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ORIGINAL ARTICLE

FIRST RECORD OF A FORAMINIFERA *PSEUDOEPONIDES ANDERSENI* WARREN, 1957 (ROTALIIDA, EPISTOMARIIDAE) FROM AL HAMMAR MARSH (SOUTHERN IRAQ) AND IMPORTANCE AS AN INDICATOR OF COASTAL MARINE MARSH ECOLOGY DURING THE LATE HOLOCENE

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ABSTRACT

The present work is intended to report a newly recorded species of foraminifera *Pseudoeponides anderseni* Warren, 1957 (Rotaliida, Epistomariidae) in this region. A total of seventeen specimens were collected from eight stations located south of Al Hammar Marsh. Each sample was analysed for both sediment texture and foraminiferal content, including species identification and relative abundance. Grain-size analysis revealed four main sediment textures in the study area: silt, sandy silt, mud, and sandy mud, with mud being the most predominant. The foraminiferal species recognized was *P. anderseni*, a benthic taxon that typically inhabits marine environments. This species is considered an important environmental bioindicator, providing evidence of marine influence in southern Iraq during the Holocene. Based on the presence of minor species *Buccella frigida* Cushman, 1922 (Rotaliida, Notorotaliidae) and *Ammonia beccarii* Linnaeus, 1758 (Rotaliida, Ammoniidae) along with the dominant species *P. anderseni*, it is hypothesized that Al Hammar Marsh was a coastal marine marsh during the Late Holocene epoch.

Keywords: Ammonia, Bioindicator, *Buccella*, Foraminifera, Holocene, *Pseudoeponides*.

INTRODUCTION

The south of Iraq is one of the most distinguished parts compared to the rest of Iraq, due to its unique environments. Al Ahwar (the Marshes), also known as the Mesopotamian Marshlands, which include a unique and an ecologically significant area in the southern part of Iraq formed through complex interactions of neotectonic activities, Holocene sea-level fluctuations, differential sedimentation rates, and climatic changes (Al-Ansari, 2020; Aqrawi, 2001). The formation and preservation of the marshes have been strongly affected by repeated geological and climatic events during the Holocene which to influence their hydrology and ecology. The environment in the area has also been susceptible to sea- level fluctuations and tectonic activity that influences the water and sediment supply, thus affecting marsh dynamics as well (Aqrawi, 2001). These geological factors plus human influence and climate change result in a diverse physical environment, which sets the southern Iraqi marshes apart from other landscapes (Aqrawi, 2001; Master, 2001). One of these crucial marshes for its extent and ecological importance is AI Hammar Marsh, one of the largest parts of the Mesopotamian Marshes located in southern Iraq with a large and complex wetland ecosystem extending over it with a history dating back to the Holocene period (Van de Noort, 2013). It is located in the floodplain of the Tigris and Euphrates Rivers, mostly occupying slightly higher ground in the case of several sites, and was due to fluvial deposition and periodic flooding which formed complex wetland habitats which were developed through rivers and their tributaries (Al-Gburi *et al*., 2017; Al-Ameri and Briant, 2019; Al-Quraishi and Kaplan, 2021; Al-Mufraji and Mohammed, 2024).

In the Holocene, and especially between c. 9000 and c. 5000 years BP, the southern Mesopotamian delta-including Al Hammar Marsh- was affected by high postglacial sea-level rise that induced a very saline/marine brackish phase transgression (Sissakian *et al*., 2020). Each phase was followed by varying degrees of marine incursion, and finally by sediment infilling from the Tigris, the Euphrates and other rivers leading to more freshwater conditions as a result of deltaic sedimentation and marsh enlargement. These complex relationships between sea-level rise, sediment supply and river dynamics created a suite of depositional environments with rapidly changing salinity gradients and facies in many parts of southern Mesopotamia during multiple periods of the Holocene (Pournelle, 2006-2011; Menshed and Al-Zaidy, 2021; Iacobucci *et al*., 2023).

The presence of marine shells-specifically gastropods and lamellibranchs-in the sediments of Al Hammar Marsh is a key indicator of past marine influence in southern Mesopotamia, as first documented by Hudson *et al*. (1957). This foundational study helped confirm that the region experienced a marine advance during the Holocene, with shell remains providing direct evidence of marine incursions that extended well inland (Hudson *et al*., 1957). Macfadyen and Vita-Finzi (1978) and subsequent works have provided additional evidence of the marine influence in sediments of southern Iraq by the presence of molluscan fauna recorded at Amarah and Qarmat Ali, which are very similar to those described by Hudson, in addition to different species of foraminifera. Weak academic phrasing evidence (to validate the effect of seawater on Southern Iraq) comes from Issa (2024) who approves the effect of seawater as a result of sea-level changes during Holocene time on sediments formed in south of Al Hammar Marsh (southern Iraq), this was based on documenting occurrence and abundance of different marine foraminiferal species in the region. The foraminifera serve as reliable bioindicators to infer paleoenvironmental conditions during specific periods (Daché *et al*., 2024; Belart *et al*., 2025). Consequently, the use of foraminifera for paleoenvironmental inference is a crucial element in any research aimed at investigating the environment of a particular region during a defined time frame, as demonstrated in the present study, particularly with the documentation of the initial appearance of species in the sediments of the area. This also strengthens the validation of the influence of paleoenvironmental conditions in the research zone (McGowran, 2005).

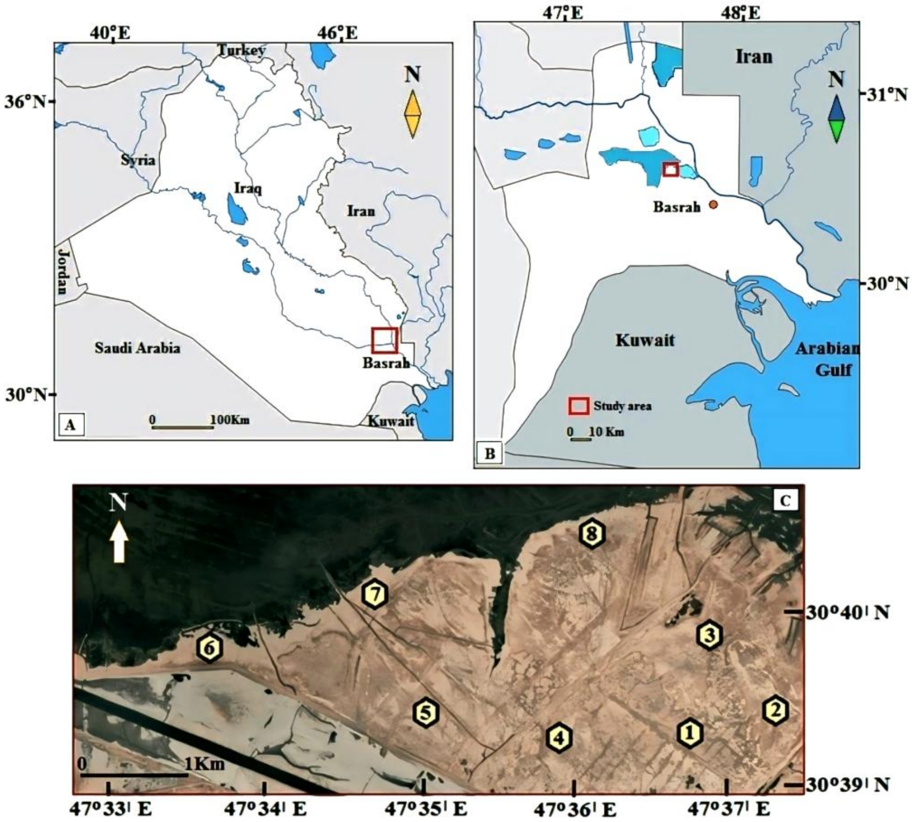
The study sought to recognize a new record species detected in the south of Al Hammar Marsh (southern Iraq), where late Holocene sediments are present, and to verify its classification as a benthic foraminiferal species. Additionally, the study aimed to uncover its environmental importance facilitated its emergence, which ultimately aids in enhancing the comprehension of the study area's paleoenvironment.

MATERIALS AND METHODS

Study area: The study was carried out in August 2019 in the southern Al Hammar Marsh as shown in Map1. Sediment samples were collected using a shovel at eight different locations, ranging between 0.35 and 1.70 m depth according to the differences in sediment colour observed in each core.

Specimens collection: A total of 100 grams of sediment was collected from each of the seventeen samples to determine sediment characteristics in the study area locations. The particle size distribution of the sediment samples was analyzed using the wet sieving method (using a 63 µm fraction sieve to separate sand from silt and clay) along with the Pipette technique (Folk, 1980).

Identification and photographs the specimens: For foraminiferal analysis, the 63 µm fraction obtained by wet sieving of each sample was selected, and the foraminiferal species under study were identified and classified using a binocular stereoscopic microscope. The species were captured in photographs using a scanning electron microscope (FE-SEM) Nova Nano SEM 450 in the Department of Physics at the University of Basrah. Foraminiferal species identification was validated by comparing representative individuals with references in the literature (Saunders, 1957; Loeblich and Tappan, 1988; Gennari *et al*., 2011; Hayward *et al*., 2021).



Map (1): (A) A map of Iraq, (B) The study area location, (C) Sampling sites.

RESULTS

Sediment grain size analysis

Sediment texture was determined using the percent composition of sand, silt, and clay. The fractions are then plotted in the ternary diagrams (Folk, 1980) used for names based on textural classification of the sediments (Diag.1; Tab.1), mud dominated the high area with about 41%, followed by silt that represents 29% and sandy mud accounts for about18% while sandy silt was only12%. These contrasts in fine (mud) and coarse fraction (sand) distribution may have been a function of the location at which the study area was placed. The drying out of the area promoted erosion processes and increased the proportion of aeolian sediments in the region. In addition, proximity of the study area to river water and marshes also contributed to environmental stress factors. Additionally, the impact of Holocene sea-level rise, which during that epoch covered the area in marine sediment (Issa, 2010).

The grain-size analysis is one of the basic tools for classifying sedimentary environments, an analysis which provides important clues to the provenance, transport history, and depositional conditions (Yi *et al*., 2015). Changes in grain size can also give insight into possible shifts in climatic or environmental conditions over time, perhaps recordings of changes in river discharge, wind intensity or sea level due to their impact on sediment supply and transport. In lacustrine and marine environments, variations in grain size may be associated with changes in water velocities, sediment sources, and sedimentation processes to recover couplets of hydrodynamic regimes and environmental dynamics (Liu *et al*., 2019). The size of sediment grains is very important in ecological terms for benthic foraminifera because it affects the stability of sediments and the suitability of microhabitats, thus determining their abundance and distribution in various sedimentary environments (Lo Giudice Cappelli *et al*., 2019; Deldicq *et al*., 2023).

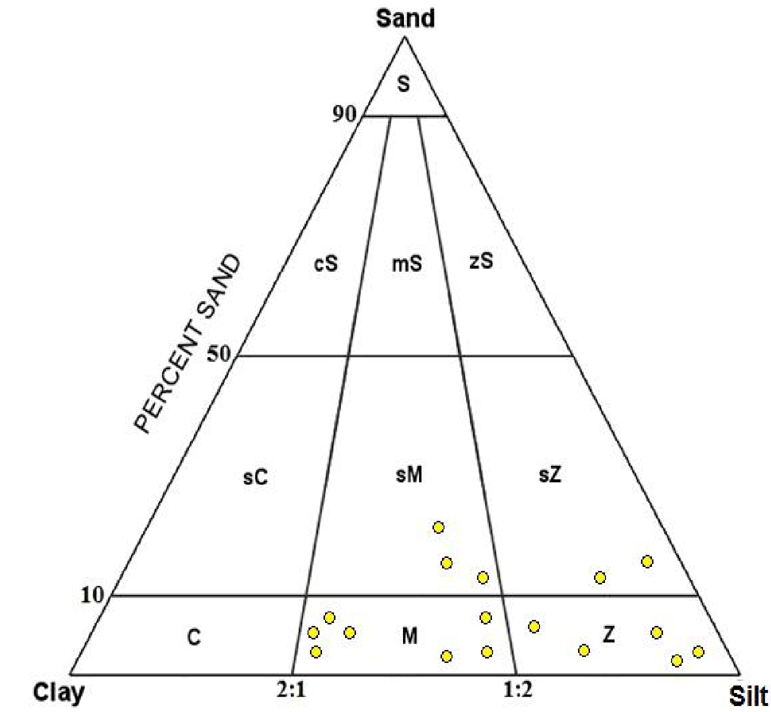


Diagram (1): Ternary diagram of the percentage of sand, silt and clay in the sediment texture of samples.

Table (1): The percentage of sand, silt, and clay in sediment texture.

Site no.	Sample depth (m)	Sand %	Silt %	Clay %	Sediment texture
1	0.50	5	85	10	Silt
	1.35	14	55	31	Sandy mud
2	0.90	22	41	37	Sandy mud
	1.50	6	56	38	Mud
3	0.60	3	94	3	Silt
	1.10	4	60	36	Mud
4	0.55	17	78	5	Sandy silt
	1.05	1	92	7	Silt
5	0.35	6	64	30	Silt
	1.15	9	56	35	Mud
6	0.65	13	73	14	Sandy silt
	1.09	2	55	43	Mud
7	0.60	16	48	36	Sandy mud
	1.70	8	34	58	Mud
8	0.75	4	72	24	Silt
	1.07	4	35	61	Mud
	1.50	6	31	63	Mud

Foraminifera analysis: The most dominant species was *Pseudoeponides anderseni* Warren, 1957 in the study area (Pl.1, 1-6). The remaining few foraminifera were represented by two species of benthonic foraminifera *Buccella frigida* (Cushman, 1922) and *Ammonia beccarii* (Linnaeus,1758) (Pl.1, 9-11). The abundance and dominance of the species *P. anderseni* over other foraminifera (Diag. 2) and Table (2) are demonstrated in the study sites' samples. The other species (Pl.1, 9-11) were considered poorly preserved and the relative mean was not important in comparison to that of the species previously cited.

Classification

According to Hayward *et al*. (2021), the classification of *Pseudoeponides anderseni* is as follows:

Kingdom **Chromista** Cavalier-Smith, 1981
Subkingdom **Harosa** Cavalier-Smith, 2010
Infrakingdom **Rhizaria** Cavalier-Smith, 2002
Phylum **Foraminifera** d'ORBIGNY, 1826
Class **Globothalamea** Pawlowski, Holzmann and Tyszka, 2013
Subclass **Rotaliana** Mikhalevich, 1980
Order **Rotaliida** Delage and Herouad, 2013
Superfamily **Rotalioidea** Ehrenberg, 1839
Family **Ammoniidae** Saidova, 1981
Genus ***Pseudoeponides*** Uchio, 1950
Species ***Pseudoeponides anderseni*** Warren, 1957 (Pl.1, 1-5)

Diagnostic characters

Shell small, trochospiral, involute umbilically with a very slightly lobate equatorial periphery; spiral side almost flat; umbilical side convex with the umbilicus concealed below a lobe of the last chamber. Axial periphery rounded, equatorial periphery slightly lobate. Wall calcareous, fragile, semi-transparent, finely perforate. Chambers slightly inflated spirally, more strongly so umbilically; 6 to 7 in the last whorl increasing in size gradually and regularly. Sutures on both spiral and umbilical sides curved, depressed. Primary aperture with irregularly shaped single or multiple opening at the base of the final chamber; in earlier chambers, a circular areal aperture is commonly developed in the middle of the terminal face. Supplementary sutural apertures present on both spiral and umbilical sides; they are partly or wholly concealed in infolds of the test wall between the chambers. Early whorls visible on the spiral side show shortened portions of the supplementary apertures remaining open.

Distribution

The species *Pseudoeponides anderseni* was recorded in deposits from numerous localities around the globe and from geological ages Quaternary (Holocene) to Recent (Modern), as shown in Table (3) would be evident that.

Ecology

Pseudoeponides anderseni occurs predominantly in marine and brackish zones. It has been reported as a foraminifera species from marine and brackish venues alone, while freshwater and terrestrial environments have yet to be documented for this species. It has been described from estuarine and euryhaline environments in ecological studies, showing tolerance of brackish water conditions that are characteristic of coastal and nearshore marine habitats (Warren, 1957; Cann *et al*., 2002). *P. anderseni* is documented in fluctuating salinity environments typical of shallow marine, estuarine, and marginal marine habitats such as salt marshes, lagoons, and mangrove settings. It co-occurs with foraminifera like *Ammonia beccarii*, indicating tolerance of a broad salinity spectrum from normal marine to hypersaline conditions (Cooper and McMillant, 1987; Resig *et al*., 1995; Cann *et al*., 2002; Culver and Horton, 2005; Murray, 2013; Verlaak and Collins, 2021). Under the present study, it was observed that *P. anderseni* is emphasized as the dominant species among a few benthic forams recorded within the study area (only two species were found). Most of these species were found to have shells that are very badly preserved, characterized by substantial deformations in their morphology, as well as shell fragments. *P. anderseni* was generally represented by species close to the 'typical' shapes and similar sizes (although some individuals displayed morphological variations: deformation of chambers, presence of additional globular chambers which form on the spiral side) (Pl.1 (7-8), Tab. 4). The decline in both species diversity and abundance, along with the prevalence of opportunistic species such as *P. anderseni*, serves as a significant paleoecological marker of environmental stress within a community. Opportunistic species like *P. anderseni* flourish in disturbed or stressed environments that are marked by variable or extreme conditions, including changes in salinity. This trend illustrates the shifts between different environmental states, where more sensitive species diminish, and resilient opportunists rise to prominence (Camacho *et al*., 2015).

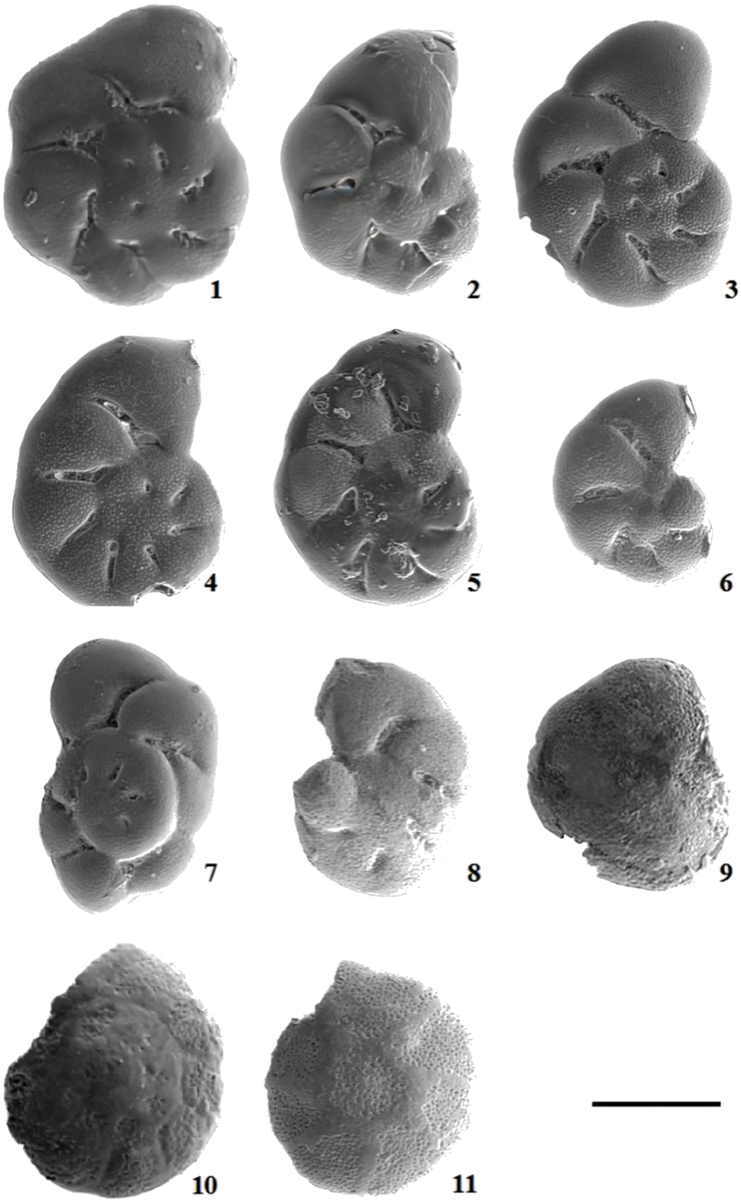


Plate (1): Scanning electron micrographs (SEM) of the identified species of benthic foraminifera. 1-5. *Pseudoeponides anderseni*, spiral view. 6. *Pseudoeponides anderseni* (juvenile specimens), spiral view. 7. *Pseudoeponides anderseni* (chamber deformation), spiral view. 8. *Pseudoeponides anderseni* (additional globular chambers on the spiral side). 9. *Buccella frigida*, spiral view. 10-11. *Ammonia beccarii*, spiral view. [Scale bar is 100 µm]

Table (2): The relative abundance of benthic foraminiferal species in the sites of the study area.

Site no.	Sample depth (m)	*Pseudoeponides anderseni* %	*Buccella frigida* %	*Ammonia beccarii* %
1	0.50	50	20	30
	1.35	72	18	10
2	0.90	76	15	9
	1.50	84	12	4
3	0.60	78	16	6
	1.10	86	9	5
4	0.55	80	15	5
	1.05	87	13	0
5	0.61	79	11	10
	1.15	89	9	2
6	0.65	80	8	12
	1.09	90	10	0
7	0.60	81	9	10
	1.70	95	4	1
8	0.75	88	10	2
	1.07	93	6	1
	1.50	99	1	0

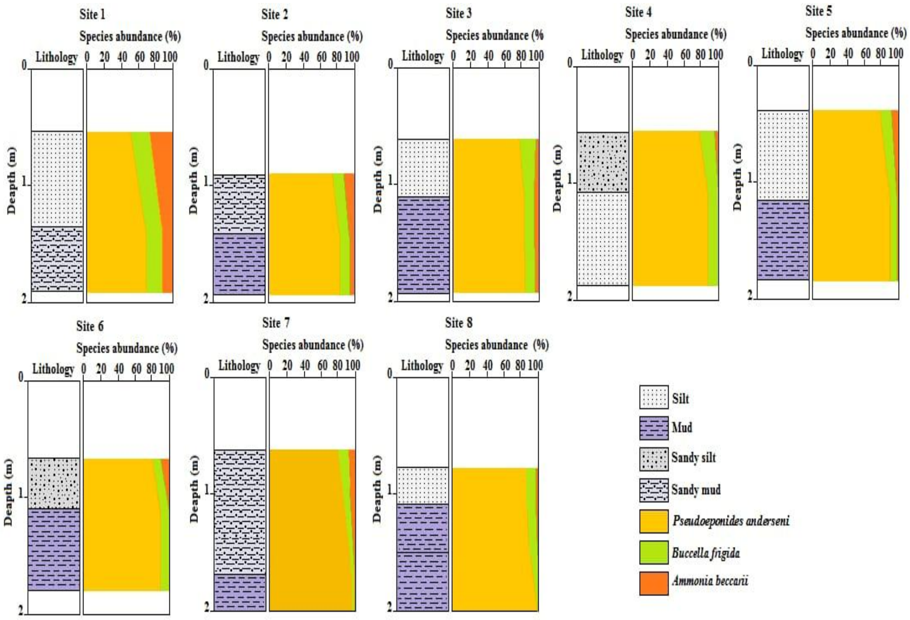


Diagram (2): Lithology and relative abundance of benthic foraminiferal species in the study area sites.

Table (3): The distribution of the foraminifera species *Pseudoeponides anderseni*.

Region/Area	Geological Epoch	Distribution Notes	Reference
Southeast, Louisiana (Buras-cofield)	Recent (Modern)	Originally described here; marine, brackish, environments	Warren (1957)
Southwest Florida, Everglades	Modern	Present in organic-rich sediments of marsh and mangrove intertidal environments	Verlaak and Collins (2021)
Western Oceanic Sediments (DSDP cores) western shelf of the Black Sea	Quaternary (Holocene)	Found in DSDP cores; presence in post-glacial periods	Gheorghian (1978)
Guadiana Estuary, Iberia	Modern	Occurs along estuarine and intertidal zones with elevation and salinity gradients	Camacho *et al.* (2015)
Bermuda mangroves, New Zealand mangroves, Massachusetts marshes, Nova Scotia marshes	Modern	Common in subtropical to tropical carbonate environments, mangrove swamps, lagoons, and marine ponds	Javaux and Scott (2003)

Table (4): Percentage of *Pseudoeponides anderseni* tests deformation in the sites of study area.

Site no.	Sample depth (m)	*Pseudoeponides anderseni* tests deformation %	Type of deformation
1	0.50	20	Chamber deformation, Additional globular chamber
	1.35	1	Additional globular chamber
2	0.90	2	Additional globular chamber
	1.50	0	-
3	0.60	1.5	Chamber deformation
	1.10	0.5	Chamber deformation
4	0.55	0.3	Additional globular chamber
	1.05	0	-
5	0.61	3	Chamber deformation
	1.15	0.2	Additional globular chamber
6	0.65	17	Additional globular chamber
	1.09	1	Additional globular chamber
7	0.60	7	Additional globular chamber
	1.70	0	-
8	0.75	0	-
	1.07	0	-
	1.50	0	-

DISCUSSION

Pseudoeponides anderseni Warren, 1957 has been documented in numerous taxonomic and micropaleontological studies, reflecting its recognized marine and brackish distribution, morphological variability, and key role in paleoenvironmental reconstructions. Its initial description traces to Warren (1957) and subsequent taxonomic refinements have solidified its place in foraminiferal literature, with world databases and recent reference works providing details on its species status, ecological range.

P. anderseni, along with a variety of other foraminiferal species, acts as a significant micropaleontological indicator within biozones that have been established for sediments across a range of facies conditions. This species is often found in marine to brackish and its presence in assemblages indicates environmental changes through time. The changes in the assemblages containing *P. anderseni* indicate changes in salinity or paleo-water depth factors that could affect the species composition and morphological characteristics of foraminifera occurring in the sediment. These assemblage changes make *P. anderseni* an important tool in palaeoenvironmental interpretation, although this may be difficult task to correlate biozones laterally within different facies because of the environmental heterogeneity (Cann *et al*., 2002; Gennari *et al*., 2011; Camacho *et al*., 2015).

P. anderseni investigations in different areas (southern Arabia, Bermuda, Australia) have contributed to revealing Holocene sea-level changes, pluvial phases, and ecosystem dynamics. Unnecessary commas, has been applied to record humid phases and ecological changes in intertidal contexts, thus corroborating hypotheses on human dispersal windows and ecosystem responses to climate change and sea-level rise (Gennari *et al*., 2011; Rossi *et al*., 2021).

The salinity and water-depth dependence of the species *P. anderseni* makes it a useful proxy for the reconstruction of Holocene sea-level and the dynamics of coastal ecosystems, as changes in the population *P. anderseni* are associated with major shifts in Holocene coastal ecosystem processes linked to sea-level rise and fall, changes in river regimes, estuary embayment development, and establishment of marsh systems. These transitions are frequently characterized by the crossing of environmental 'tipping points' owing to changed water level and salinity distributions (Rossi *et al*., 2021). In particular, in Holocene coastal and tidal flat sequences from a number of studies show evidence for increased abundance of *P. anderseni* associated with marine transgressions when the sea advances and tidal flat environments are established. This trend is similar to that seen in various geographic localities such as New Zealand and Australia, where *P. anderseni* has been associated with increasing sea level and the expansion of saline or brackish intertidal environments during the Holocene (Hayward *et al*., 1999; Cann *et al*., 2002; Wang *et al*., 2013).

Hence, the occurrence of *P. anderseni* within an area becomes a significant means of proving that at some stage the area became covered by seawater and was conducive to settlement of this species in its sediments. From this, it can be deduced that the studied area where the species *P. anderseni* appeared with clearly dominant abundance was subject to marine inundation, during the Holocene, and especially in its Late (Aqrawi, 2001). Supporting evidence also comes from Issa (2010), who mentioned that the southern Iraq region in which the study area is located has also experienced sea-level changes during the late Holocene (3000 y BP). The range limit can be found associated with this can be found at a depth of approximately not more than two meters below ground level (Issa, 2016).

It is important to highlight that the emergence of a morphological alteration in a minor fraction of the species *P. anderseni*, as illustrated in Plate (1.7-8) and Table (4), coincided with the occurrence of the secondary species *Ammonia beccarii*, depicted in Plate (1.10-11) and Table (4), which was found in larger quantities compared to the other species *Buccella frigida*, at shallow depths in the first and sixth locations.

Morphological variants in benthic foraminifera, including *P. anderseni*, often reflect adaptations to different environmental niches along salinity gradients, but the exact forms or morphotypes that correlate precisely with salinity levels for this species are not clearly distinguished in available research (Resig, 1995; Camacho *et al.*, 2015). The secondary presence of *Ammonia beccarii* alongside *P. anderseni* indeed suggests the influence of a freshwater source diluting the salinity of seawater in the area. *Ammonia beccarii* is known to tolerate a range of salinities and is often associated with brackish environments where freshwater input moderates marine salinity levels. Typically, the combination of these two species suggests a salinity gradient from marine to more brackish or fresh and freshwater influence. This interpretation aligns with prior studies on the tolerance of *Ammonia beccarii* for lower salinity environments and its use as an indicator for freshwater influence in coastal and estuarine sedimentary environments (Martínez-Colón *et al.*, 2018; Kenigsberg *et al.*, 2020). Therefore, this fact indicates that the morphological variations the shell of *P. anderseni* could be associated with salinity fluctuations.

What distinguishes the co-occurrence of *Ammonia beccarii*, *Buccella frigida* and *P. anderseni serves* as a biological signature of a marine marsh environment on a coast where salinity and tidal flooding create a dynamic habitat favoring such foraminiferal assemblages (Hayward *et al.*, 1999). This ecological association is well established as indicative of such coastal marsh environments.

Considering the aforementioned facts, it can be concluded that Al Hammar Marsh during the Late Holocene epoch (3000 y BP) functioned as a coastal marine marsh, as the presence of *P. anderseni* has been recorded within its sediments. Its occurrence is considered significant evidence for periods when the marsh was covered by seawater, confirming the influence of marine incursions during the Late Holocene. This paleoecological marker supports reconstructions of past shorelines, reflecting the marsh's coastal marine character during that time.

CONCLUSIONS

This study presents the first record of *Pseudoeponides anderseni* in Iraq, identified in the Late Holocene (~3000 yr BP) sediments of the southern Al Hammar Marsh. This finding provides clear evidence that southern Iraq experienced marine inundation during the Late Holocene. The study further concludes that, during this period, Al Hammar Marsh functioned as a coastal marine marsh, as indicated by the foraminiferal assemblage dominated by *Pseudoeponides anderseni*, accompanied by minor species such as *Buccella frigida* and *Ammonia beccarii*. The sediments deposited at that time were primarily mud, with subordinate silt, sandy mud, and sandy silt.

CONFLICT OF INTEREST STATEMENT

"The author has no conflicts of interest to declare".

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أول تسجيل لنوع المنخربات *Pseudoeponides anderseni* (Warren, 1957) (Rotaliida, Epistomariidae) في هور الحمار (جنوب العراق) وأهميته كمؤشر على بيئة مستنقع بحري ساحلي خلال أواخر العصر الهولوسيني

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الخلاصة

هدفت هذه الدراسة إلى تسجيل نوع جديد *Pseudoeponides anderseni* (Warren, 1957) (Rotaliida, Epistomariidae) من المنخربات في جنوب العراق حيث رواسب الهولوسين المتأخر، اذ تم توثيق هذا النوع لأول مرة في هذه المنطقة. جمعت سبعة عشر نموذج من ثمانية مواقع عند جنوب هور الحمار. تم دراسة كل نموذج من حيث انواع الرواسب ومحتواها من المنخربات، بما في ذلك تحديد الأنواع ووفرتها النسبية. كشف تحليل الحجم الحبيبي للرواسب عن أربعة أنواع رئيسية من الرواسب في منطقة الدراسة هي: الغرين، والغرين الرملي، والوحل، والوحل الرملي، وكان راسب الوحل هو الأكثر انتشارًا من بين انواع الرواسب. وفيما يخص انواع المنخربات كان النوع *Pseudoeponides anderseni* Warren, 1957 الاكثر تميزا وسيادة وهو نوع قاعي يسكن عادةً البيئات البحرية. يعتبر هذا النوع مؤشرًا حيويًا بيئيًا مهمًا، حيث يقدم دليلاً على التأثير البحري في جنوب العراق خلال الهولوسين. وبناءً على الحقائق التي توفرها وجود الأنواع الثانوية *Buccella frigida* Cushman, 1922 و *Ammonia beccarii* Linnaeus, 1758 مع النوع السائد *Pseudoeponides anderseni* Warren, 1957، فقد تم طرح فرضية مفادها أن مستنقع الحمار كان مستنقعًا بحريًا ساحليًا خلال عصر الهولوسين المتأخر.