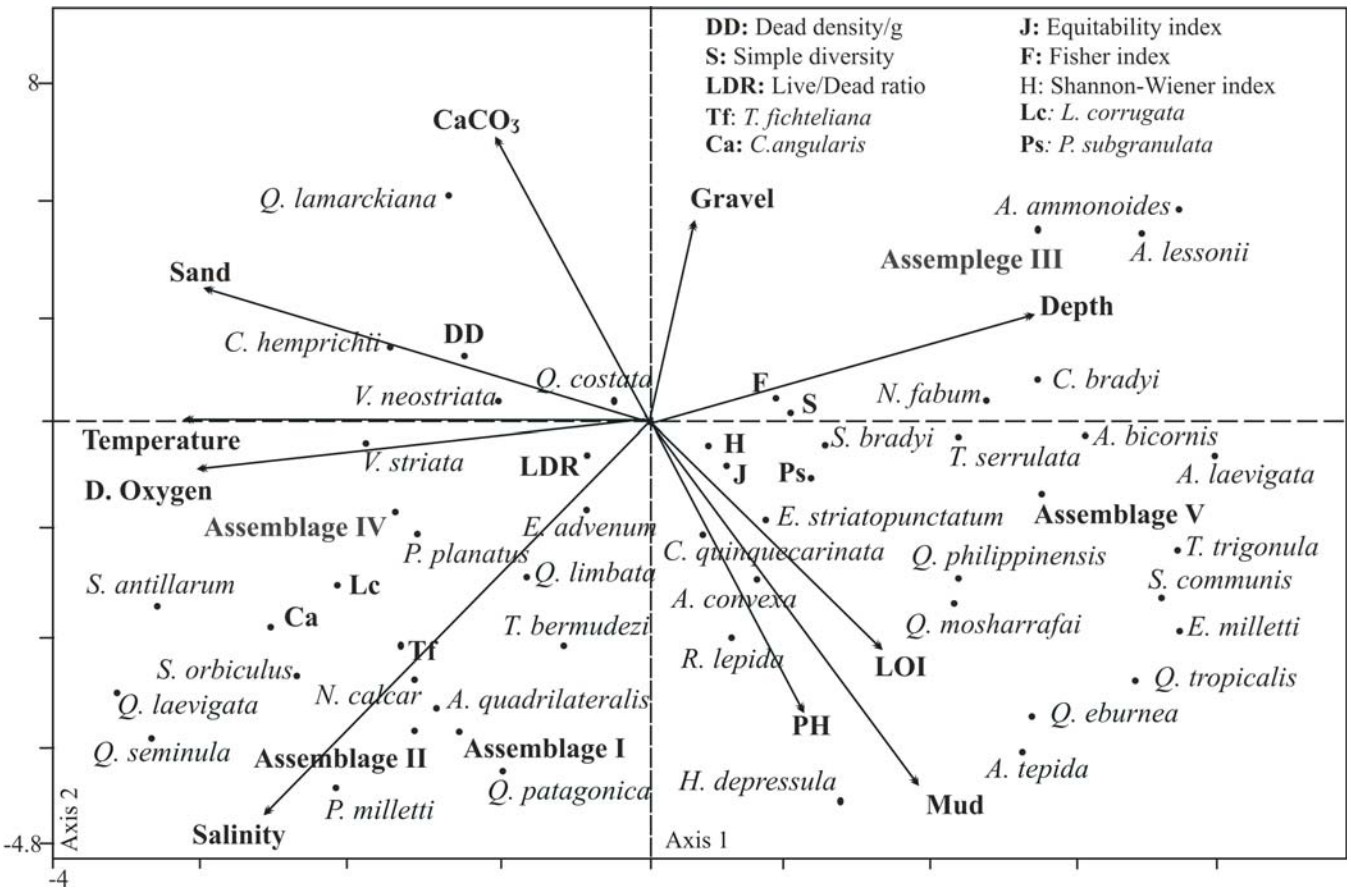
DISCUSSION

The southern tip biotope

This biotope is dominated by the *Quinqueloculina seminula-Q. Laevigata* assemblage. This assemblage showed the highest frequency distribution in the bottom sediment of the intertidal area, especially in sheltered, shallow waters of the lagoon, with a faunal density of 100 tests/g and diversity of 12 species. The environmental parameters of this biotope are very characteristic. Its water depth ranged 0.0–1 m; and its water salinity and temperature were the highest in the lagoon, displaying values of 45‰ and 31 °C, respectively, and DO of 7.1 mg/l. These parameters may have allowed the proliferation of algal mats (filamentous cyanobacteria) and mangroves that occur most abundantly near-shore in muddy, soft substrates rich with organic matter. As a result, the above-mentioned benthic foraminiferal assemblages dominated this niche.

Quinqueloculina seminula was the highest (38%) species in this biotope enriched in soft substrates, occurring under the above-mentioned environmental parameters. These conditions probably favor *Q. seminula* due to their dominance in these areas. This confirms that *Q. seminula* is considered to be relatively tolerant to environmental stress (Debenay et al. 2000; Abu-Zied et al. 2016; Abu-Zied and Hariri 2016). This species declines or disappears towards the deeper waters of the central and northern portions of the lagoon, with only low abundance along the eastern side, suggesting that *Q. seminula* can benefit from muddy, seaweed-rich substrates. However, Abu-Zied et al. (2016) reported that the dominance of *Q. seminula* in proximity to the sewage outfall areas of the southern Corniche of Jeddah indicates that this species may benefit from the high organic matter content in these environments. In this study, *Q. seminula* has also a positive relationship with salinity. Worldwide, *Q. seminula* predominates normal to high salinity, inlet environments (Quilty and Hosie 2006) and it occurs with high abundance in the vicinity of seaweeds (Pruitt et al. 2010).

Ammonia tepida is also a common species (10%) in the *Q. seminula-Q. laevigata* assemblage, which is a characteristic assemblage for the southern portion of the KL. *Ammonia tepida* showed a preference for the environmental conditions of this area as indicated by CCA, in which a positive relationship with organic matter (LOI), pH, and muddy substrates is observed. In this study, *A. tepida* is more abundant in areas where temperature and salinity were (23–29° C) and (40–45‰), indicating its preference to these environmental conditions. Many authors have mentioned that this species has the ability to withstand and survive in harsh environmental conditions (Debenay et al., 2000; Abu-Zied et al., 2016; Abu-Zied and Hariri, 2016). *Ammonia tepida* is a euryhaline, opportunistic species (Martins et al. 2013), dominating estuarine conditions worldwide (Buzas-Stephens and Buzas 2005) or in inland lakes with either hypersaline or brackish waters (Abu-Zied et al. 2011b; Almogi-Labin et al. 1992; Debenay et al. 2009). However, in the open sea such as the Red Sea, this species is nearly absent from shallow waters sediments (Haunold et al. 1997; Hottinger et al. 1993; Reiss and Hottinger 1984; Abu-Zied et al. 2011a). Recently, this species was recorded by Al-Dubai (2011) and Abu-Zied et al. (2013; 2016) in polluted areas of the Jeddah coast, especially in Al-Arbaeen and Al- Shabab inlets and in the



TEXT-FIGURE 13
Canonical-correspondence-analysis (CCA) showing the relationship between of foraminiferal species, assemblages I, II, III, IV, V (text-fig. 4), diversity indexes and environmental variables (arrows) such as depth, temperature, salinity, DO, pH, grain size and LOI in the KL.

southern Corniche of Jeddah, respectively. This may confirm that organic-rich, muddy substrate is an important parameter for the dominance of *A. tepida* either under hypersaline or estuarine conditions. The asymbiotic small miliolid species (*Q. laevigata, Parrellina milletti, Q. eburnea, Q. costata* and *Triloculina bermudzi*) and rotaliid species (*Elphidium advenum* and *Haynesina depressula*) also colonized the southern area of the KL where abundant food sources and soft substrates are dominant.

Mid-eastern side biotope

This biotope is dominated by *Affinetrina quadrilateralis-Neorotalia calcar* assemblage. This assemblage showed the highest frequency distribution (up to 36%) in the intertidal sediments of the middle of the eastern side of the KL. Faunal density there was around 300 tests/g and faunal diversity ranged from 17 to 43 species.

The environmental parameters of this biotope are very characteristic; its water depth ranged from 0.0 to 4 m; water salinity and temperature were 40–43‰ and 25–30 °C, respectively. The DO concentrations in this biotope were 5.6–7.3 mg/l, with an average of 6.4 mg/l. These parameters are probably good for the proliferation of the macro-algae *Turbinaria ornata*, filamentous green algae, and epiphytes in hard substrates covered by a thin layer of muddy sand substrate with a high content of clastic sediments. As a result, the agglutinated *A. quadrilateralis* and *N. calcar* dominated this area. The abundance of *N. calcar* declined towards the central part of the lagoon where fine-grained substrates dominate. These findings indicate a possible relationship between this species and sandy substrates. Murray (1986) pointed out that shell sands may provide shelter and attachment for certain forms, and are suitable for epifaunal feeding. *Neorotalia calcar* is an epiphytic taxon, and it commonly lives attached to macroalgae, seagrasses, and phytal remnants (DeLaca and Lipps 1972; Dobson and Haynes 1973; Langer 1993; Röttger and Krüger 1990; Abu-Zied et al. 2011a), among filamentous algae, their spines may form a mechanical means of stabilization and give it an advantage among tangled filaments (Hohenegger 1994; Lobegeier 2002). *Neorotalia calcar* was also recorded in the southern Corniche of Jeddah (SCJ) at depths ranging from 0.4 to 20 m (Al-Dubai 2011; Abu-Zied et al. 2016). However, in the present study, it was captured at depths of 0.0–4.5 m, suggesting that this species is not depth-limited when it lives in shallow waters. But rather, its proliferation may rely on the dominance of its host such as green filamentous algae and hard to sandy substrates (Abu-Zied et al. 2016). Also, *N. calcar* depends on diatom symbionts, thus, it is mostly found in shallow waters (Lobegeier 2002), preferring high-energy environments where wave action or currents predominate (Hohenegger 1994; Lobegeier 2002). Moreover, the CCA showed positive relationships between *N. calcar* and temperature, salinity and DO; but a negative relationship with depth.

The inlet biotope

The inlet biotope is dominated by the symbiotic rotaliid *Amphistegina lessonii* assemblage. This assemblage showed the highest frequency distribution in the bottom sediment of the inner and outer inlet, with a density of 200 tests/g and a diversity of 22 species. Its environmental parameters are very typical to those of normal Red Sea waters, having 10–30 m water depth, water salinity and temperature were 39‰ and 25 °C with DO of 6.1 mg/l and coarse-grained substrates, mainly of reef rubble. These environmental parameters may a reason for the dominance of the *A. lessonii* assemblage in the inlet environments, since all live tests there were mostly of this species.

The photosymbiotic *Amphistegina lessonii* was associated with other algal symbiotic species such as *Assilina ammonoides*, *A. lobfera*, *A. radiata* and *Borelis schlumbergeri*. They prefer to live on hard substrates as epiphytes on algae and seagrasses (Reiss and Hottinger 1984). In the present study, the highest frequency (45%) of *A. lessonii* was recorded at 30m water depth at the outer inlet. It disappeared from the lagoon due likely to the occurrence of shallower habitats with high salinity and as resultant a decline in the abundance of its algal symbionts needed for growth and calcification (Cockey et al. 1996). In the Gulf of Elat (Aqaba), Hottinger (1977) reported that *A. lessonii* has a depth range to approximately 90 m below sea level. The physico-chemical conditions of the ambient sea waters for the region of the inlet biotope such as salinity of 38–39‰, DO of 6.5 mg/l, temperature of 25 °C, and pH of 8.4 during the sampling period could reflect the influence of normal Red Sea waters. Furthermore, the transparent, oligotrophic waters provide ample light penetration for endosymbiont photosynthesis (Abu-Zied et al. 2016). The distribution of the *Amphistegina lessonii* assemblage in the inlet biotope dominated by corals and coarse gravelly sediments (mostly in cracks between reefs) does appear largely dependent on the above-mentioned physico-chemical conditions and sediment substrate type. This is also indicated by its (*A. lessonii*) strong positive relationship with gravel sediments in the ordination plot of CCA. Hohenegger et al. (1999) stated that *A. lessonii* adapted itself for living on coarse sediment substrates that are agitated by waves. Also, many authors reported that *A. lessonii* and *Assilina ammonoides* prefer to live on hard substrates (coral reef), algae, or seagrasses (Hayward 1979; Hohenegger 2004; Langer 1993; Reiss and Hottinger 1984; Troelstra et al. 1996; Walker et al. 2011; Abu-Zied et al. 2016). *Amphistegina lessonii* is used as an indicator of warm temperate tropical waters and is also considered an important component for tropical reef carbonates (Hallock 2000, 2012; Hallock et al. 2003; Langer et al. 2013, 2016).

The whole intertidal-subtidal biotope

This biotope is dominated by a *Peneroplis planatus-Coscinospira hemprichii-Sorites orbiculus* assemblage which showed the highest frequency distribution in the surficial bottom sediment of intertidal-subtidal areas of the lagoon with 0–4 m water depth, density of 900 tests/g, and a diversity of 44 species. The environmental parameters of this biotope are very characteristic; the highest water salinity and temperature (44‰ and 30 °C) were recorded at the mid-western and northeastern sides of the lagoon, respectively, with DO of 8.5–9 mg/l. These parameters allowed the proliferation of dense algal mats (filamentous cyanobacteria), macro-algae (*Padina boryana* and *Turbinaria ornata*), sea-grasses (*Cymodocea rotundata* and *Avrainvillea*

PLATE 1

1 *Clavulina multicamerata,* side view.

2 *Clavulina angularis,* side view.

3-4 *Vertebralina striata*, (3) dorsal view (4) ventral and apertural views.

5 *Spiroloculina communis*, side view.

6 *Spiroloculina costigera,* side view.

7 *S. rugosa,* side view.

8 *Spiroloculina* sp, side view.

9 *Spiroloculina sulcata,* side view.

10 *Spirophthalmidium* sp., side view.

11-12 *Agglutinella compressa,* side view.

13 *Agglutinella robusta,* side view.

14 *Lachlanella subpolygona,* side view.

15 *Lachlanella corrugata,* side view.

16-17 *Siphonaperta pittensis,* side view.

18 *Siphonaperta* cf. *S. agglutinans,* side view.

19-20 *Affinetrina quadrilateralis,* side view.

21 *Schlumbergerina alveoliniformis,* side view.

22 *Pseudomassilina reticulata,* side view.

23 *Pseudomassilina pacificiensis,* side view.

24 *Pseudomassilina macilenta,* side view.

25 *Pseudomassilina australis,* side view.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amadelpha), and epiphytes on a bioclastic sandy substrate. As a result, the *P. planatus*-*C. hemprichii*-*S. orbiculus* assemblage dominates this biotope.

The species *P. planatus* and *C. hemprichii* are epiphytic miliolids with hosts mainly of red algal endosymbionts (Lee and Anderson 1991). High frequencies of *P. planatus* (~50%) and *C. hemprichii* (20%) were recorded in the shallow, sheltered, warm waters where muddy sand substrates, macro-algae, and mangrove vegetation occur. Their frequency declined to lowest values towards the deep waters in the central part of the lagoon, where low DO and muddy, fine-grained substrates dominate. The composition and distribution pattern of these species appears to be controlled by the substrate-type where seagrasses and algae are important controlling factors. Halfar and Ingle (2003) mentioned that *C. hemprichii* and *Peneroplis* spp. are richer in the shallow water of the southwestern Gulf of California (Mexico) and their distribution is largely governed by substrate type. Amao et al. (2016) documented that the distribution of peneroplids in a shallow restricted lagoon in Bahrain correlates with the presence of vegetation in the lagoon. Haunold et al. (1997) reported that *C. hemprichii* and *P. planatus* prefer to live in both seagrasses and sediment substrates, and their presence in bottom sediments is indicative of (par)-autochthonous sediments. Troelstra et al. (1996) mentioned that *Peneroplis pertusus* was abundant on coral reefs in the outer-shelf area, where they lived preferentially epiphytic on seagrasses and algae at depths from 1 to 21 m. Because of the unavailability of the preferential habitat known from other areas, *P. planatus* moved to a different habitat at the Spermonde Archipelago. In the present study, *P. planatus* and *C. hemprichii* were found with a low abundance at depths ranging from 10 to 18 m on the reefal habitats around the inlet of the lagoon, indicating the transparent, oligotrophic waters providing sufficient light penetration for endosymbiont photosynthesis, where these species could be less dependent on algal endosymbionts. Several authors have reported that reefal assemblages (e.g., *P. planatus* and *Coscinospira hemprichii*) usually live under transparent, oligotrophic waters in order to facilitate photosynthesis of their algal endosymbionts (Hallock 1981; Hohenegger 2004; Abu-Zied et al. 2016). Hohenegger (2004) concluded that light is the most important factor for benthic foraminifera that host algal endosymbionts, due to their dependence upon photosynthesis by their algal endosymbionts for growth and calcification. Furthermore, the dominance of the porcellaneous species, larger benthic foraminifera such as *P. planatus* and *C. hemprichii* in nearshore shallow-water sites indicates that these species are able to withstand extremes of salinity and temperature, reflecting a warm, dry climatic conditions (Semeniuk 2001; Abu-Zied et al. 2016; Abu-Zied and Hariri 2016; Amao et al. 2016) with high pH and salinity which enhance the formation of large, thick, porcellaneous tests (Abu-Zied et al. 2016). This is also indicated by the CCA that shows a positive relationship between *P. planatus* and *C. hemprichii* and higher temperatures, salinities, and DO.

Sorites orbiculus is an epiphytic species, and is commonly found attached to seagrasses and phytal remnants (DeLaca and Lipps 1972; Dobson and Haynes 1973; Langer 1993; Abu-Zied and Bantan 2013). It was recorded sporadically in the intertidal areas of the KL, with highest frequency up to >50% of total assemblage on the northeastern portion of the lagoon where coarse sand substrates with seagrass (*Cymodocea rotundata*) dominate, but it was absent from the rest of the lagoon particular towards the subtidal area (deep-water), indicating post-mortem onshore transport. *Sorites orbiculus* lives attached on the blades of seagrasses. When these blades are shed, the *Sorites* tests are readily transported by currents and waves to accumulate at the beach (Hippensteel et al. 2002; Hohenegger 2004; Wilson and Ramsook 2007; Abu-Zied et al. 2011a). Thus, fossils of *S. orbiculus* can be used as a tracer for shoreline development (Abu-Zied et al. 2011a; Abu-Zied and Bantan 2015). It was also suggested that *Sorites* tests indicate allochthonous shoreline sediments (Hallock and Larsen 1979; Vance et al. 2006). *Sorites orbiculus* decreases towards the deep-water and fully disappears at the central part and outlet of the lagoon; this is probably related to the lack of its seagrass host (Reiss and Hottinger 1984) with increasing depth. Its decrease towards the center and northern parts of the lagoon might be attributed to a lower temperature (25 °C) and salinity (39‰) in the ambient sea water of

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PLATE 2

1-2 *Cycloforina sulcata*, side view.

3 *Cycloforina quinquecarinata*, side view.

4-7 *Cycloforina carinatastriata*, side views.

8 *Pseudotriloculina granulocostata*, side view.

9 *Pseudotriloculina subgranulata*, side view.

10 *Pseudotriloculina* cf. *P. chrysostoma*, side and apertural views.

11-12 *Triloculina fichteliana*, side views.

13 *Triloculina serrulata*, side view.

14-15 *Pseudotriloculina* cf. *P. oblonga*, side views.

16 *Triloculina* cf. *T. schreiberiana*, side view.

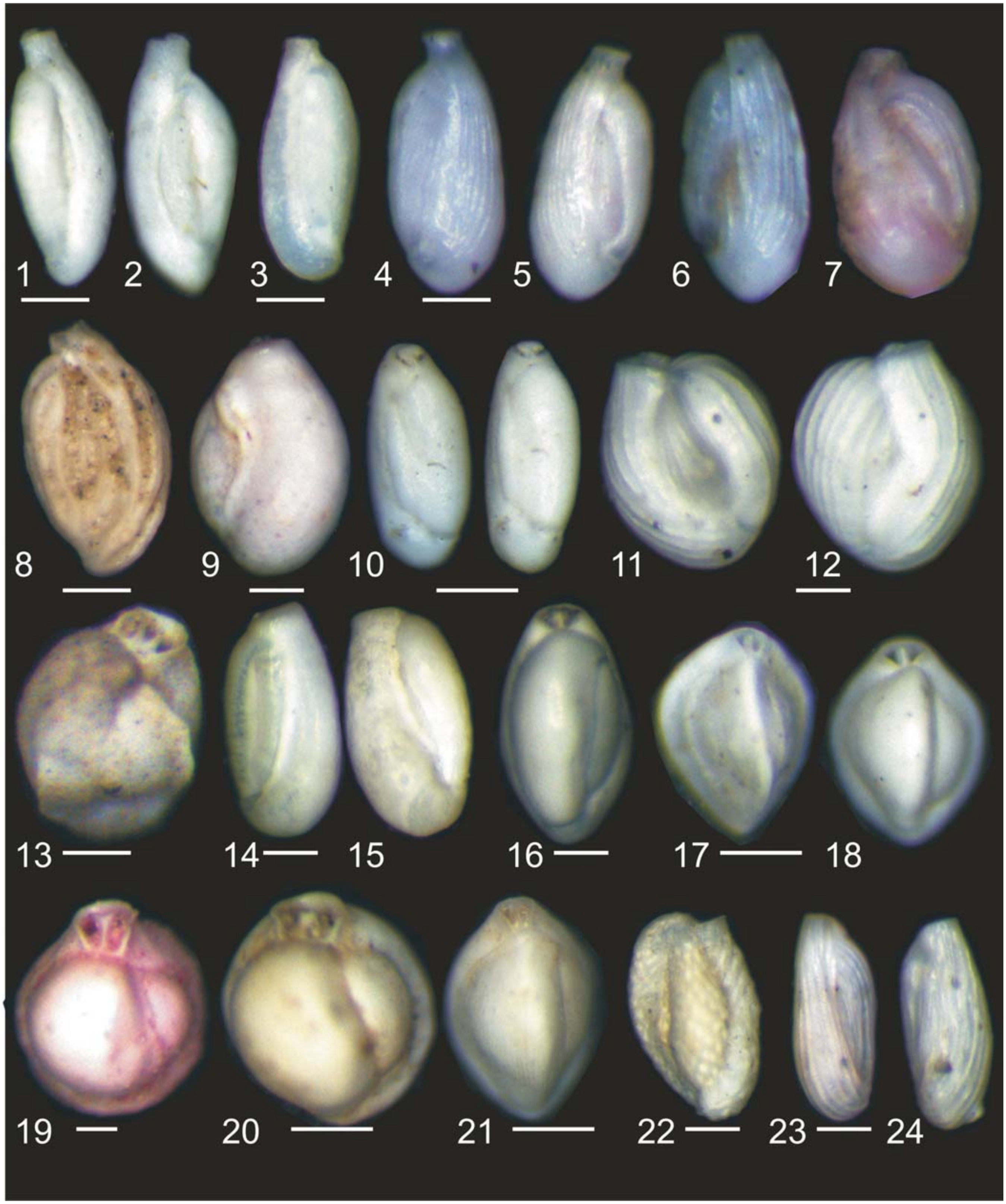
17-18 *Triloculina tricarinata*, side views.

19-20 *Triloculina trigonula*, apertural views.

21 *Triloculina terquemiana*, side view.

22 *Quinqueloculina pseudoreticulata*, side view.

23-24 *Q. limbata*, side views.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the deep-water and inlet biotopes, comparing to extreme temperatures (up to >30 °C) and salinity (up to 44 ‰) in the regions of whole intertidal-subtidal areas and southern tip biotopes, especially at the shoreline that allows *S. orbiculus* to settle and thrive (Hyams et al. 2002; Gruber et al. 2007; Lazar 2007; Merkado et al. 2013). In the Gulf of Eilat, *S. orbiculus* was found attached to *H. stipulacea* leaves (at about 1 m water depth), which forms meadows over vast areas of the Gulf's shallow habitats (Merkado et al. 2013).

Deep water biotope, the lagoon centre

This biotope is dominated by a *Spiroloculina communis-Triloculina serrulata-T. trigonula* assemblage. They showed the highest frequency distribution in the bottom sediment of the central part of the lagoon and were rare in the intertidal areas of the lagoon, with a density of 200 tests/g and diversity of 17–32 species. Its bathymetry ranged from 4 to 8m with salinity and temperature of 40–41‰ and 25° C, respectively, and bottom water DO of 5–6.5 mg/l. These parameters allowed the proliferation of sea-grasses (*Halophila stipulacea*) and epiphytes in organic-rich, muddy substrates. As a result, the above-mentioned environmental conditions may have favored the *S. communis-T. serrulata-T. trigonula* assemblage.

Similar results were recorded in the deep water sediments of the Shuaiba Lagoon (80 km south of Jeddah City) where these species were found in soft muddy substrates enriched with the green macro- alga *Caulerpa ethelae* and with lower bottom salinity than those recorded in the intertidal area (Abu-Zied and Bantan 2013). These species could benefit from the soft-substrates of the deep region (the deep-water biotope), which usually contain more organic matter remnants, since they are suitable for both infaunal and epifaunal feeding behavior (Murray 1986; Abu-Zied et al. 2007; Abu-Zied and Bantan 2013). In the bi-plot of CCA, the deep-water assemblage was positively correlated with mud, muddy substrates, and pH, and it was negatively correlated with sandy substrates, carbonate, temperature, and salinity, which are the highest in the shallow waters of the southern tip and intertidal-subtidal biotopes of the KL. The ambient water salinity of the deep-water biotope was ~40‰, and it was lower than those recorded in the shallow water (southern tip biotope) near the shoreline (about 44‰). This possibly allows the assemblage (*Spiroloculina communis-Triloculina serrulata-S. trigonula*) to dominate the deep-water habitats in the lagoon as indicated also by the CCA where the deep-water assemblage showed a positive relationship with water depth. Consequently, the composition and distribution pattern of this assemblage may also be governed by water depth.

CONCLUSIONS

The surface sediments of the Al-Kharrar Lagoon show in general low faunal density and diversity with averages of 135±300 dead tests/g and 23±10 species, respectively. Five foraminiferal assemblages are recognized in the bottom sediments of the lagoon based on cluster and CCA analyses. These assemblages colonized five ecological biotopes as follows: the southern tip biotope, the mid-eastern side biotope, the inlet biotope, the whole intertidal-subtidal biotope and deep-water biotope. The *Q. seminula-Q. laevigata* assemblage dominated the southern tip biotope (A1) where the clastic materials from Wadi Rabigh predominate. The mid-eastern side biotope (A2) is rich with green filamentous algae and hard to sandy substrates that allowed the occurrence of an *Affinetrina quadrilateralis-Neorotalia calcar* assemblage. The inlet biotope (B) is influenced by the normal Red Sea waters that allowed the proliferation of the *Amphistegina lessonii* assemblage below 10 m water depth. The *Peneroplis planatus-Coscinospira hemprichii-Sorites orbiculus* assemblage was found abundantly in the shallowest areas (biotope D) of the lagoon where the extremes in temperature and salinity occur. The deeper part of the lagoon (biotope C) is enriched in sea-grasses, epiphytes, organic-rich, muddy substrates, and the *Spiroloculina communis-Triloculina serrulata-T. trigonula* assemblage. As a conclusion, the density, diversity, distribution, and composition of benthic foraminiferal species in the studied lagoon seem to be governed by many various environmental conditions such as bathymetry, substrate-types and their phytal cover, salinity, temperature, DO and food supply.

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PLATE 3

1-3 *Quinqueloculina lamarckiana,* side views.

4-5 *Quinqueloculina bosciana,* side views.

6-7 *Quinqueloculina tropicalis,* side views.

8-9 *Quinqueloculina costata,* side views.

10-11 *Q. distorqueata,* side views.

12-14 *Q. eburnea,* side views.

15-16 *Q. mosharrafai*, side views.

17-18 *Varidentella neostriata,* side views.

19-21 *Adelosina bicornis,* side views.

22 *Adelosina laevigata,* side view.

23-24 *Adelosina longirostra,* side views.

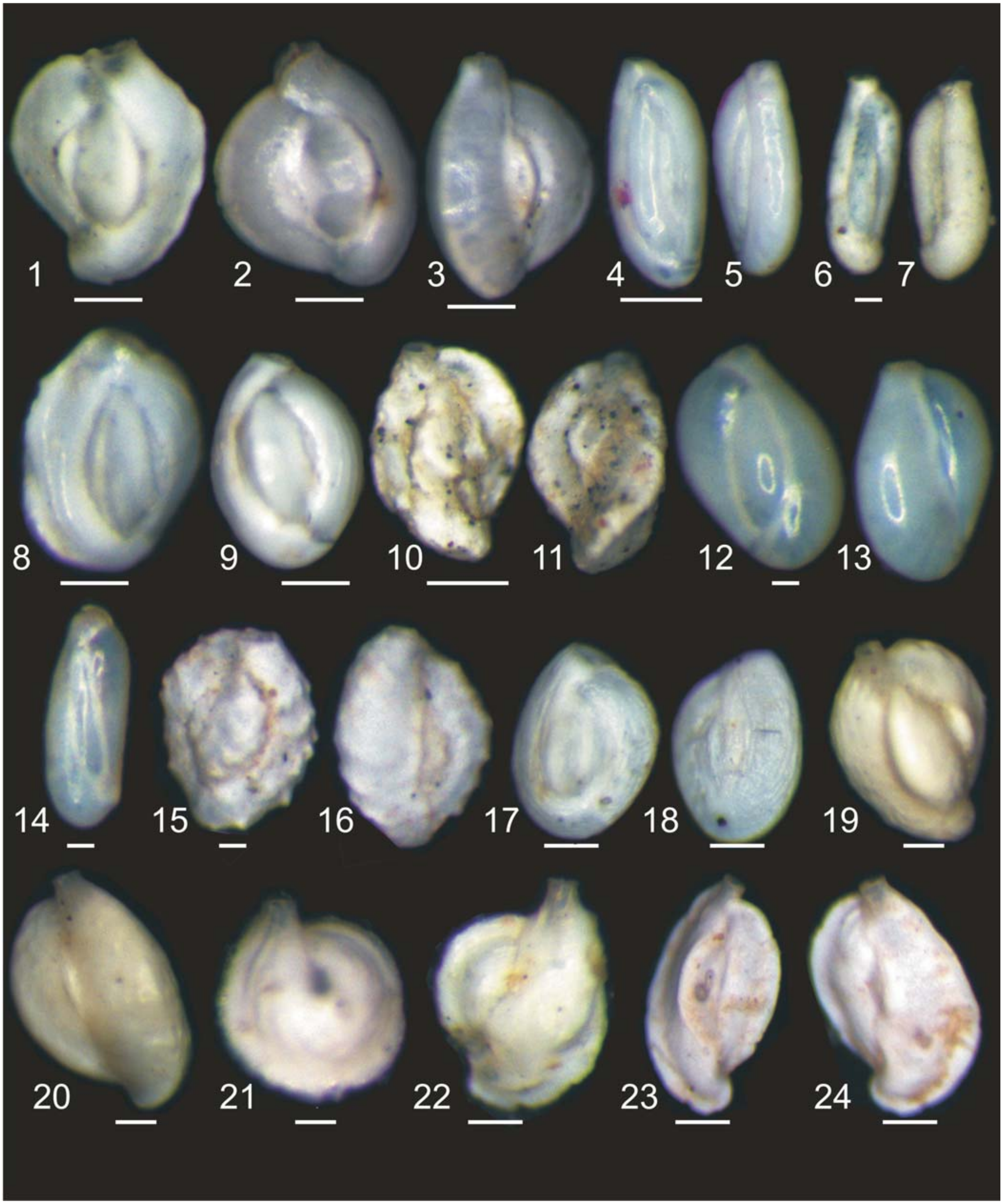
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PLATE 4

1 *Sigmoihauerina bradyi*, side view.

2 *Articulina antillarum*, side view.

3 *Parrina bradyi*, side view.

4 *Borelis schlumbergeri*, side and apertural views.

5-6 *Coscinospira hemprichii*, side views.

7 *Monalysium acicularis*, side view.

8 *Peneroplis planatus*, side view.

9 *Sorites orbiculus*, side view.

10-11 *Eponides repandus*, (10) spiral view, (11) ventral view.

12 *Epistomaroides punctatus,* side view.

13-14 *Amphistegina lessonii*, side views.

15 *Amphistegina papillosa*, dorsal view.

16 *Nonion fabum*, side view.

17-18 *Neorotalia calcar*, spiral views.

19 *Assilina ammonoides*, spiral view.

20 *Heterostegina depressa*, side view.

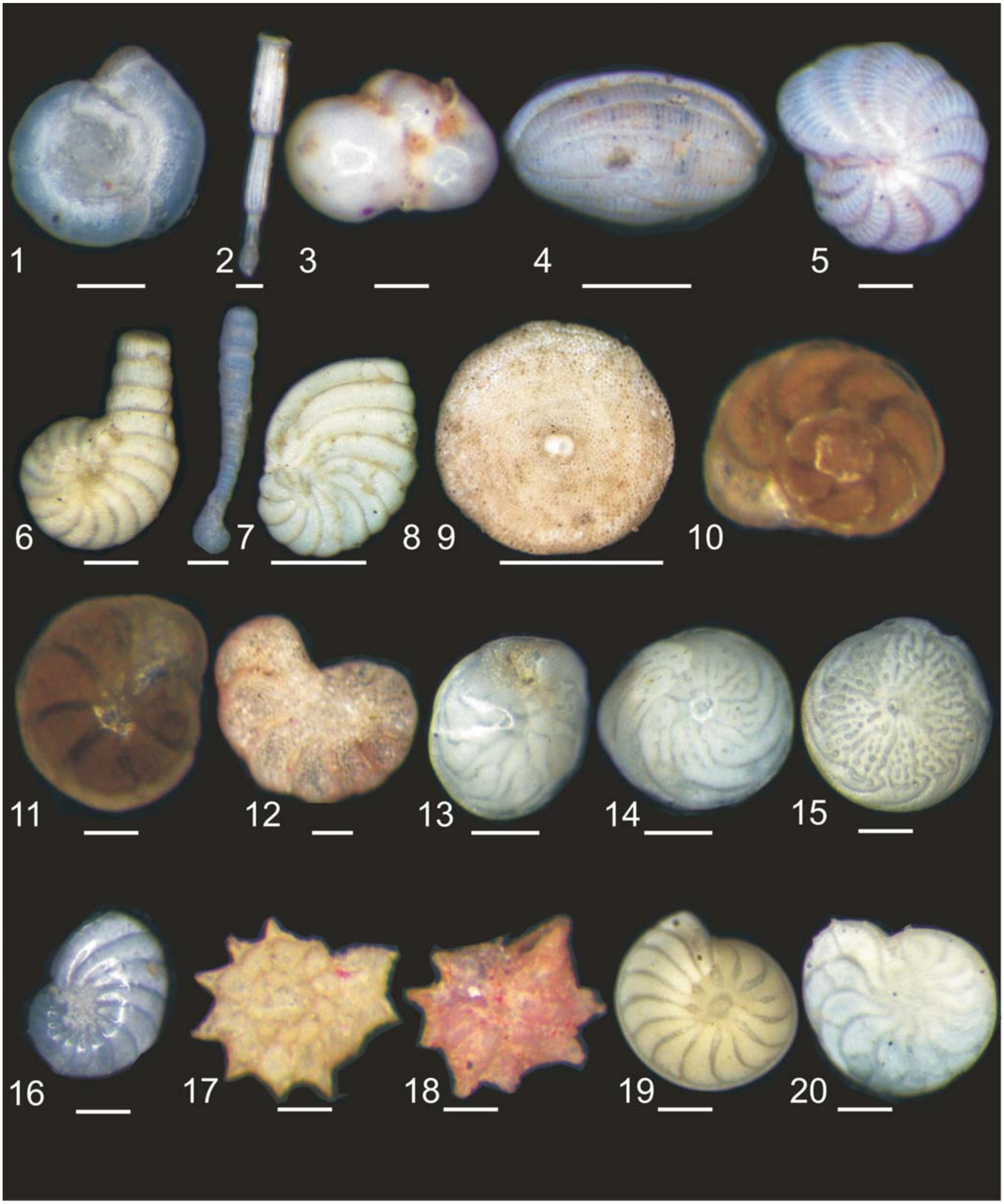
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PLATE 5

1-3 *Ammonia convexa*, (1) spiral views (2-3) umbilical views.

4-5 *Challengerella bradyi*, (4) spiral view (5) umbilical view.

6 *Elphidium advenum,* side view.

7 *Elphidium crispum*, side view.

8 *Elphidium striatopunctatum,* side view.

9 *Elphidium jenseni,* side view.

10 *Elphidium craticulatum,* side view**.**

11 *Elphidium discoidalis multiloculum,* side view.

12 *Heterolepa praecincta,* spiral view.

13-14 *Rosalina globularis,* (13) spiral view (14) umbilical view.

15-16 *Rupertianella rupertiana,* side and apertural views.

17 *Edentostomina milletti,* side view.


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