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Research Article

Thriving in extreme: A new coral assemblage of ten Scleractinia coral species tolerating high-temperature, high salinity and turbid marine ecosystem in Iraq, North West Persian/ Arabian Gulf

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Abstract
The Iraqi marine waters, as part of the far Northwest Persian/Arabian Gulf, are characterized by unique environmental conditions. This region recently witnessed the discovery of coral reefs, which were previously considered unsuitable for coral growth due to high turbidity, making them undetectable by satellites. The present study aimed to document the species of Scleractinia corals in a Palinurus Rock area (28 km^2) in an unexplored area of the northwest Gulf, is an important scientific addition to the National Biodiversity Register, providing essential data for understanding species distribution and their ability to adapt to harsh environmental conditions, and it completes the picture of coral diversity in the region. Coral species were identified by bleaching small pieces of skeleton in the laboratory. This study has identified 10 coral species belonging to 5 families: Dendrophyllidae, Merulinidae, Psammocoridae, Rhizangiidae and Caryophylliidae and 8 genera were identified for the first time. However, the recent exploration missions carried out in this study have revealed healthy coral populations. The families included stress-resistant genera such as *Dipsastraea*, *Favites*, *Duncanopsammia*, and *Paracyathus*. These colonies have demonstrated high temperatures (18.54 – 34.44°C) and very high turbidity (11.5-40.7 mg/l). Despite the destruction of coral reefs worldwide. Although the number of coral colonies in Iraqi marine waters is limited, they provide valuable insights into coral adaptation and resilience and may serve as natural refuges in the face of global climate change.

Keywords: Corals, Iraqi marine waters, Morphological identification, Scleractinia

INTRODUCTION

Coral reefs are among the most important ecosystems on the planet, particularly for biodiversity and economic value. Its global environmental and economic services are estimated at several trillion dollars, from tourism and coastal protection to fisheries resources, and it constitutes a national treasure for countries (Burt *et al*., 2014; Gower *et al*., 2025; Chen *et al*., 2025).The Persian/ Arabian Gulf later abbreviated as the Gulf, is a harsh marine environment due to its shallow average depth of 35 m, the extremely arid nature of its surrounding environment, and its semi-enclosed geography that restricts water exchange with the Indian Ocean through the Strait of Hormuz and it has very low tides (ROPME, 2015; Vaughan *et al*., 2019; Kavousi *et al*., 2021).
These characteristics have made the Gulf a high-temperature ecosystem, and many scientific reports describe it as having extreme temperatures. Corals have genetically adapted to cope with these conditions and now represent the most temperature-tolerant corals in the world (40–42°C) (Burt *et al*., 2020; Burt, 2024; Seraphim *et al*., 2025). The Gulf sea surface temperatures reach the highest levels globally (≥37°C), with annual averages ranging from 12–36°C, and salinity levels reaching 44 psu in open waters and even higher in embayments—70–80 psu in tidal basins—and may exceed 50 psu in some southern bays of the Gulf.

Additionally, high evaporation rates, frequent turbidity, and occasional oxygen deficiency are common (Bouwmeester *et al*., 2021; de Verneil *et al*., 2021; Seraphim *et al*., 2025). Although these temperatures are typically lethal to coral reefs in most parts of the world (Riegl and Purkis, 2012), marine organisms in the Gulf live close to their ecological tolerance limits (Hughes *et al*., 2017; Kavousi *et al*., 2021). This has not prevented corals from thriving and adapting to this harsh environment (Carpenter *et al*., 2018).

Coral reef communities are found in all eight countries of the ROPME Sea Area (the Arabian states and Iran) and represent the most biodiverse ecosystem in this arid region (Vaughan *et al*., 2019; Bartholomew *et al*., 2021; Gower *et al.,* 2025). According to recent records, the number of coral species in the Gulf is estimated at approximately 100—about a quarter of the total specie in the Indian Ocean (Veron, 2000). In other words, the Gulf hosts a relatively hardy subset. These coral reefs are better adapted to critical conditions than anywhere else in the Indo-Pacific region (Sheppard *et al.,* 1991; Coles, 2003; Seraphim *et al.,* 2025). Therefore, the Gulf hosts a relatively hardy subset of coral reefs, with diversity accounting for 10% of the Indian Ocean's total and the Coral species, reef fishes, and coral-associated invertebrates are largely dominated by stress-resistant species (Bouwmeester *et al*., 2021; Seraphim *et al*., 2025).

Iraqi marine waters constitute a significant gap in an important region that has not yet been studied in great detail. Its coastline is approximately 58 km long and covers an area of about 700 km². The importance of these waters lies in the fact that they represent an environment somewhat different from the rest of the Gulf due to the direct influence of the Shatt al-Arab estuary, which is laden with sediments and nutrients, resulting in high turbidity, and polluted due to its proximity to Iraqi oil ports (Pohl *et al*., 2014). In addition to the high salinity and temperatures that characterize the Gulf. Coral reefs in Iraqi marine waters were unknown before 2013 due to the region's critical conditions. The wars between 1980 and 2003 (the Iran-Iraq War, the First Gulf War, and the Second Gulf War), along with the dangerous events that accompanied them, prevented researchers from continuing their expeditions, especially into deeper Iraqi marine waters. However, in rare cases, some coral skeletons were obtained, possibly carried by currents toward limited fishing areas at the time. Some researchers observed and preserved these skeletons among the fish caught and organisms collected in bottom trawls from fishing boats (personal communication and personal observation).

Therefore, the prevailing belief was that these waters were devoid of coral reefs, but recent discoveries proved otherwise. The coral reefs of Iraqi territorial waters are among the shallowest sites and represent the last major discovery in the region. They are considered the first large, unique, and healthy living coral reefs under extreme conditions (Pohl *et al*., 2014; Burt, 2014; Gutekunst *et al*., 2018). High turbidity, nutrient and sediment load from rivers reduce light transmittance, which is why these coral reefs remained undetected by satellite observations (Rezai *et al*., 2004; Pohl *et al*., 2014).

Information on Iraqi coral reefs is very limited, except for an exploratory study by a German-Iraqi research team that documented the presence of new coral reefs in Iraqi marine waters. Joint expeditions carried out by SCUBA divers from the Scientific Diving Center (SDC) in Freiberg (Germany) and the Marine Science Centre (MSC) at the University of Basrah (Iraq), conducted in September 2012 and May 2013, revealed the presence of coral reefs. These cruises were followed by two other survey missions in 2014 and 2015. Pohl *et al*. (2014) reported that coral reefs in Iraqi marine waters cover approximately 28 km² and are located at Palinurus Rock at latitudes 29°37'00"N and 48°48'00"E. The initial survey identified a coral reef area measuring 6 km by 3 km, at depths of 7–20 m.

Although more than ten years have passed since the discovery of coral in Iraqi marine waters, only one study has been published documenting the growth of the stony coral *Paracyathus stokesii* on the breakwater rocks of the Al-Faw Grand Port, which constitutes a new colonization of a newly established artificial habitat (Ahmed *et al*., 2023). Therefore, it is necessary—as a goal of this study—to conduct further taxonomic research on these reefs to identify their species and characteristics. This serves two important purposes: first, to compare them with coral species found elsewhere in the Gulf, and second, to draw attention to the need for further environmental and ecophysiological research on these reefs (Scucchia *et al*., 2023).

Furthermore, it is well known that coral reefs in the seas and oceans are exposed to environmental pressures from warming and acidification, with an increasing frequency of bleaching events. Projections suggest that 90% of the world's coral reefs will be exposed to severe bleaching by 2050 (Hoegh-Guldberg *et al.*, 2018, Reverter *et al.*, 2020; Mellin *et al.*, 2024).

The main objective of the present study was to shed light on hermatypic scleractinian coral species that naturally occur in Iraqi marine waters, which are considered well adapted to the critical limits of environmental conditions, as indicated by many studies in other global seas.

MATERIALS AND METHODS

This study was based on preserved materials of hard coral deposited in the reference's samples Laboratory at Marine Science Centre, University of Basrah. Previously collected from Iraqi coral colonies during the period 2013-2015 (Pohl *et al.,* 2014). The second method was used in the present study, which involved collect-

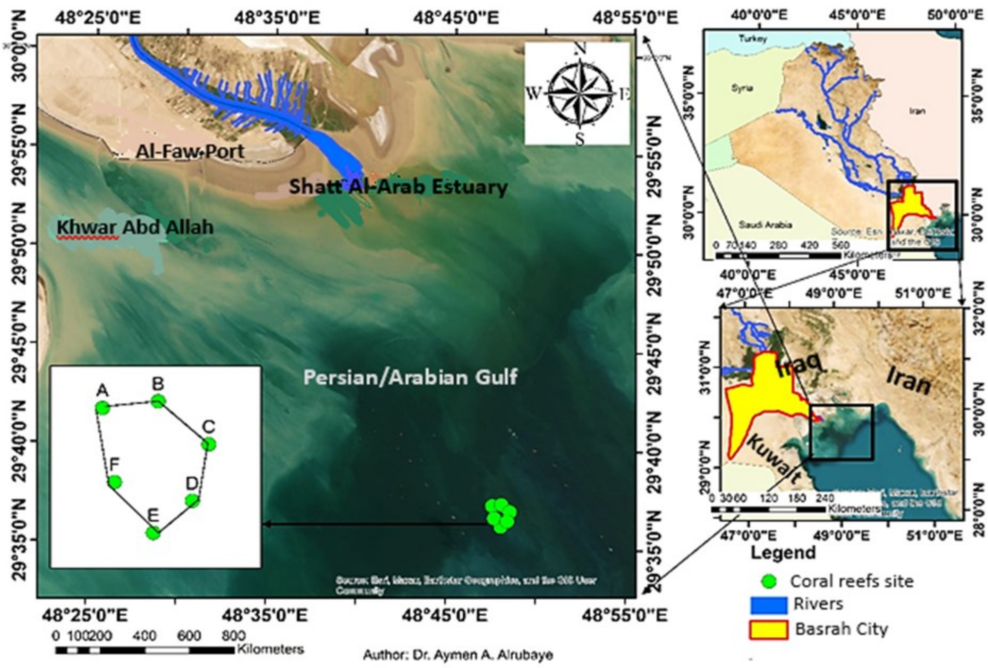

Fig 1. *Map of coral reef site in the Iraqi marine waters*

ing data through two methods. SCUBA diving by 2–3 divers equipped with diving gear provided by the Iraqi Naval Forces, which facilitated sea trips to the area aboard their boats.

Coral samples were collected at depths of 7–20 meters, with a tidal height of 3 meters, in the offshore open sea area near the Iraqi Oil Port (N: 29°37'00", E: 48° 48'00") (Fig. 1), during the period from August 2024 to April 2025, from nearby locations and photographed *in situ* using an underwater camera (Gopro Be a Hero3). Fragments of each colony, measuring 5–10 cm², were cut using a hammer and chisel. In some cases, entire colonies were collected, transferred to the boat, and preserved in plastic containers filled with 70% methanol.

In the laboratory, 2 cm² coral samples were bleached using sodium hypochlorite for 24–48 hours to ensure complete tissue dissolution. The samples were then thoroughly rinsed with fresh water and dried completely using an air pump. Each sample was examined under a dissecting microscope and photographed to reveal the entire colony and corallite structure. For skeletal examination, 8–15 corallites were randomly selected from each colony.

Coral species were identified based on skeletal morphology using available taxonomic guides (Veron and Wallace, 1984; Veron, 2000; Riegl and Purkis, 2015; Alidoost Salimi, 2018).

For genetic analysis, numerous samples were collected, their living tissues were extracted, and they were sent to the specialized laboratories for DNA extraction and species identification, in Iraq such as (Wahaj Al-dana Co.) in Baghdad, University of Basrah and University of Thi Qar.

All collected samples (68 Scleractinia coral specimens) are currently deposited in the Marine Biology Museum, Marine Science Centre, University of Basrah (MSC), Accession nos. MSC 201 to 210.

Environmental factors

Digital data on annual sea surface temperatures (SST), salinity, and turbidity for the last five years (2020-2025) for the coral were obtained from recordings at the Basrah Oil Terminal, Iraq. Data sources are the National Oceanic and Atmospheric Administration (NOAA, 2026) and the Copernicus Marine Environment Monitoring Service (CMEMS, 2026).

Animal ethic approval

All applicable international, national, and/or institutional guidelines were followed for the care and use of animals. Ethical approval for this study (Document No. 4/12 May 2024) was obtained from the MSC ethics committee of the Marine Science Centre, University of Basrah, Iraq.

RESULTS

Environmental factors

Fig. 2 shows the digital reading of sea surface temperature (SST) for the five years 2020-2025 at the coral reefs site for depth (0-5m), the range of SST for the mean monthly was from the lowest 18.2 °C in January 2021 to the highest 34.7 °C in August 2023.

Fig. 3 shows the digital reading of salinity for the five-year period 2020-2025 at the coral reef site; the range for the same period ranged from 37.7 psu in February in both 2021 and 2025 to 42.9 psu in August 2023.

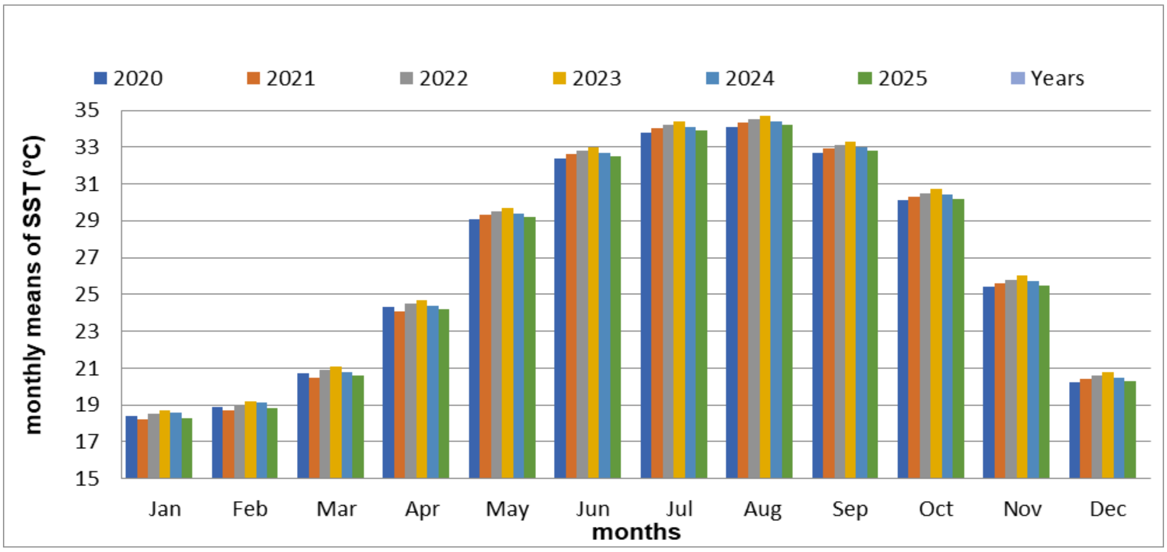

Fig. 2. *Monthly means of sea surface temperatures (°C), during the period 2020-2025 at the coral reefs site in the Iraqi marine waters, Northwestern Gulf*

The proximate values for monthly mean water turbidity for the same period ranged from 11.5 mg/l to 43 mg/l, with the highest recorded in August 2023 (Fig. 4).

During the study period, which extended from August 2024 to July 2025, sea surface water temperatures (SST) ranged between 18.3 °C in January and 34.4 °C in August 2025, and the (SST) were < 32- 34°C for 6 months April to October (Fig. 2). Salinity value recorded for the same period ranged between 37.7 psu in February 2025 and 42.7 psu in August 2024 (Fig. 3).Turbidity during the study period (August 2024-July 2025) ranged from 11.6 mg/L in January 2025 to 40 mg/L in August 2024.

Ten species belonging to eight genera from five scleractinian families were identified from 68 scleractinian coral samples collected from the Iraqi coral colony area (Table 1). The species were considered new records for the region. The details of these species are as follows:

Systematics

Kingdom: Animalia
Phylum: Cnidaria (Hatschek, 1888)
Subphylum: Anthozoa (Ehrenberg, 1834)
Class: Hexacorallea (Haeckel, 1896)
Order: Scleractinia (Bourne, 1900)
Suborder: Refertina (Okubo, 2016)
Family: Dendrophylliidae (Gray, 1847)

Genus: *Cladopsammia* Lacaze-Duthiers in 1897 WoRMS (2026)

***Cladopsammia gracilis* Milne Edwards and Haime, 1848**

Synonym: *Dendrophyllia gracilis* Milne Edwards and Haime, 1848 **;** *Dendrophyllia coarctata* P.M. Duncan, 1889; *Dendrophyllia arbuscula* C.J. van der Horst, 1922*;* *Rhizopsammia chamissoi,* Wells, 1954

Material examined: Four colonies from Palinurus Rock, Iraqi marine waters MSC 201. (Fig. 5)

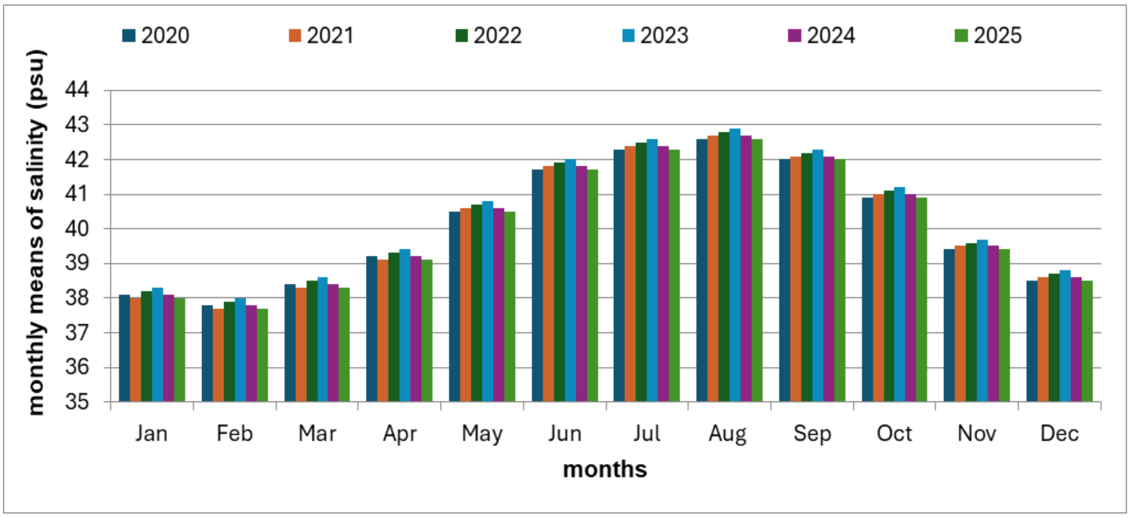

Fig. 3. *Monthly means of sea salinity levels (psu), during the period 2020-2025 at the coral reefs site in the Iraqi marine waters of the Northwestern Gulf*

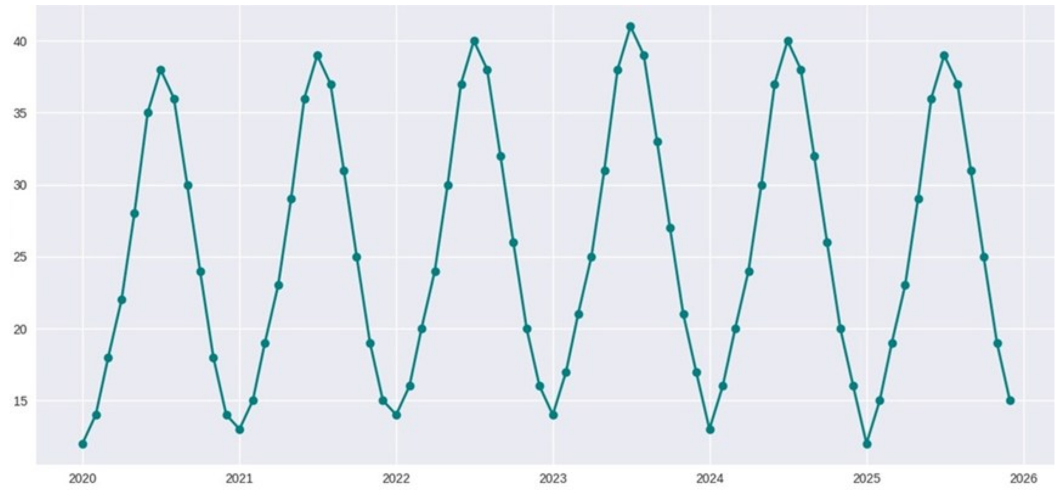

Fig. 4. *Monthly means of turbidity (mg/l), during the years 2020-2025 at the coral reefs site in the Iraqi marine waters, northwestern Gulf*

Diagnosis characters: Branched colonies ranging in diameter from 4-6 cm. The colony consisted of twigs ranging in height from 12 to 20 mm that are fused. The larger twigs were oval.

Corallites: Tubular, fused together, oval in adults, ranging in diameter from 4.09-12.79 mm and 5.05-8.50 mm deep. The outer surface of the corrugellae was grooved alternately with rows of teeth.

Septa: Arranged in four portal-shaped orders. The primary septa bulged inward to form a long, smooth lobe. The primary and secondary septa were more prominent than the tertiary and quaternary septa, which themselves bear small serrations. There were 64 septa in adults and 22 in new shoots. All septa extended to the columns.

column: Spongy and contained twisted skeletal tissue.

Distribution: Widely distributed in tropical and subtropical regions of the Indo-Pacific and the Gulf.

IUCN status: The IUCN Red List status for this species is Vulnerable (VU).

Genus: *Duncanopsammia* (Wells, 1936) WoRMS (2026)

***Duncanopsammia peltata* (Esper, 1794)**

Synonym: *Gemmipora peltata* Esper, 1794; *Madrepora peltata* Esper, 1790; 1794; *Turbinaria dichotoma* Verrill, 1870; *Turbinaria maxima* Ortmann, 1888; *Turbinaria peltata* (Esper, 1790).

Material examined: Five colonies from Palinurus Rock,Iraqi marine waters MSC 202.

Diagnostic characters: Commonly known as disc coral, the colony is small and easily identifiable by its disc-like shape or flat, horizontal, bowl-like plate. It is also referred to as cup coral or mushroom coral due to its broad, coral-free stalk, 2–4 cm long. Colony diameter ranges from 5–18 cm, with disc plate thickness between 6–11 mm. Characterized by large polyps and corallites. (Fig. 6)

Corallites: Large, round or oval, distinguishing this species from other *Duncanopsammia* species. The corallite arrangement was plocoid, with diameters ranging from 1.56 to 3.82 mm. Calyx diameter ranges from 2.5–4 mm. Corallite spacing was wide at the surface and narrows toward the colony edges. Corallites were protruded slightly (1–6.5 mm high) or were submerged.

Septa: Two orders were present with 20–23 septa, which did not reach the column. All septa had small, protruding indentations.

Columella: Was domed and intertwined.

Distribution: It was a widespread species found in shallow tropical reef systems across the Indian Ocean, the western and central Pacific Ocean, and the South China Sea. It was native to the Indo-Pacific.

IUCN status: It was classified as "Vulnerable" (VU), and was considered threatened with extinction unless conditions affecting its survival and reproduction improved.

Remarks: Although commonly found in deeper waters (22 m) and at the base of coral reefs, where it was never abundant (Hodgson and Carpenter, 1995; Alidoost Salimi *et al*., 2018), colonies were abundant at a depth of 9 m. in Iraqi marine waters. The tissue was dark

Fig. 5. *Cladopsammia gracilis colony from Iraqi marine waters, view of the corallites, scale bar= 4mm.*

brown, while the polyps were white and emerged at night. Colonies in Iraq resembled a mushroom shape and had not developed into other forms. This was the common form in the Gulf, as well as in Iran, Kuwait, Qatar, and the United Arab Emirates (Hodgson and Carpenter, 1995; Riegl *et al*., 2012; Alidoost Salimi *et al*., 2018). The multi-layered or vertical leaf form was more common in the western Pacific Ocean (Bernard, 1897). The unaccepted name was *Turbinaria peltata* , Arrigoni *et al*. 2014 suggested changing the genus name from *Turbinaria* to *Duncanopsammia*.

Family: Merulinidae Verrill, 1866

Genus: *Cyphastrea* Milne-Edwards and Haime, 1848

***Cyphastrea serailia* (Forskål, 1775)**

Synonym: Cyphastrea brueggemanni, Quelch, 1886; *Cyphastrea danai*; Quelch, 1886; *Cyphastrea conferta* Nemenzo, 1959; Cyphastrea incrustans Klunzinger, 1879; *Cyphastrea laticostata* Nemenzo, 1959; *Cyphastrea maldivensis* Gardiner, 1904; *Cyphastrea suvadivae* Gardiner, 1904; *Madrepora serailia* Forskål, 1775; .

Material examined: Six colonies from Palinurus Rock,Iraqi marine waters MSC 203.

Diagnosis characters: The colony was large, flat or hemispherical, 16–25 cm in diameter. (Fig. 7)

Corallites: The corallites were separate-walled (plocoid), circular, and regularly arranged measuring 2.1–3.35 mm in diameter. The intercoral spaces were covered with small, tapered spines.

Septa: The septa were arranged in two distinct orders, the primary (12) and the secondary (12) in most septa. The primary septa are serrated and project 0.48 mm above the wall margin, reaching the columns. The secondary septa are small and confined to the inner edge of the wall. The sides of the primary septa were granular.

Distribution: The species was widespread in the Indo-Pacific, the northern Red Sea, and the Gulf region, extending to South Africa. and eastward to Hawaii and French Polynesia.

Remarks: The species found in Iraqi marine waters at a depth of 8.5 meters; colonies were mostly flat.

IUCN status: It was recently assessed on the IUCN Red List of Threatened Species in 2023 and listed as Least Concern (LC).

Genus: *Favites* Link, 1807

***Favites pentagona* (Esper, 1794)**

Synonym: *Aphrastrea deformis* Milne Edwards and Haime, 1848; *Favia adduensis* Gardiner, 1904; *Favites gailei* Chevalier, 1971; *Favites parvicella* Nemenzo, 1959; *Goniastrea rudis* Milne Edwards and Haime,

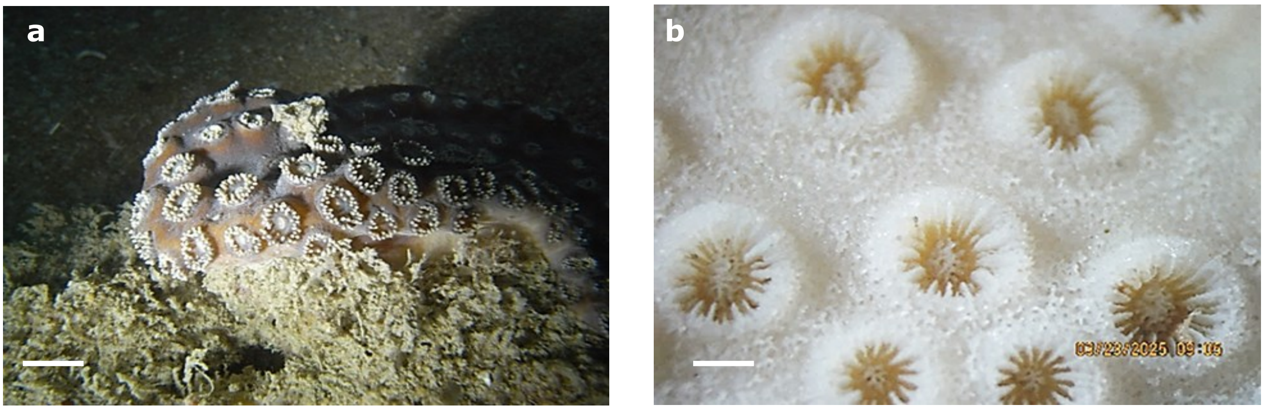

Fig. 6. *Duncanopsammia peltat a, colony photographed underwater Scale bar =5cm (photo by Abdullah Al-Nasser);*

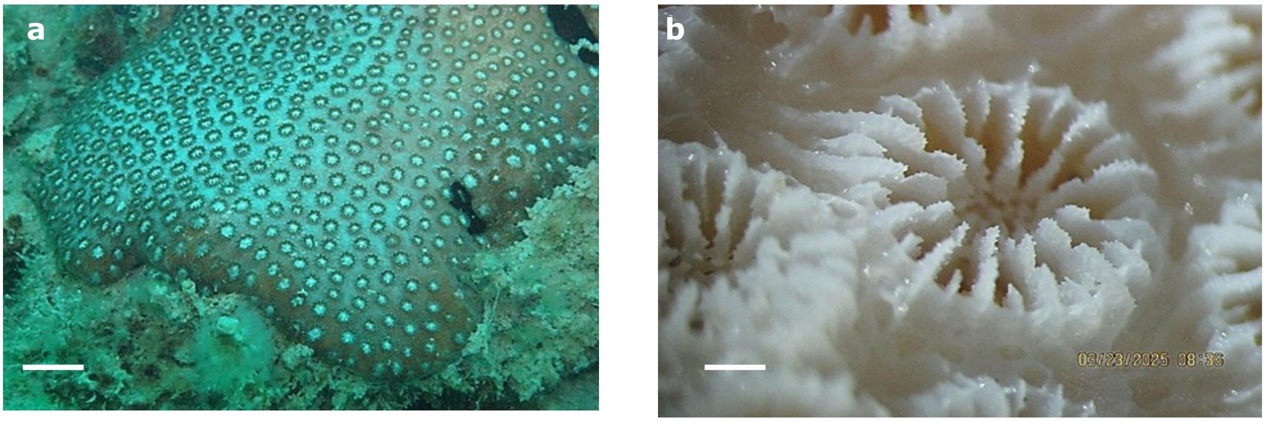

Fig. 7. *Cyphastrea serailia a, colony from Iraqi marine waters scale bar= 5cm . b, close-up view of the corallites. Scale bar = 1mm*

1850; *Madrepora pentagona* Esper, 1795; *Plesiastrea haeckeli* Brüggemann, 1878; *Prionastraea gibbosissima* Milne Edwards and Haime, 1850.

Material examined: Four colonies from Palinurus Rock, Iraqi marine waters MSC 204

Diagnosis characters: Colonies were small, flat, to submassive, thickly encased, or massive, often irregular, with humps or protuberances up to a few centimeters in height, and might sometimes have developed into a tree-like, branch-like shape. They budded within the tentacle. The average colony size was 20 cm, but in some specimens, it might have reached nearly a meter. (Fig. 8)

Corallites: The walls were thin and irregular in shape, ranging from sub-circular to polygonal, and often clearly pentagonal. Their diameters ranged from 7.3–9 mm, while their depth ranged from 2–4.5 mm.

Septa: Few in number, divided into three orders, totaling no more than 32 septa. The primary always reaches the column. The margins of the septa contained 8-10 small, regular horizontal teeth. Paliform lobes were prominent and well-developed forming a crown around the column. The secondary septa were small, devoid of projections, and were wall-bound, extending less than halfway up the columns. The tertiary septa were reduced.

Columella: Sometimes irregular and composed of a few intertwined spongy cells. The colony's color was often brightly, brown, red, or orange, with common green oral discs and often a lighter oral space.

Distribution: It was widespread in the tropical and subtropical regions of the Indo-Pacific, the Gulf, the Red Sea, East Africa, and the Great Barrier Reef.

IUCN status: Recently assessed on the IUCN Red List of threatened species in 2023, this species was listed as Least Concern (LC).

***Pentagona chinensis* (Verill, 1866)**

Synonym*: Prionastraea chinenis* Verrill, 1866; *Favites yamanarii* Yabe and Sugiyama, 1935.

Material examined: Three colonies were examined from Palinurus Rock, Iraqi marine waters MSC 205.

Diagnosis characters: Colony was encrusted and irregular in shape, with a few humps in a few centimeters above the general surface of the colony. (Fig 9)

Corallites: Were shallow, semi-circular to polygonal in shape, with five sides, a ceroid arrangement with thin, common walls. They formed by budding within the tentacle. The calyx was 7–10.5 mm in diameter. Some corallites were prominent and nodular. 10–13 were known.

Septa: They were straight and widely spaced, without pale lobes, and are connected above the walls to those of neighboring coralline septa. There were 40 septa in two orders the primary reached the column; the secondary was reduced and limited to the wall. The margin of the septum was well serrated, with the serrations increasing near the center of the calyx. Paliform lobes were absent or inconspicuous.

Columella: It was spongy

Distribution: It was rare in the Gulf and the Indo-Pacific

IUCN status: The International Union for Conservation of Nature (IUCN) had classified as "Vulnerable" (VU).

Remarks: Specimens contained corals slightly larger than those found in other areas of the Gulf. This species may have been confused with *F. pentagona* in the field. However, the wall of *F. chinensis* was thinner than that of *F. pentagona*, the corals were more moderately angular (Sheppard and Sheppard 1991), and the presence of paliform lobed buttresses in *F. pentagona* but it was absent in *F. chinensis*.

Genus *Dipsastraea* de Blainville, 1830

***Dipsastraea pallida* (Dana, 1846)**

Synonym: *Astraea* (*Fissicella*) *denticulata* Dana, 1846; *Astraea cellulosa* Verrill, 1872; *Astraea doreyensis* (Milne Edwards and Haime, 1857); *Astraea ordinata* Verrill, 1866; *Favia amplior* (Milne Edwards and Haime, 1849); *Favia denticulata* Gardiner, 1904; *Favia doreyensis* Milne Edwards and Haime, 1850; *Favia laccadivica* Gardiner, 1904; *Favia okeni* Milne Edwards and Haime, 1857; *Favia pallida* (Dana, 1846); *Favia tubulifera* Klunzinger, 1879; *Goniastraea serrata* Ort-

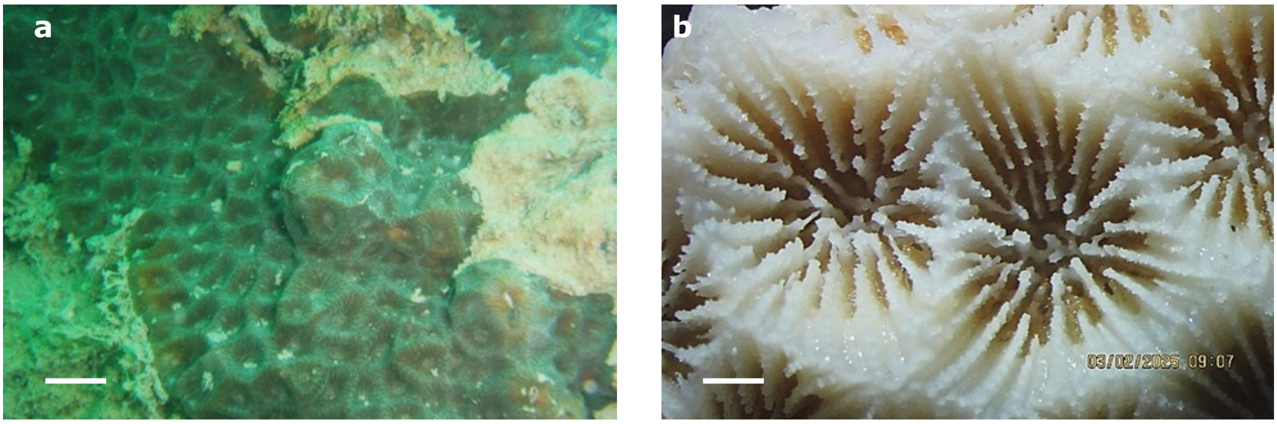

Fig. 8. *Favites pentagona a, colony from Iraqi marine waters scale bar= 5cm. b, close-up view of the corallites. Scale bar= 4mm*

mann, 1889; *Heliastrea borradailei* Gardiner, 1904; *Parastrea amplior* Milne Edwards and Haime, 1850; *Parastrea verrilleana* Milne Edwards and Haime, 1850.

Material examined: Seven colonies from Palinurus Rock Iraqi marine waters MSC 206.

Diagnosis characters: The colony was massive and hemispherical, 20 cm in diameter. (Fig. 10)

Corallites: They were massive, sub-circular, arranged in plecoid, sub-plecoid, and even sub-cerioid patterns. Corallites form by budding within the tentacle, are 6.5–9.35 mm in diameter, sometimes reaching 13 mm. The depths of the septa were uneven, ranging from 2.32-6.00 mm.

Septa: There were 22–28 in two orders (sometimes indistinguishable), but some corallites exceeded 40. The septa were well separated and projected above the wall margin. Most septa descended abruptly to the bottom of the lining and then reached the column. The margins of the septa were always decorated with very short, irregular teeth, numbering 3–5. These teeth were finely toothed, especially at their tips, which often form fine horizontal fans.

Columella: This was spongy, usually dense, and composed of twisted ridges, equal and sometimes adjacent ribs were joined together.

IUCN status: The International Union for Conservation of Nature had classified it as "Least Concern" (LC). This species was first described in 1846 as *Favia pallida* by the American zoologist James Dwight Dana; it was later transferred to the genus *Dipsastraea*, although some experts still used the original name.

Remarks: Colonies in the field showed varying colors ranging from green to light pink to reddish brown, and their shapes varied from domed to flat. The diameters of the calyces in some corals reached 14.61 mm and sometimes 15 mm.

Distribution: It was widespread in the Gulf, the Red Sea, and the Indo-Pacific.

Family: Psammocoridae Chevalier and L. Beauvais, 1987 WoRMS (2026)

Genus: *Psammocora* Dana, 1846 WoRMS (2026)

***Psammocora stellata* (Verrill, 1866)**

Synonym: *Psammocora* (*Stephanaria*) *brighami* Vaughan, 1907; *Stephanaria stellata* Verrill, 1866.

Material examined: Five colonies from Palinurus Rock, Iraqi marine waters MSC 208.

Diagnosis characters: A sub massive incrusting base colony, not exceed 10 cm, branched out into numerous short, irregular, nodular branches, ranging in length from 1-3 cm. (Fig. 11).

Corallites: Polygonal, shallow-walled, ill-defined. The calyx diameter ranges from 1-1.5 mm

Septa: They were thin, 8-10 in number, reaching the column, three to four of which are petal shaped. The margins of the septa bear granulated dentations

Columella: It was short, present in almost all corals, and composed of approximately 8 rounded, spongy protuberances. It was poorly developed or absent. color was beige to brown, sometimes greenish, and usually lighter at the tips of the branches

Distribution: This species was widely distributed in the western and central Pacific Ocean and various locations in the Indian Ocean. It was found in the southern Red Sea. It was common in Kuwait, Qatar, and some Iranian islands, such as Kish Island, primarily as free-living colonies.

IUCN status: It was recently assessed on the IUCN Red List of Threatened species in 2023. This species was listed as Least Concern (LC).

***Psammocora columna* Dana, 1846**

Synonym*: Coscinaraea columna* Dana,1846; *Coscinaraea fossata* (Dana, 1846); *Psammocora columna* Dana, 1846; *Psammocora fossata* Dana, 1846

Material examined: Three colonies from Palinurus Rock Iraqi marine waters MSC 207. (Fig. 12)

Diagnosis characters: The colony was a massive, encrusted colony, with free margins, typically 10-15 cm in diameter and possibly larger in shallow waters.

Corallites: Thes were Intertwined with irregular, common-walled corallites, or the walls were weak and low, either solitary or formed in a linear series of 8–10, ridge -like structures. In some cases, the boundaries be-

Fig. 9. *Favites chinensis a, colony from Iraqi marine waters scale bar= 5cm. b, close-up view of the corallites. Scale bar= 5mm*

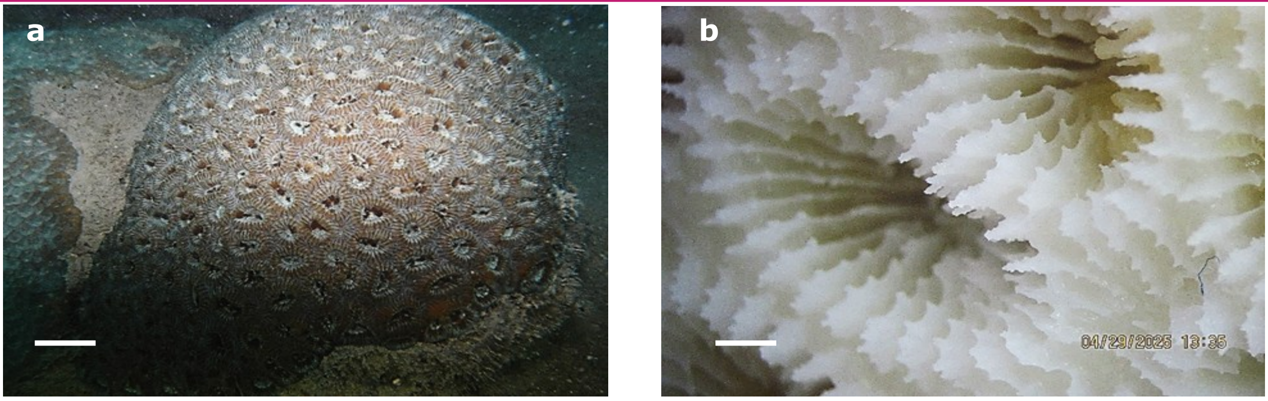

Fig. 10. *Dipsastraea pallida . a, colony from Iraqi marine waters scale bar=5cm . b, close-up view of the corallites. Scale bar= 5mm*

tween adjacent corals were absent. The calyxes were 3 –7 mm in diameter in coral laminae.

Septa: There were up to 40 septa on the walls, but 8–9 of these reach columns.

Distribution: Widespread in the tropical and subtropical regions of the Indo-Pacific, rare to common, and was found mainly in sandy habitats throughout the Gulf. IUCN status: status for this species least concern (LC).

Family Rhizangiidae d'Orbigny, 1851 WoRMS (2026)

Genus *Siderastrea* de Blainville, 1830

***Siderastrea savignyana* Milne Edwards and Haime, 1850**

Synonym: *Siderastrea savignyana* Milne Edwards and Haime,1850.

Materials examined: One colony was examined from Palinurus Rock, Iraqi marine waters MSC 209. (Fig. 13)

Diagnosis characters: Living colony was characterized by a light blue color, thick, often flat, and encrusted to semi-huge, reaching a maximum diameter of 20 cm. The coral surface was surrounded by irregular humps.

Corallites: The order of corals was ceroid, polygonal in shape at its outer borders, adjacent to each other, separated by a thin wall. They are small (2-3 mm in diameter). They form by budding from the tentacles.

Septa: The septa were thin and numerous, approximately 24-30 septa in two orders, sometimes merging into triangular groups toward the center of the polyp skeleton, forming the characteristic triangular or wedge-shaped cluster, typically found in the families Siderastreidae and Coscinaraeidae.

Columella: The columella was small, oblong, or slightly oval. The walls colony's color were usually white, and the polyps range in color from brown to green.

Distribution: This species was common in coral reef and sandy habitats. It was restricted to the western Indo-Pacific, from South Africa to Sri Lanka, including the Red Sea and the Gulf, where it appears to be rare.

IUCN status: The International Union for Conservation of Nature (IUCN) had classified as a Least Concern (LC).

Family: Caryophylliidae Dana, 1846

Genus: *Paracyathus* Milne Edwards and Haime, 1848

***Paracyathus stokesii* Milne Edwards and Haime, 1848**

Synonyms: *Acanthocyathus stokesii*

Material examined: 15 colonies from Palinurus Rock, MSC 210 and 10 from breakwater of Al-Faw Port MSC 211, Iraqi marine waters. (Fig. 14)

Diagnosis characters: A solitary cup-shaped coral. The coral reaches a height of 16 mm, with a flat base. The coral stalk is cylindrical in juveniles and tapered in adults, reaching around the base and to the top of the coral. The coral diameter ranges from 5.70 to 10.72 mm.

Septa: 84 septa of four orders, irregularly projecting on the wall, sloping steeply into the cup. All contain projections. Black in color.

Column: Long and narrow. Black in fresh specimens.

Distribution: Widespread in the Indian and Indo-Pacific Oceans.

Remarks: Widely distributed in Iraqi marine waters and is found on rocks, soft coral axes, snail and oyster shells, and crustacean surfaces. It has been found in shallow areas at depths ranging from less than 1 to 10 meters. It is a habitat for barnacle and tubeworm species.

IUCN status: The IUCN red list status for this species is Not Evaluated (NE).

DISCUSSION

The digital data on temperature, salinity, and turbidity recorded over five years (2020-2025) for Iraqi coral reef waters are interesting with regard to assessing the ability of these reefs to adapt to unusual conditions, according to coral reef literature in general. Globally, coral reefs recognized highly sensitive ecosystem, living with narrow ranges of environmental facters temperature, salinity and turbidity primary determininig factors for the appropriate conditions for reef building and growth (Burt *et al.,* 2020; van Woesik and Kratochwill, 2022; Burdett *et al.,* 2024).

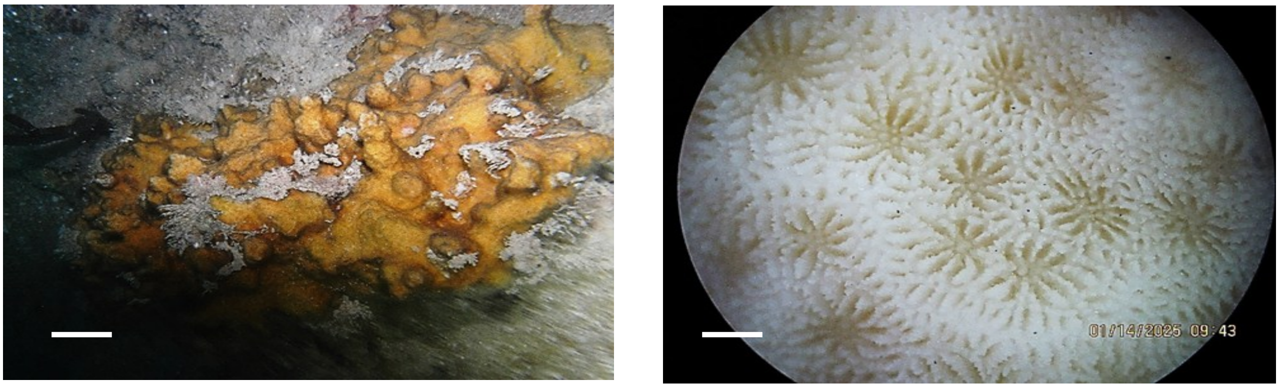

Fig. 11. *Psammocora stellata* a, colony from Iraqi marine waters scale bar= 5cm. b, close-up view of the corallites.

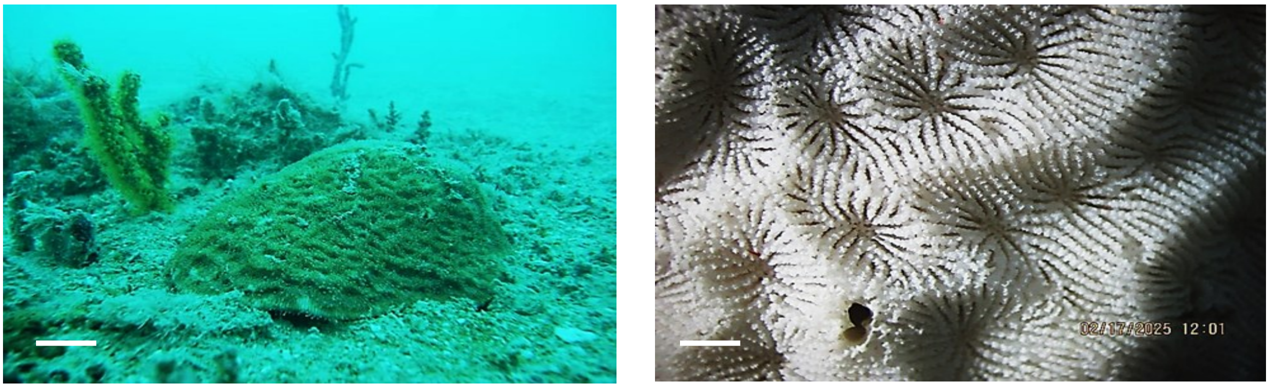

Fig. 12. *Psammocora columna a, colony from Iraqi marine waters scale bar= 5cm . b, close-up view of the corallites. Scale bar= 4mm*

Turbidity for pristine open water extreme low 0 mg/l to 1 mg/l, and in clear coastal water of a range 1-5 mg/l, the optimum turbidity for healthy coral reef less than 2 mg/l (Anthony and Fabricius, 2000). The study results showed flourishing of 10 scleractinian coral species (Fig. 5-14) in the Palinurus Rock coral colony during the period of this investigation, August 2024 to July 2025. The values of the environmental parameters, temperature, salinity and turbidity, which are the determining factors for coral growth, were found to have high upper ranges (Fig. 2, 3, 4). The coral species experienced a temperature above 34.4°C, outside the globally recognized range for corals, for a period of six months. Also, recording salinity, its values were high < 35 psu, throughout the year, reaching up to 43 psu (Fig. 3). Turbidity values were very high during the study period (11.5-40.7 mg/l), which were a clear indicator of the extreme environmental conditions of these coral reefs.

The optimal range of temperature for healthy coral reefs, generally ranging between 23-29°C, and for salinity between 32-35 psu in the tropical and subtropical regions (Vaughan *et al*. 2019; Seraphim *et al.,* 2025), outside these ranges between 18.54–34.44°C (or less than 18°C during winter months, and exceeding 34°C during summer months) (Fig. 2), and salinity levels above 43 psu (Fig.3), also exceed the normal ranges in the most of the world's reefs, providing additional evidence for the extreme environmental conditions of Iraqi reefs and underscoring the need for continued research to obtain broader information about the ecosystem.

These extreme conditions, characterized by prolonged periods of high water temperatures, high salinity, and often turbidity, have a substantial impact on coral reef ecosystems (Thirukanthan *et al.,* 2023; Seraphim *et al.,* 2025; Gower *et al.,* 2025).

Molecular studies of corals appear very difficult, and there are few specialized laboratories in the world. A study by Alvarado-Cerón *et al*. (2023) showed that out of 1500 species of hard coral, only 117 species have been studied in population genetics covered regions such as the Caribbean, the Australian Barrier Reef, and South Kuroshio in Japan, which are among the ecoregions with the most population genetic data. The Coral Triangle region has less data.

In order to identify Iraqi corals, coordination with one of these international laboratories is necessary to complete the work.

Environmental data indicates that Iraqi marine waters are characterized by high thermal stress, high salinity, and high turbidity. However, biological productivity remains relatively stable, with scattered colonies of more thermally tolerant and stress-resistant coral species at the upper limits of their physiological tolerance. This may explain the low number of coral species in this area. The present study recorded 10 coral species in

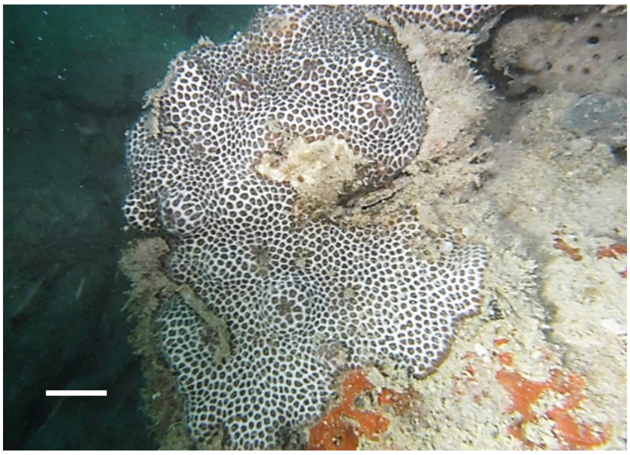

Fig. 13. *Siderastrea savignyana colony from Iraqi marine waters scale bar= 5cm*

Iraqi marine waters; this number is relatively low compared to the coral diversity documented in other parts of the Gulf. The ten species identified are among those found adjacent to the Iraqi coast, particularly in Kuwait and Iranian waters. Reports indicate the presence of more than 50 coral species around some Iranian islands (Fatemi and Shokri, 2001; Riegl and Purkis, 2015; Alidoost Salimi *et al*., 2018), and 35 species in Kuwaiti waters (Gholoum and Karam, 2024). It is likely that the Coriolis Currents helped many coral polyps in the northern part of the Gulf, particularly in Iranian marine waters, move to the hard substrates available in the Iraqi marine waters. The total number of coral species in the Gulf may reach up to 120 (Kourandeh *et al*., 2021). It is worth noting that the taxonomic composition of coral species in the Gulf accounts for only about 10% of those widespread in the Indo-Pacific region (Coles, 2003).

The limited coral diversity in the Iraqi marine environment reflects environmental conditions unsuitable for coral growth, due to temperatures, salinity, and high turbidity, as indicated by previous studies in the Gulf (Pohl *et al*., 2014; Kavousi *et al*., 2021). Coral reefs in the Gulf are generally found around islands and along the coasts of the seven countries bordering it (Gower *et al*., 2025; Seraphim *et al*., 2025), with the exception of Iraq, where coral colonies are located tens of kilometers from the coast and grow at depths exceeding 7 meters. Fiegel *et al*. (2025) attribute the presence or absence of certain species in different parts of the Gulf to changing environmental factors that affect the substrate conditions necessary for coral larval settlement. On the other hand, Coles (2003) confirmed that the presence or absence of certain species in different parts of the Gulf remains unclear, as is the case with the coral colonies under study.

The similarity and overlap in phenotypic characteristics among coral species in the Gulf, combined with the fact that many areas remain unsurveyed, highlight the need for further research to determine the true number of coral species in the Gulf (Arrigoni *et al*., 2014; Alidoost-Salimi *et al*., 2018; Arrigoni *et al*., 2020; Alidoost-Salimi, 2021). As for the coral species found in Iraqi marine waters, they have been matched and phenotypically confirmed.

The results of the present study showed that Merulinidae dominate the Scleractinian coral population. They are common and dominant reefs and are widely distributed across various regions of the Gulf. Mostly large colonies with thick tissues and layers, they are also the most tolerant of high temperatures and salinity, as well as resistant to high concentrations of suspended sediments and nutrients specially in the Northwest and west the Gulf (Burt and Bauman, 2019; McClanahan *et al.,* 2020; Gonzalez *et al.,* 2024).

The family Merulinidae consists mainly of species belonging to three genera:

Cyphastrea serailia, *Favites pentagona F. chinensis* and *Dipsastraea pallida* (Table 1, Fig.s 7-10, respectively). These species are resistant to severe thermal stress (Burt *et al.,* 2019; Burt, 2023).

studies by Burt *et al*. (2011, 2019) showed that species of the Merulinidae family, along with those of the Poritidae family, constitute more than 90% of the coral cover on the shallow southern coasts of the Gulf. Several studies, including Hadj-Hammou *et al*. (2025), Burt (2023), and Jones *et al*. (2025), confirmed that when

Fig. 14. *Paracyathus stokesii a, Individuals settled on soft coral branches scale bar= 4cm. b, different skeleton of adult*

Table 1. Scleractinia coral species from the Iraqi marine waters

Family	Species
Dendrophylliidae Gray, 1847	*Cladopsammia grasilis* (Lacaze-Duthiers, 1897)
	Duncanopsammia peltata (Esper, 1794)
Merulinidae Verrill, 1866	*Cyphastrea serailia* (Forskål, 1775)
	Favites pentagona (Esper, 1794)
	Favites chinensis (Verrill, 1866)
	Dipsastraea pallida (Dana, 1846)
Rhizangiidae d'Orbigny, 1851	*Siderastrea savignyana* (Milne Edwards and Haime, 1850)
Psammocoridae Chevalier & L. Beauvais, 1987	*Psammocora stellata* (Verrill, 1866)
	Psammocora columna (Dana, 1846)
Caryophylliidae Dana, 1846	*Paracyathus stokesii* (Milne Edwards and Haime, 1848)

coral cover declined by more than 80% along the UAE coasts during the past decade, repeated coral bleaching events led to a decline or extinction of the less thermal-tolerant species, leaving only the more stress-resistant species from the Merulinidae family.

The present study also recorded the widespread species *Duncanopsammia peltata* (Fig. 6), which is known to prefer turbid environments that are typically unsuitable for coral growth (Veron and Pichon, 1980; Chou and Ng, 2010).

It appears that *D. pallida* and *D. peltata* are the most dominant coral species in Iraqi marine waters, based on analysis of images, videos, and samples collected from the seabed during the study period. Reports indicate that these two species are common in turbid environments and are resistant to high temperatures (Gonzalez *et al*., 2024; Mellin *et al*., 2024).

In this study, a specimen of *Siderastrea savignyana* (Fig. 13) was found. This species is common and widespread, and among the most tolerant of harsh environmental conditions in the Gulf (Riegl and Purkis, 2015). Its colonies are often observed to be partially layered or crusty over the underlying substratum, buried in sediments, and it is the only species of the genus *Siderastrea* recorded in Gulf waters (Alidoost-Salimi *et al*., 2018; Kavousi *et al*., 2021; Shokri and Kabiri, 2025). It is believed that broader surveys may reveal its presence more abundantly in Iraqi marine waters.

The species *Psammocora stellata* (Fig. 11) is characterized by its clearly branched and clumped forms and is less abundant in Iraqi marine waters. However, the genus *Psammocora* is widespread in the Indo-Pacific, with six species recorded in the Gulf (Riegl and Purkis, 2015;), and is abundant in Kuwaiti coral reefs (Benzoni *et al*., 2007).

The list of recorded species includes the wrinkle coral *Psammocora columna* (Fig. 12). In Iraqi marine waters, its colonies form clumps or low massive structures, sometimes appearing as small circular clusters with diameters not exceeding 15–20 cm. In other regions, they may reach up to 75 cm and form brown or dark-green mounds (Papathanasopoulou and Zogaris, 2015). Externally, the shapes of their polyps resemble brain coral patterns, forming maze-like structures (Shokri and Kabiri, 2025). This coral is common in most of Kuwait's coral reefs and is often found in both shallow and deep waters.

Two cup coral species were recorded in the current study: *Cladopsammia gracilis* and *Paracyathus stokesii* (Fig. 5 and 14, respectively), both known for their wide distribution in the Indo-Pacific Ocean (Papathanasopoulou and Zogaris, 2015). Among them, *P. stokesii* appears to be the most widespread and abundant in Iraqi marine waters. It tolerates turbidity and can settle on various substrates such as rocks, gorgonian branches, and submerged objects. Notably, this species has recently been recorded settling in the breakwater area of the Grand Faw Port, which is currently under construction along the Iraqi coast (Ahmed *et al*., 2023).

There is growing evidence that turbid ecosystems can support coral communities with coverage comparable to, or even exceeding, that of clear-water reefs (Morgan *et al*., 2016; Schleyer and Porter, 2018). Several studies over the past decade have documented lower levels of bleaching and mortality in turbid corals compared to clear-water corals, despite exposure to similar or higher temperatures (van Woesik *et al*., 2012; Morgan *et al*., 2017). Key contributing factors include the dominance of stress-resistant species and reduced light intensity due to suspended sediment loads, which help mitigate the additional stress of solar radiation during high-temperature periods (Morgan *et al*., 2017; Teixeira *et al*., 2019).

Recent modelling studies suggest that turbidity may reduce the severity of bleaching events caused by high temperatures in 12% of the world's coral reefs. Furthermore, corals in turbid waters have shown faster recovery and lower mortality rates after bleaching (Burt *et al*., 2020).

Globally, coral reefs have experienced four major bleaching events in 1998, 2010, and 2015/2016/ 2024 (Heron *et al*., 2016, NOAA 2024). These events were triggered by recurring marine thermal waves, which are becoming increasingly frequent in the Gulf (Burt and Bauman, 2020; ROPME, 2021; Burt, 2024). Although coral reefs in the Gulf are genetically adapted to withstand extreme temperatures, they now have among the highest thermal tolerance in the world (40–42°C) (Hadj-Hammou *et al*., 2025; Seraphim *et al*., 2025).

This study, in line with the observations of Pohl (2014) and Gutekunst *et al*. (2018), confirms that coral colonies in Iraqi marine waters have remained in good health since their discovery in 2013.

While no bleaching cases were observed within the limits of the samples examined in this study, this conclusion cannot be generalized due to the lack of a comprehensive survey and examination of additional samples. The bleaching cases in Iraqi marine waters reported by Pohl *et al*. (2014) were attributed to anchor damage, as many cargos ships dock for extended periods near Iraqi oil ports, where coral colonies are concentrated. ROPME (2015) confirmed that anchor damage increases in deeper waters (10–15 m), while the best growth of hard corals was recorded on the upper slope at depths less than 10 m, with peak diversity at 8 meters.

Severe bleaching in the Gulf has been linked to shallow sites (3–5 m), which are most affected by warming, making coral reefs more vulnerable to rising sea surface temperatures (Burt *et al.,* 2024; Gonzalez *et al*., 2024). In some cases, complete coral mortality was recorded at depths of about 3 meters in Saudi Arabia, the UAE, Qatar, and Bahrain, while higher survival rates were observed in deeper waters (Sheppard and Loughland, 2002; Hadj-Hammou *et al*., 2025).

Fortunately, despite environmental disturbances in Gulf reefs, evidence from Pohl *et al.* (2014) and findings from the current investigation indicate that optimal coral growth occurs at a depth of 8.0 m, suggesting that these reefs continue to demonstrate effective survival.

Additionally, reports on coral bleaching indicate that genera with thick tissues, such as *Dipsastraea* and *Favites*, which are abundant in Iraqi marine waters, exhibit high tolerance to thermal stress (Burt, 2023; Hadj-Hammou *et al*., 2025). However, the issue of coral bleaching in the world's oceans, including the Gulf due to thermal waves, has been documented in many literatures, for example, coral bleaching (van Woesik and Kratochwill, 2022).

The recent research suggests that, due to the Gulf's exposure to high temperatures since coral colonization of the area over 12,000 years ago, these corals have genetically adapted to harsh conditions. This genetic adaptation is a hypothesis drawn from the broader literature and now represents one of the most thermally tolerant coral reefs in the world (Burt and Bauman, 2020; Seraphim *et al*., 2025).

Consequently, given the rapid pace of climate change, the Gulf's coral reefs have become a valuable resource for research on coral resilience and adaptation to extreme climatic conditions. A coral bleaching database documented 34,846 bleaching records from 14,405 locations in 93 countries between 1980 and 2020, demonstrating that marine thermal waves are the greatest threat to corals worldwide (van Woesik and Kratochwill, 2022; Thirukanthan *et al*., 2023; Paparella and Burt, 2024).

Based on the data from previous studies, some of which are referred in this study and others, which consider that the reefs live under extreme high temperature and salinity, as well as the observations recorded in this study with regard to the coral reefs in the Iraqi marine waters, many questions and hypothesis can raised regarding too extreme environmental factors, resistance to bleaching factors, the positive effect of the depth and turbidity on the survival of the corals, and what is concerned with climate warming effects (Camp *et al*., 2018; Chow *et al*., 2019; Soares, 2020; Burt *et al*., 2024). All of these environmental factors cannot be determined unless further experimental field, and laboratory research, and appropriate digital measurements are conducted.

Coral reefs are among the highest biodiversity hotspots in the world, characterized by remarkable species richness (Cecchini *et al*., 2024). However, in an area such as the Iraqi marine waters, were the environmental condition i.e. the physicochemical parameters are somewhat extreme for corals life in general, the diversity of Iraqi corals is less than most coral reefs in other parts of the Gulf in particular and seas and oceans in general, but it still maintains its survival and continuity.

However, the study believes that the extreme upper limits of temperature and salinity, along with the high diversity of sedimentary material in this reef. Unfortunately, due to several logistical factors, including the ongoing security conflicts in the region, further experimental work was not possible.

Conclusion

This study recorded 10 coral species for the first time, representing a portion of the known species in the Gulf. While this number is small compared to the coral populations in nearby Iranian and Kuwaiti waters. It enhances and expands the scarce information on coral diversity of the unique reefs in Iraqi marine waters, and the latest discoveries in the northwest Gulf. Despite the high environmental conditions, represented by high temperatures, salinity, and turbidity, this coral community demonstrated sufficient adaptation and survival. This water acts as a filter, trapping species that are more resistant to extreme environmental conditions. Although morphological diagnosis of species is confirmed, genetic analysis remains necessary to provide greater confidence in the results. According to environmental observation, such as high temperatures (18.54-34.44 °C), salinity (37.7-42.9 psu) and turbidity (11.5-40.7 mg/l), which was also confirmed by previous studies; as well as the absence of any bleaching record in the samples of this study, it is suggested conducting further ecophysiological and field research to determine whether these reefs adapted to an extreme environmental condition.

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Conflict of interest

The authors declare that they have no conflict of interest.

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