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THE USES OF FORAMINIFERA AS BIOINDICATOR FOR POLLUTION

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Abstract

Benthic foraminifera, unicellular marine protists, exhibit a globally extensive distribution, high population densities, and significant species richness. Their robust tests (shells) are readily preserved within sedimentary archives, providing a detailed historical record. Furthermore, their demonstrated sensitivity to environmental perturbations renders them valuable bioindicators in paleoenvironmental and modern ecological change studies.

Benthic foraminiferal assemblages are increasingly employed as bioindicators of environmental disturbance, as their sensitivity to pollutants manifests in compositional shifts, providing valuable insights into ecosystem health. This study focused on assessing the impact of both organic and inorganic pollutants, noting that Ammonia tepida is recognized as a pollution–tolerant species.

Ammonia tepida is consistently documented across numerous polluted sites, indicating its potential as a robust bioindicator species. The species' preference for fine–grained, organic carbon–rich sediments may explain its observed dominance in these impacted environments. Morphological abnormalities, including twinned or reduced chambers, coiled or uncoiled shells, surface protrusions, irregular suture lines, and test dissolution, are frequently observed in

foraminiferal tests from polluted regions. Over the past decade, there has been a significant increase in laboratory culture studies aimed at elucidating foraminiferal responses to specific pollutants. These controlled experiments have facilitated improved differentiation between natural and anthropogenic environmental alterations. Furthermore, the Uvigerina jacksonensis, Bulimina jacksonensis, and Nonion scaphum are relevant to environmental studies.

Key Words: Benthic foraminifera, identification, Description and pollution.

1. Introduction:

The Fayum Depression, a prominent circular geological feature, is located in the Western Desert, adjacent to the Nile Valley. Its geographical coordinates are approximately defined by latitudes 28° 50' N to 29° 50' N and longitudes 30° 00' E to 31° 15' E.

The Eocene stratigraphic succession of the region, initially described by Beadnell (1905), was subsequently revised, with Said (1962) introducing the Gehannam Formation. This formation has been widely adopted in subsequent studies (e.g., El–Badry & Eid 1987; Saber 1998; Helal 2002; Abdallah et al. 2003; Abu El Ghar 2012 and references therein). However, Strougo (1992) and Strougo & Faris (2008) proposed a refined subdivision of the Middle–Upper Eocene sequence at Gebel Na'alun, delineating four distinct lithostratigraphic units, in ascending order: the Beni Suef, Gehannam, Shaibun, and Birket Qarun Formations (Dina M. Sayed et al. (2023); Hewaidy et al., (2024)).: Foraminifera represents the dominant marine protozoan group within benthic, epipelagic, and upper mesopelagic environments. Their adaptability to diverse habitats, particularly in shallow benthic zones, results in high biodiversity and abundance, reflecting their varied ecological niches.1 Furthermore, their short life cycles, coupled with the capacity for genetic recombination through sexual reproduction, facilitate rapid responses to environmental fluctuations.2 Consequently, foraminifera serve as effective bioindicators for monitoring both short– and long–term changes in marine ecosystems, spanning global to highly localized scales.3 Furthermore, foraminiferal responses to environmental variations are manifested in test morphology and composition. Agglutinated tests, characterized by organic cement, are indicative of acidic aquatic environments, including estuaries, hyposaline lagoons, polar marine settings, and regions below the carbonate compensation depth (CCD). Porcelaneous tests, conversely, typically predominate in well–illuminated, hypersaline, shallow, alkaline, and warm water environments. Hyaline and transparent tests exhibit a broader environmental tolerance, spanning a range of habitats from estuarine systems to depths below the CCD. Benthic foraminifera are extensively utilized as bioindicators in environmental monitoring due to their species richness, capacity for preserving

paleoenvironmental data, and sensitivity to marine, abiotic, and geographical variables (Frontalini and Coccioni, 2011; Lei et al., 2015). Their limited mobility, abbreviated life cycles, and rapid responses to environmental perturbations underscore their suitability as environmental indicators within marine ecosystems (Nigam et al., 2006; Donnici et al., 2012; Bergamin et al., 2019). Foraminifera are recognized as potential proxies for ecological assessment and environmental surveillance, representing benthic community dynamics within the trophic levels of marine food webs (Mojtahid et al., 2006; Denoyelle et al., 2010; Bouchet et al., 2012). Numerous investigations have examined benthic foraminiferal responses to organic and inorganic pollutants, establishing their role as sensitive indicators of environmental change (Sabean et al., 2009; Lei et al., 2015). However, environmental monitoring studies employing benthic foraminifera as bioindicators for metal and hydrocarbon pollution remain relatively scarce in India and Southeast Asia (Jayaraju et al., 2011; Reddy et al., 2016; Sreenivasulu et al., 2019).. Heavy metal contamination, particularly mercury (Hg), represents a significant environmental concern. While certain heavy metals are essential for cellular metabolism and growth, elevated concentrations pose a substantial threat to marine biota. Heavy metals, due to their recalcitrance, persist within marine environments. Mercury, a globally distributed element found in the atmosphere, geosphere, and biosphere, exhibits diverse chemical and physical forms, influencing its bioavailability and toxicity. Benthic foraminifera, as unicellular protists, demonstrate a high sensitivity to ecological and environmental perturbations, thereby serving as valuable bioindicators across a spectrum of marine habitats.

In the United States, public health concerns regarding mercury contamination primarily focus on the consumption of methylmercury–contaminated fish. Neurotoxicity constitutes the most significant health risk associated with mercury exposure. Methylmercury readily enters the bloodstream, distributing throughout various tissues and traversing the blood–brain barrier to access the central nervous system. Its ability to cross the placenta poses a particular risk to developing fetuses, making pregnant women and women of childbearing age a vulnerable population. Low–level methylmercury exposure has been associated with learning disabilities in children and reproductive impairments in piscivorous fauna. Furthermore, mercury exposure in humans can induce a spectrum of adverse health effects, encompassing neurological, renal, gastrointestinal, genetic, cardiovascular, and developmental disorders, culminating in potential mortality.

Mining operations, particularly those involving manganese and iron extraction, constitute a significant economic sector in

the region. However, these activities generate substantial quantities of mining waste, which are subsequently transported to estuarine environments via the Mandovi River. It is critical to recognize that the capacity of any ecosystem to assimilate pollutants is finite, and consequently, mining activities exert deleterious effects on marine biota. Foraminifera, microscopic marine protists within the meiofauna, exhibit exceptional sensitivity to subtle alterations in marine environmental conditions. Their robust preservation and fossilization potential render them valuable bioindicators in pollution studies globally.

In humans, lead exposure elicits a spectrum of biological responses contingent upon both the concentration and duration of exposure. Differential effects manifest across a broad dose range, with fetuses and infants exhibiting heightened sensitivity compared to adults. Elevated lead levels can induce toxic biochemical alterations, leading to disruptions in hemoglobin synthesis, renal dysfunction, gastrointestinal disturbances, articular complications, reproductive system impairments, and acute or chronic neurological damage..

Copper contamination poses a significant environmental challenge, stemming from the release of copper ions into natural aquatic systems. Anthropogenic activities, particularly mining and waste incineration, contribute substantially to copper release into soils. Aqueous copper contamination arises from soil erosion, industrial effluents, sewage treatment discharges, and antifouling paints. Shallow, near–shore environments, notably estuaries, receive frequent and substantial inputs of industrial and sewage waste, acting as sinks for diverse anthropogenic pollutants. Heavy metals, including copper, exert a potent adverse impact on foraminiferal assemblages. Copper, characterized by its high heavy metal toxicity, is frequently detected at elevated concentrations in estuarine environments. Over the past three to four decades, benthic foraminifera have been investigated as potential bioindicators of pollution, aiming to elucidate their responses to contaminated environments and establish correlations between emerging pollution and these responses. Yanko et al. (1998) hypothesized that heavy metals can enter foraminiferal cells through ingested food sources, such as algae and bacteria, subsequently disrupting the foraminiferal cytoskeleton, which governs organismal morphology. However, the precise effects of varying heavy metal concentrations on benthic foraminifera remain incompletely understood .

Specimens were collected from the Naalun stratigraphic section, located in the eastern region of the Fayum Depression (Figure 1), at coordinates 29° 27′ 43″ N latitude and 31° 18′ 23″ E longitude. This study provides a detailed description of large benthic foraminiferal species recovered from this section, dating to the late Middle to Late Eocene epoch.

This study aims to investigate the impact of pollution on benthic foraminiferal assemblages, specifically focusing on alterations in morphology, diversity, and test ornamentation. Subsequently, the study seeks to utilize these pollution-induced foraminiferal changes as bioindicators for environmental contamination.Pollution-tolerant foraminiferal species include Ammonia tepida, Uvigerina jacksonensis, and Quinqueloculina lamarckiana

2. The Theoretical Framework:

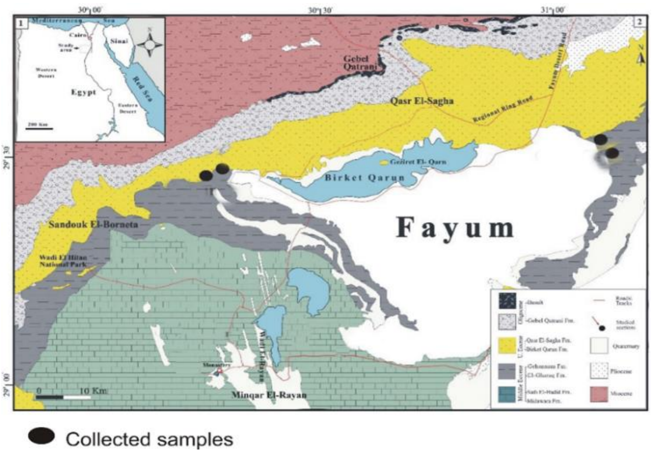

Figure 1. A Geological map of the Fayum Depression depicting the sampling localities for the conducted study.

3: Methods of Research and the tools used:

Fifteen rock samples, representative of the stratigraphic section under investigation within the Fayum Depression, Egypt, were collected. Microfossils were extracted through a standardized washing procedure. Approximately 100 g of each sample was subjected to soaking in water with the addition of dilute hydrogen peroxide (H_2O_2). Subsequently, the samples were washed through a 63-µm sieve, and the resulting residues were dried. A consistent, representative aliquot of approximately 15 specimens from the dried, cleaned residue was qualitatively examined using a binocular stereomicroscope (Figure 2). Benthic foraminiferal specimens were selected, identified, counted, and mounted onto micropaleontological slides. Total benthic foraminiferal counts were compiled to determine species diversity, a metric employed to assess the impact of pollution on ornamentation and diversity.

Identified benthic foraminifera were then imaged using a Scanning Electron Microscope.

4. Results and discussion

SYSTEMATIC PALEONTOLOGY

This study followed Loeblich and Tappan (1988), taking into account the new approach in systematic nomenclature for small foraminifera.

Superfamily: Globorotaliacea Cushman, 1927

Family: Globorotaliidae Cushman, 1927

Subfamily: Globorotaliinae Cushman, 1927

Genus: *Uvigerina* Cushman, 1925

Uvigerina jacksonensis Cushman, 1925

(fig.2., 18.19)

1984. *Uvigerina jacksonensis* -Anne Boersma, p.88, figs. 1,2,3,4.
1986. *Uvigerina jacksonensis jacksonensis* - Samir, p. 98, pl. 13, figs. 1-5.
1994. *Uvigerina jacksonensis jacksonensis* - Anan, p. 224, fig. 9,2.
2000. *Uvigerina jacksonensis* – Abul-Nasr, p. 53 , fig. 12, 6.
2002. *Uvigerina jacksonensis jacksonensis* - Helal, p. 119, pl. 3, fig. 5.

Description: *Uvigerina jacksonensis is characterized by a relatively large, fusiform test, exhibiting a 7–9 continuous costume. The chambers are arranged triserially, with a progressive increase in height during ontogeny. The final chamber is rounded, smaller than the preceding whorl, and displays compact coiling. The aperture is located on a terminal neck.*

Discussion: *Uvigerina jacksonensis was identified from the Middle Eocene (Bartonian) Gehannam Formation. This species has also been documented in the Cocoa Sand of Alabama, USA (Cushman 1925a). In Egypt, its occurrence has been reported from the Fayum Depression (Samir 1986, Selima 1989, Anan 1994, Helal 2002), the vicinity of Gebel Libni, northern Sinai (Farouq 2007), and within the ElGharaq and Gehannam formations (Al Menoufy 2015).*

Remarks: By observations of preceding species, such as *B. jacksonensis, Uvigerina jacksonensis* is recognized as a characteristic Eocene species with a global distribution.

Family: BULIMINIDAE Jones, 1875

Genus: *Bulimina* d' Orbigny, 1826

Bulimina jacksonensis Cushman, 1926

(fig.2., 2-4)

1955. *Bulimina jacksonensis* - Ansary, p. 87, pl. 3, fig. 4.
1986. *Bulimina jacksonensis* - Samir, p. 96, pl. 13, figs. 4-7.
1990. *Bulimina jacksonensis* – Abdel-Ghany, p. 69, pl. 2, fig. 13.
1994. *Bulimina jacksonensis*- Bolli, Beckmann and Saunders, p. 348, fig. 53.31-33.
2000. *Bulimina jacksonensis* – Abul-Nasr, p. 62 , fig. 13, 13.
2002. *Bulimina jacksonensis* - Helal, p. 118, pl. 3, fig. 3,4.

Description: *Bulimina jacksonensis is characterized by the presence of six to nine distinct longitudinal costae that extend the length of the test, remaining continuous across the sutures, except the final chambers where they become less pronounced. The aperture is comma-shaped and subterminal, forming a loop that extends upward from the base of the final chambers. The test exhibits a tapering, triserial morphology, with 6-7 chambers in the final whorl.*

Discussion: *Bulimina jacksonensis has been documented within the Middle Eocene (Bartonian) Gehannam Formation. This cosmopolitan species is prevalent in Eocene strata both within Egypt and globally and exhibits anomalous abundance under conditions of low oxygen availability (Cushman 1925a, Ansary 1955, Tadros 1968, Zahran 1982, Samir 1986, Abdel Ghany 1990, Hussein 1992, Bolli et al. 1994, and Helal 2002), as well as in the ElGharaq and Gehannam formations (Al Menoufy 2015).*

Remarks: This species is distinguished from *Bulimina sculptilis* (Cushman 1923) by its larger, tapering test and a greater number of costae. Table 1 presents the characteristic features of the studied species before pollution exposure.

Family: Ammonidea Jones, 1875

Genus: *Ammonia* Cushman, 1926

Ammonia tepida Cushman, 1926

Description: *Ammonia tepida (Figure 4) exhibits rounded chambers, a* *somewhat lobate periphery, and a smooth surface, typically with 7 or 8 chambers in the final whorl. The sutures are slightly depressed or limbate, and interlocular spaces are absent on the spiral side.*

Discussion: *Ammonia tepida is a benthic foraminifer inhabiting the sediment of brackish water environments. While morphologically similar to Ammonia beccarii, which typically resides on the surface of red algae, they occupy distinct ecological niches. Although previously regarded as a cosmopolitan species, recent genetic and morphological investigations have demonstrated that numerous specimens formerly classified as A. tepida are, in fact, distinct species within the genus Ammonia.*

Nonion scaphum Fichtel 1985

(fig.2., 12-14)

1955. *Nonion scaphum* - Ansary, p. 71, pl. 2, fig. 24.

1975. *Nonion scaphum* - Braga, et al. p. 108, fig. 6.23.

Holotype: Nonion scaphum Fichtel

Description: *Nonion scaphum is characterized by a planispiral test, granules filling the umbilical region, coiling that ranges from involute to slightly evolute, depressed sutures, 11–12 chambers in the final whorl, and an interiomarginal, slit-shaped aperture.*

Remarks: *Nonion scaphum has been identified from the Middle Eocene (Bartonian) Gehannam Formation (Giza section). This species (Figure 3) has also been documented from the Eocene deposits of the Eastern Coast of North America (Cushman 1927) and the Possagno section (Braga et al. 1975). In Egypt, it has been reported from the Fayum Depression and the Nile Valley by Ansary (1955), Tadros (1968), Samir (1986), and Helal (2002), as well as from the ElGharaq and Gehannam formations (Al Menoufy 2015). Table 2 presents the characteristic features of the studied species following pollution*

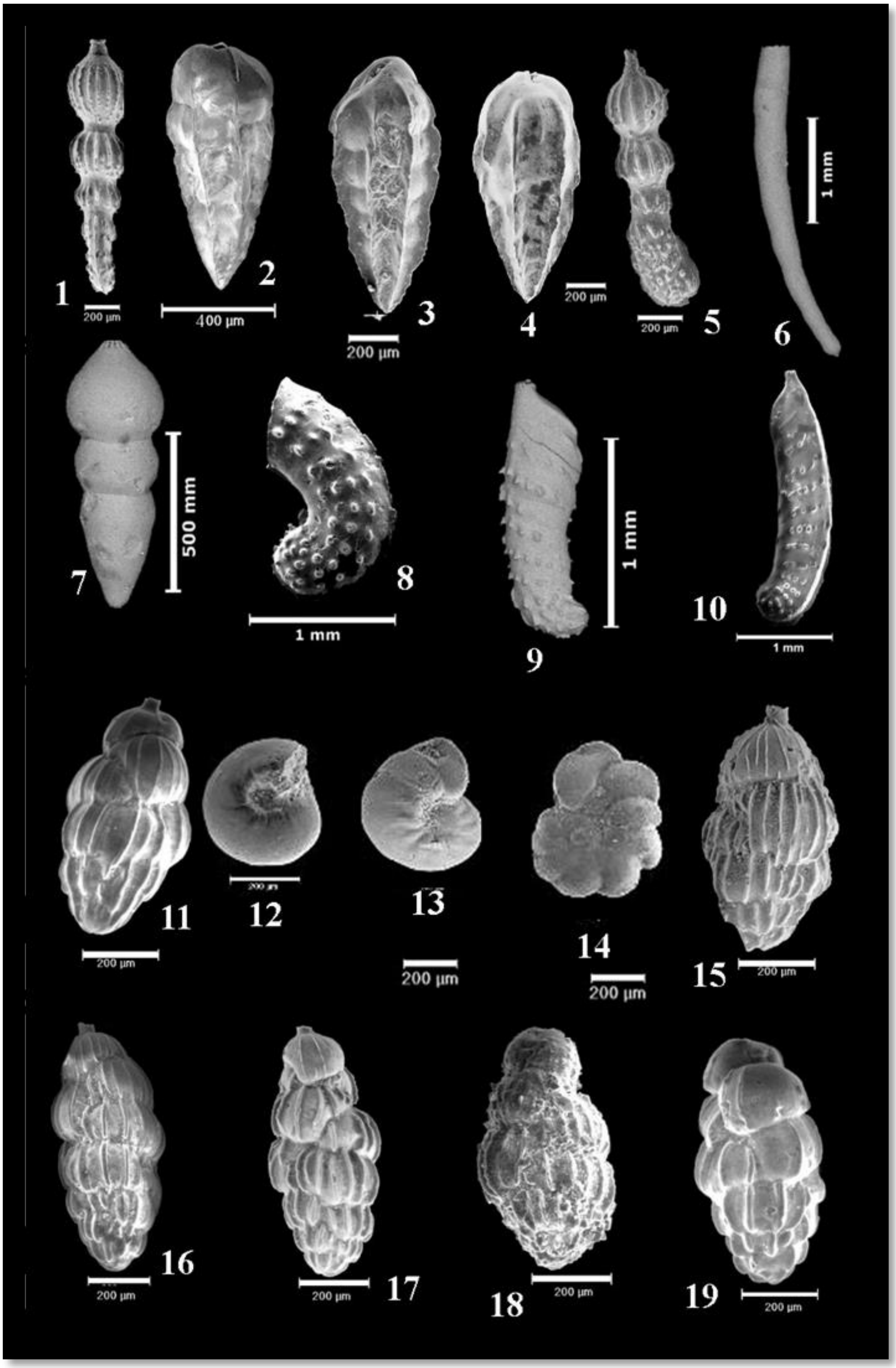
1
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Figure 2

1,5. ***Marginulina* cf. *costatus* Batsch, 1931**, middle Eocene. (Bar scale = 1µm).

2,3,4. ***Bulimina jacksonensis*** middle/Upper Eocene. (Bar scale = 1µm).

6. ***Dentalina consorbina* d'Orbigny, 1846**: middle Eocene. (Bar scale = 1mm).

7. ***Pseudoglandulina elliptica* Reuss, 1863**: middle Eocene. (Bar scale = 1mm).

8. ***Marginulinopsis tuberculata* Plummer, 1927** middle Eocene. (Bar scale = 1mm).

9,10. ***Marginulina infracompressa* Thalmann, 1937**: middle Eocene. (Bar scale = 1µm).

10. ***Marginulina* cf. *costatus* Batsch, 1931**; middle Eocene. (Bar scale = 1µm).

11. Uvigerina jacksonensis jacksonensis Cushman 1925**.** section 338, sample 13, ElGharaq Formation, Wadi Hitan, Fayum, middle Eocene. (Bar scale = 1µm).

12,13,14. ***Nonion scaphum* Fichtel** : middle Eocene.

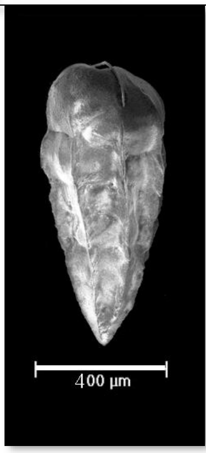
15,16. ***Uvigerina havanensis* Cushman & Bermudezm, 1937** : middle Eocene. (Bar scale = 1µm).

17. ***Uvigerina sp*1:** middle Eocene. (Bar scale = 1µm).

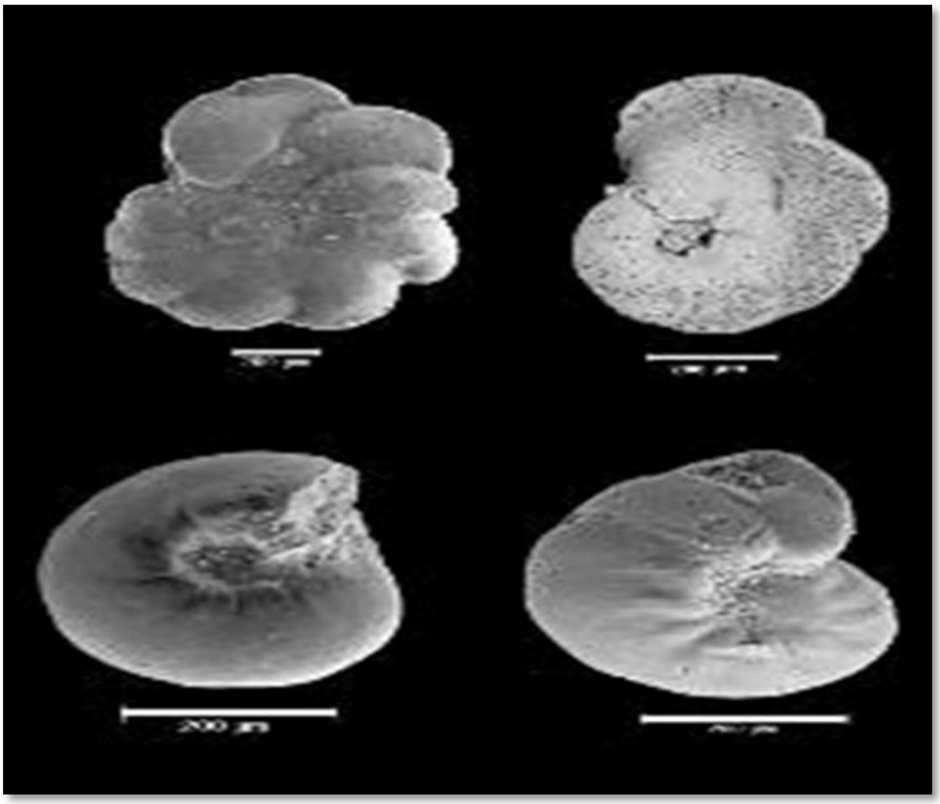
18. ***Uvigerina sp2:*** middle Eocene. (Bar scale = 1µm).

19. ***Uvigerina jacksonensis jacksonensis*** middle Eocene. (Bar scale = 1µm).

Bulimina jacksonensis

Before pollution		After pollution
		

✓ <u>**Nonion scaphum after pollution**</u>



- ✓ **Uvigerina jacksonensis**

Before pollution	After pollution
 	

- ✓ **Ammonia tepida after pollution**

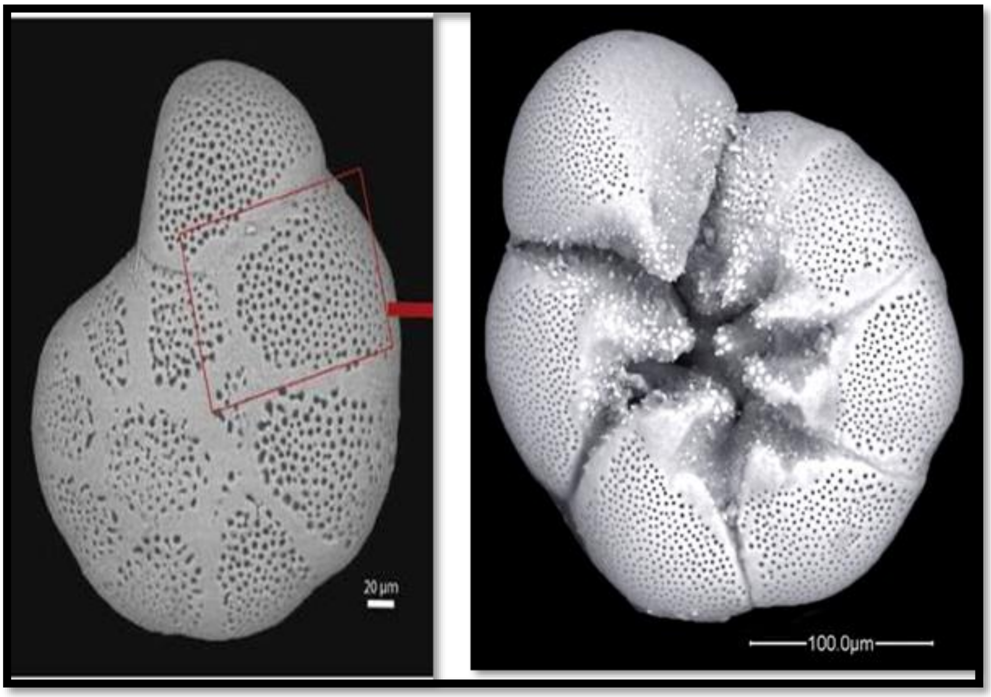


Table 1: Show the Characteristic features of studied species before pollution.

	Bulimina jacksonensis	***Uvigerina jacksonensis***	***Nonion scaphum***	***Ammonia tepida***
Test	hyaline	hyaline	Calcareous hyaline	Calcareous, biconvex
Number of whorls	3	3 to 4	3	3
Number of chambers	12	18	4-8	3-9
Suture line	flush	depressed	disappear	depressed
ornamentation	Coastal	Striation	hispid	rugosa
aperture shape	terminal	Phyaline on neck	basal	Slit- basal

❖ **Table 2:Show the Characteristic features of studied species after pollution.**

	Bulimina jacksonensis	***Uvigerina jacksonensis***	***Nonion scaphum***	***Ammonia tepida***
Test	hyaline	hyaline	hyaline	calcareous
Number of whorls	2	3	2	3
Number of chambers	4	3	1-3	3
Suture line	Fractured	deformed	depressed	raised
ornamentation	Separate striation	Striation with accumulation surrounds grains	smooth	Filled with mineral
aperture shape	depressed	fractured	basal	Increase in size

5 Interpretation of Results:

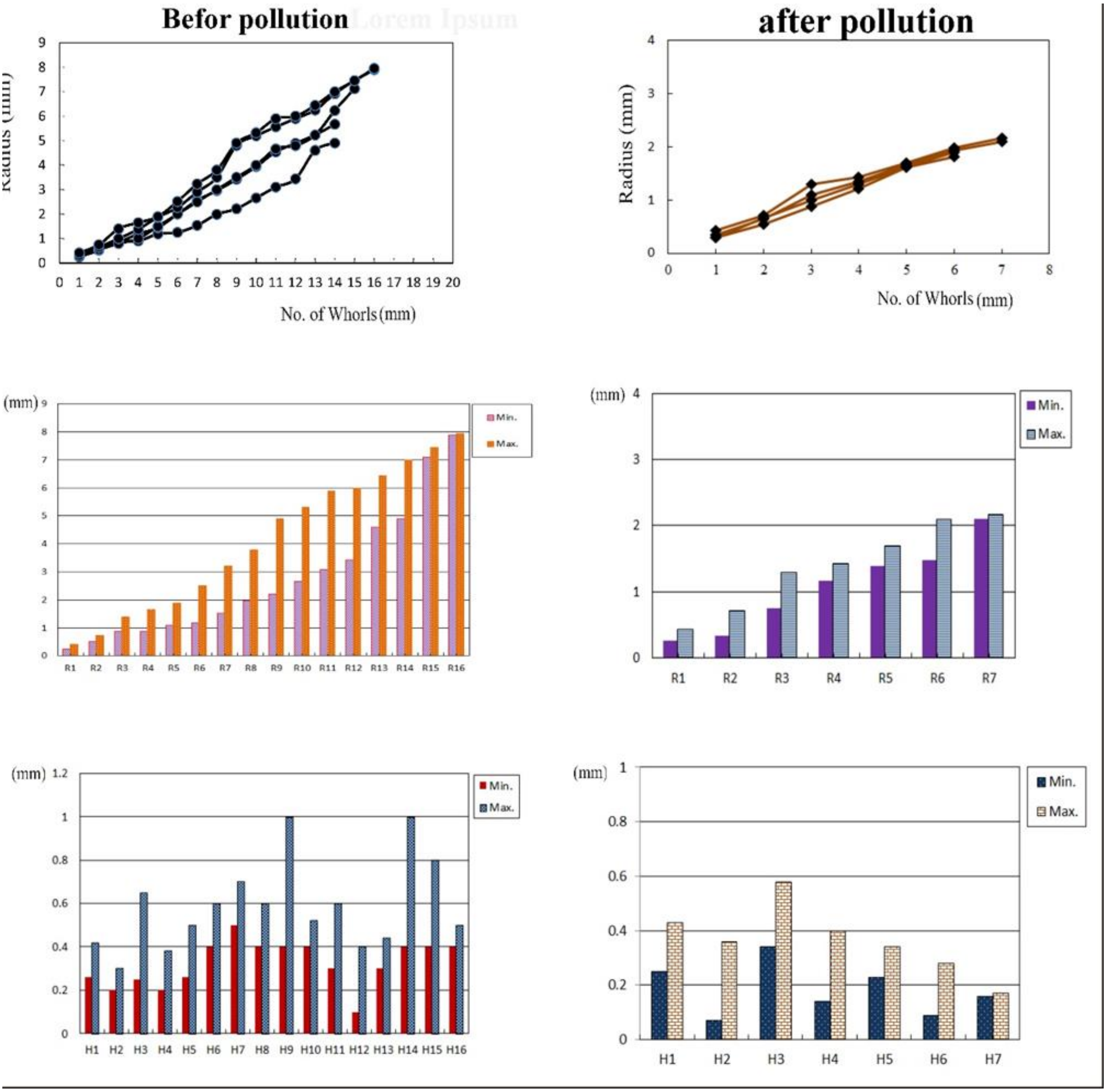


Figure 3: Relation between the Number of whorls to Nonion scaphum before and after pollution.

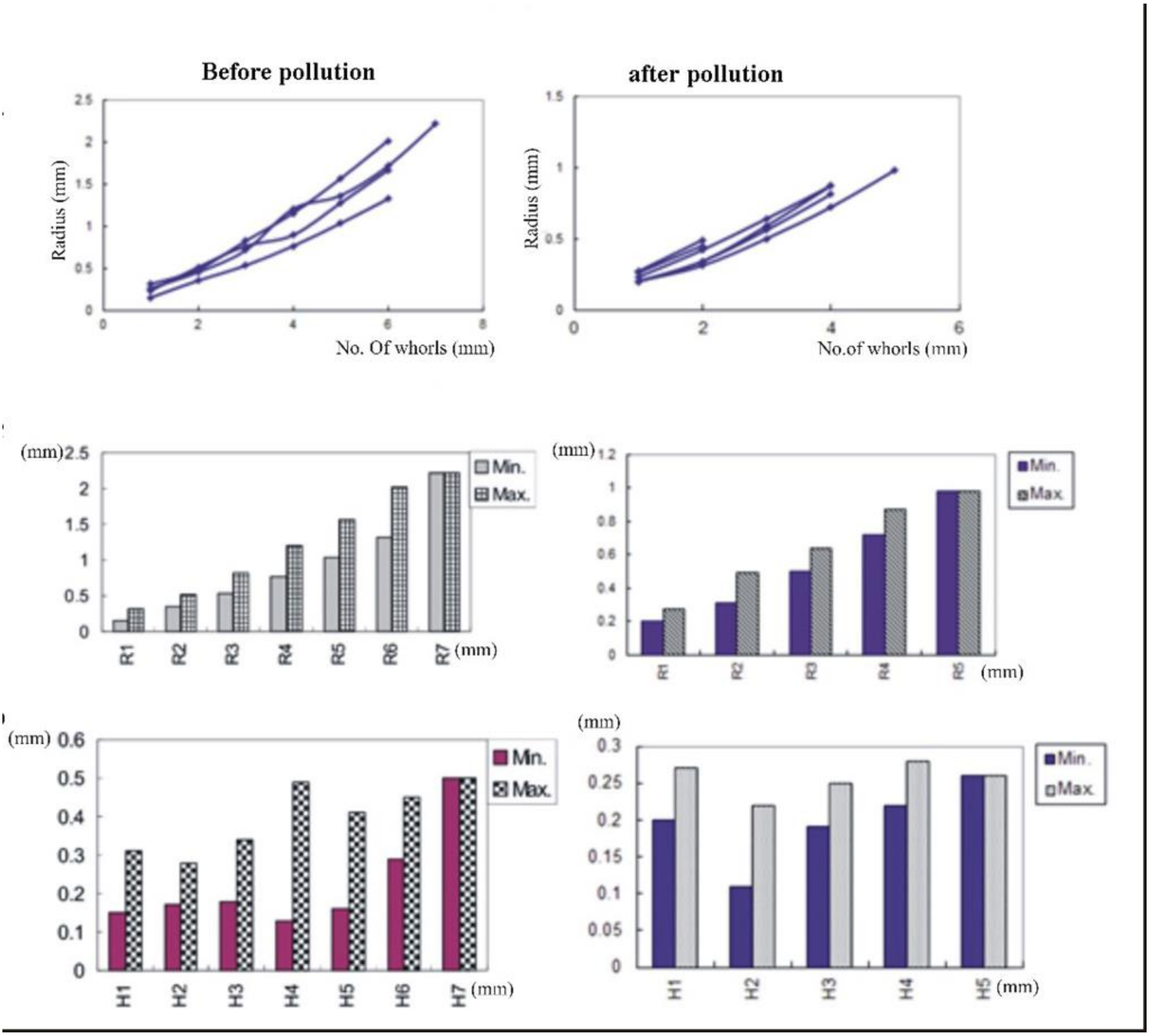


Figure 4: Relation between the Number of whorls to Ammonia tepida before and after pollution.

5. Conclusion

This study highlights the widespread application of foraminifera as an effective bioindicators, drawing upon observations from diverse pollution sites, including industrial effluent zones, human settlements, oil refinery locations, and offshore petroleum drilling sites. A significant proportion of field investigations documented the presence or absence of characteristic benthic foraminifera, alongside an increased frequency of morphological abnormalities. These field-based observations were corroborated by laboratory culture studies. The integration of molecular techniques into culture studies has facilitated a deeper understanding of the mechanisms underlying foraminiferal responses to pollutants. In conclusion, benthic foraminifera represent a reliable tool for pollution monitoring. However, further research is imperative to delineate the specific foraminiferal responses to individual pollutants.In the study area, Bulimina jacksonensis, Uvigerina jacksonensis, and Ammonia tepida exhibited heightened susceptibility to environmental stress, evidenced by an increased prevalence of test anomalies, recognized as early biomarkers of heavy metal contamination. Conversely, spatial and temporal variations in the percentages and types of foraminiferal abnormalities within the Bay reflect dynamic shifts in environmental conditions.

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