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New records and updated checklist of the seaweeds of the phycologically little-known coast of Fujairah, United Arab Emirates

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A checklist of the benthic marine algae (seaweeds) of the Emirate of Fujairah is presented, with a total of 38 species: 9 brown algae (Ochrophyta, Phaeophyceae), 23 red algae (Rhodophyta), and 3 green algae (Chlorophyta). Of this number 17 species are new records and are based on samples collected in 2023 in shallow coastal waters with many from floating structures. Earlier records come mostly from intertidal surveys carried out in the late 1990s of open rocky shores that are common along the northern part of the 70 km long coastline of Fujairah. One of the seaweeds, namely *Lomentaria strumosa*, is only recorded from Fujairah and the neighbouring Sultanate of Oman. Just over 25% of the seaweed flora of Fujairah are not recorded from the more inhospitable coasts of those emirates bordering the southern basin of the Arabian Gulf. Just over 95% are known from southern Oman, including the neighbouring species-poor part of the coast of the sultanate. The low diversity of the seaweed flora of Fujairah and adjacent coast of Oman contrasts markedly with the exceptionally rich (over 350 spp.) coastal region lying further south that during the south-western monsoon season is influenced by upwelling of nutrient-rich and cooler water.

Keywords Checklist, Benthic, Macroalgae, Biogeography, Fujairah, Indian Ocean

Marine macroalgae (seaweeds) represent a large, diverse group of marine organisms with around 11,000 species described to date[1]. The uses of seaweeds has expanded very significantly since the turn of the century with the global market for seaweeds having tripled in the last two decades and amounted to about 1 billion US dollars by 2021[2]. Seaweed was traditional consumed or used as a food additive, but is increasingly used in various industrial sectors, including in pharmaceuticals, animal feed, fertilizer, cosmetics, textiles, bio-packaging, and more recently in environmental projects linked to carbon capture through to renewable energy production. Despite the potential importance of seaweeds little is known of the seaweed resources of most countries worldwide with Fujairah no exception.

Fujairah and neighbouring Northern Oman are the only two countries bordering the Arabian Sea for which there was not a single seaweed mention in Silva et al.'s 'Catalogue of the Benthic Marine Algae of the Indian Ocean[3]. It was published in 1966 which happened to be the first-year seaweeds were studied at some wave-exposed localities along the coast of Fujairah. There was a follow up visit in March 1997, and both were undertaken in order to compare the seaweed floras of Fujairah and Abu Dhabi, the latter an emirate bordering the southern basin of the Arabian Gulf. These visits were undertaken by members of a team of biologists from London's Natural History Museum who were carrying out a 5-year long (1996–2001) biological survey of the marine life of Abu Dhabi that was sponsored by the Abu Dhabi Company for Onshore Oil Operations (now ADNOC Onshore).

The findings of these early studies on the seaweeds of Fujairah are briefly discussed in a chapter published in 2005 on the seas and shores of the emirates[4] and also almost 20 years later in 'The Natural History of Fujairah'[5] in which are mentioned three recently discovered seaweeds. Since the surveys in the 1990s the coast of Fujairah has become transformed by the construction of many new harbour systems and marinas. This transformation has resulted not only in the loss of natural habitats but has provided new opportunities by providing seaweeds with new surfaces for colonization, including various floating structures along with breakwaters and sea walls.

The present contribution is the first checklist of the benthic marine algae (seaweeds) of Fujairah and includes photographs of many species not previously recorded from this emirate. Knowledge of the seaweeds of Fujairah

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still remains far too incomplete for a detailed comparison to be made between its seaweed flora with that of other regions.

Materials and methods

The present study lists the seaweeds collected on floating structures off Dibba and Dadna, as well as on wave-beaten shores around Snoopy Island, the neighbouring mainland shore, Ras Dibba, and two islands known as Dibba Rock and Martini Rock (Table 1, Fig. 1); the latter lying just south of Khor Fakkan which is an exclave of the emirate of Sharjah.

Most of the new records were collected in 2022 on relatively wave-sheltered rocky shores and on the steeply sloping sides of floating structures where growing less than a metre or so below the sea surface, except for *Champia compressa* that was photographed at a depth of about 8 m. No consideration is given to the seaweeds cast up on beaches due to uncertainty attaching to the source of the material. It is possible some of the drift material might be transported from the wave-sheltered lagoons and channels of the Khor Kalba Conservation.

Reserve in Sharjah (see Fig. 1). Several larger seaweeds (e.g., *Caulerpa sertularioides, Ulva flexuosa, Gracilaria* spp., *Sargassum* sp.) were collected from this reserve in visits made in March 1996 and some photographs taken in 2022. All the seaweeds listed are briefly described and the new records are illustrated. All previous records of seaweeds from Fujairah by John & George[4] and John[5].

Shallow water seaweeds were sometimes collected by snorkel diving although some deeper ones were sampled by SCUBA diving. All seaweeds were placed in plastic bags and stored in a cold box before processing**.** Information accompanying each specimen included date of collection, location, co-ordinates, and the collector's name. Some minute forms were discovered when dense turf-like growths were teased out under a low powered stereomicroscope. Several seaweeds have previously been recorded from Fujairah[5], including *Herposiphonia secunda, Taenioma nanum, Chaetomorpha ligustica* and *Rhizoclonium riparium*.

The most useful guide for identifying Fujairah seaweed has proved to be one on the seaweeds and seagrasses of Tanzania[6]. More limited was a review of the marine organisms of the Eastern African coast since focusing only on more common seaweeds[7] and includes crustose corallines[8] and blue-green algae[9]. There is a guide to the common seaweeds of neighboring Oman[10] where more than 300 species have been recorded[11] but few are known from Fujairah. Most of the Omani seaweeds are restricted to its Arabian Sea coast which is a well hot spot for seaweed diversity relating to seasonal upwelling of colder and nutrient-rich water.

The seaweed samples were preserved in 4% formalin and larger specimens mounted on herbarium sheets. The liquid preserved and dry mounted specimens collected during the present survey and an earlier one sponsored by ADCO are housed in the Cryptogamic Herbarium at the Natural History Museum (BM), London. Accompanying the specimens and liguid-preserved mixed collections is detailed locality and habitat information as well as on collector and date of collection.

Results

The majority of the newly recorded seaweeds grew on relatively wave-sheltered shores or along with fouling animals on the steeply sloping sides of floating structures, including pontoons and wave protected floats associated with metal cages. Those attached to these floating surfaces typically grew to less than a meter below the sea surface, except *Champa compressa* that was photographed at a depth of about 8 m.

Check list

The following is a list of taxa of the seaweeds belonging to the three major groups, the brown algae (Class Phaeophyceae in the Ochrophyta), the red algae (Rhodophyta), and the green algae (Chlorophyta). The online resource AlgaeBase[12] was used to check the current taxonomic status, nomenclature of the entries and classification.

All new records are indicated by as asterisk (*) and all others were previously recorded from Fujairah by John & George[4] and John[5].

Also included are identification keys and all the seaweed species known from Fujairah are listed in a supplementary information file table.

PHYLUM CHLOROPHYTA

Locality	Co-ordinates	Habitat
Dibba Rock	N 25 36.11 E 56 21.12	All samples from rocky and coral-dominated surfaces at about 10 m below CD and in the Dibba region red seaweeds were photographed on a metal floating structure
Ras Dibba	N 25 33.35 E 56 35.11	Intertidal cliff areas and gently sloping rocky platforms
Jazirat al Gubbah (Snoopy Island)	N 25 29.34 E 56 21.50	Intertidal rocky shores around island and similar habitats on nearby mainland shores
Dadna farm	N 25 31.21 N 25 29.0 N 25 31.21 56 22.16 E 56 21.41 E 56 22.16	Floating pontoons about 500 m from shore and seaweeds collected down to depths of 1–3 m below surface. Seaweeds also collected floating in calmer water between the pontoons
Martini Rock	N 25 20.06 E 56 22.52	All crustose coralline algae collected on rock surfaces about 10 m below CD

Table 1. Details of the seaweed sampling sites along the coast of Fujairah.

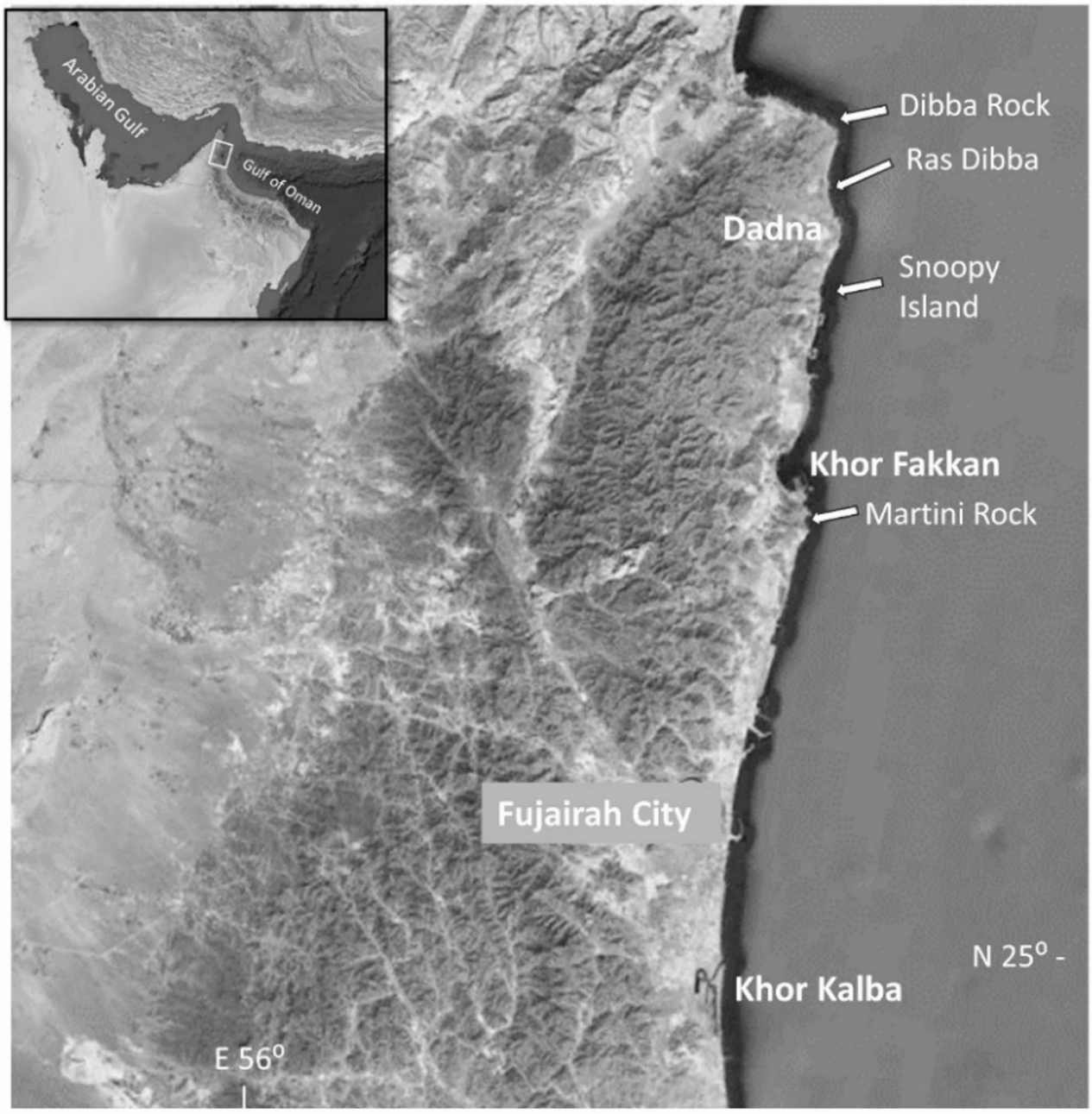

Fig. 1. Map of Fujairah showing localities mentioned in the text and Khor Kalba in Sharjah. Insert showing position of Fujairah in relation to the Arabian Gulf and Gulf of Oman. Map created from Google Earth, based on Landsat/Copernicus imagery (2023). Reused per Google Terms of Service. Modified by authors.

Key to species

1 Filamentous, uniseriate, unbranched or many times divided ……..…… 2
1 Pseudoparenchymatous or truly parenchymatous ……..…… 4
2 Filaments unbranched, with or without short rhizoidal branches ……..…… 3
2 Filaments irregularly divided and entangled, forming green spongy cushions or moss-like mats ……..... *Cladophoropsis fasciculata*
3 Cells generally cylindrical, <25 µm in diam; filaments sometimes having short rhizoidal branches …… *Rhizoclonium riparium*
3 Cells cylindrical to barrel-shaped, 40–100 µm in diam; filaments always undivided …… *Chaetomorpha ligustica*

4 Consisting of creeping branches, bearing erect, flattened, simple or forked, branches, bearing two opposite rows of oval to oblong, curved pinnules, each with an acute tip ..... *Caulerpa taxifolia*
4 Otherwise 5
5 Forming hair-like tufts or mats of much divided and entangled branches ..... *Ulva clathrata*
5 Forming rosette-like tufts of often orbicular, membrane-like fronds ..... *Ulva lacinulata*

Order Bryopsidales
Family Caulerpaceae

Caulerpa taxifolia (Vahl) C.Agardh (Figs. 2A, 3A,B)

Consisting of slender, creeping, cylindrical branches attached at intervals by descending rhizoids, bearing flattened linear to lance-shaped erect branches, simple or a few times forked, up to about 15 cm high, bearing pinnules arranged in two rows on opposite sides of the axes, each pinnule oval to oblong and narrower at base, often slightly curved and having acute tips. Occurs on the vertical sides of pontoons and other floating structures as well as on sand.

Morphologically the pinnules resemble those of *Caulerpa mexicana* but differs in not overlapping in their middle parts. These species are morphologically very variable and only *C. mexicana* is reported from neighbouring Oman[11] although both are known from the Iranian side of the Arabian Gulf[13]. Still to be reported from Fujairah is *Caulerpa sertularioides,* a species common within the sheltered channels of Khor Kalba Conservation Reserve in Sharjah[5].

Order Cladophorales
Family Boodleaceae
Cladophoropsis fasciculata (Kjellman) Wille

Forming compact, spongy, light to medium green, cushions or moss-like mats, often several cm across, composed of tightly interwoven filaments, entangled, irregularly divided below and unilateral above, cross wall formation often delayed, occasionally filaments anastomosing or attached to one another by tentacular cells as well as multicellular rhizoids.

Family Cladophoraceae
Chaetomorpha ligustica (Kützing) Kützing

Consisting of uniseriate filaments, often stiff, forming green, woolly, entangled tufts of strongly curled filaments, basally attached; cells cylindrical, 40–100 µm in diam., (1–)2–3 times longer than broad, thin-walled.

Rhizoclonium riparium (Roth) Harvey

Minute, light green, unbranched filaments, usually entangled with turf or mat-forming seaweeds; cells cylindrical, up to 25 µm in diam., 1.5–3(–5) times as long as broad, thin-walled (2–3 µm thick).

Order Ulvales
Family Ulvaceae
Ulva clathrata (Roth) C.Agardh

Forming hair-like tufts or mats, 2–15 cm in length, consisting of thread-like branches, up to 1 mm in diam., much divided and entangled, with successive branches becoming shorter and tapering to an often spine-like tip, with many lateral spines present.

Ulva lacinulata (Kützing) Wittrock (Fig. 2C)

Forming often small, light green rosettes, consisting of stiff, orbicular, flattened, membrane-like fronds, 2–5 cm long, variously dissected and lobed, 2 cells thick, parenchymatous, with margins commonly bearing minute, multicellular teeth.

Formerly referred to as *Ulva rigida* C.Agardh but Hughey et al.[14] believe this species to be confined to the Atlantic Ocean and records from elsewhere should most probably be attributed to *U. lacinulata.* Molecular analysis is needed to confirm the identity of this species.

PHYLUM OCHROPHYTA

Key to species

1 Composed of branched microscopic filaments consisting of a single row of cells 2
1 Composed of a more complex structure 3
2 Forming tufts, up to 15 mm high, with filaments 30–60 µm in diam.; plu.rilocular sporangia elongate and cylindrical to ellipsoidal ..... *Feldmannia mitchelliae*

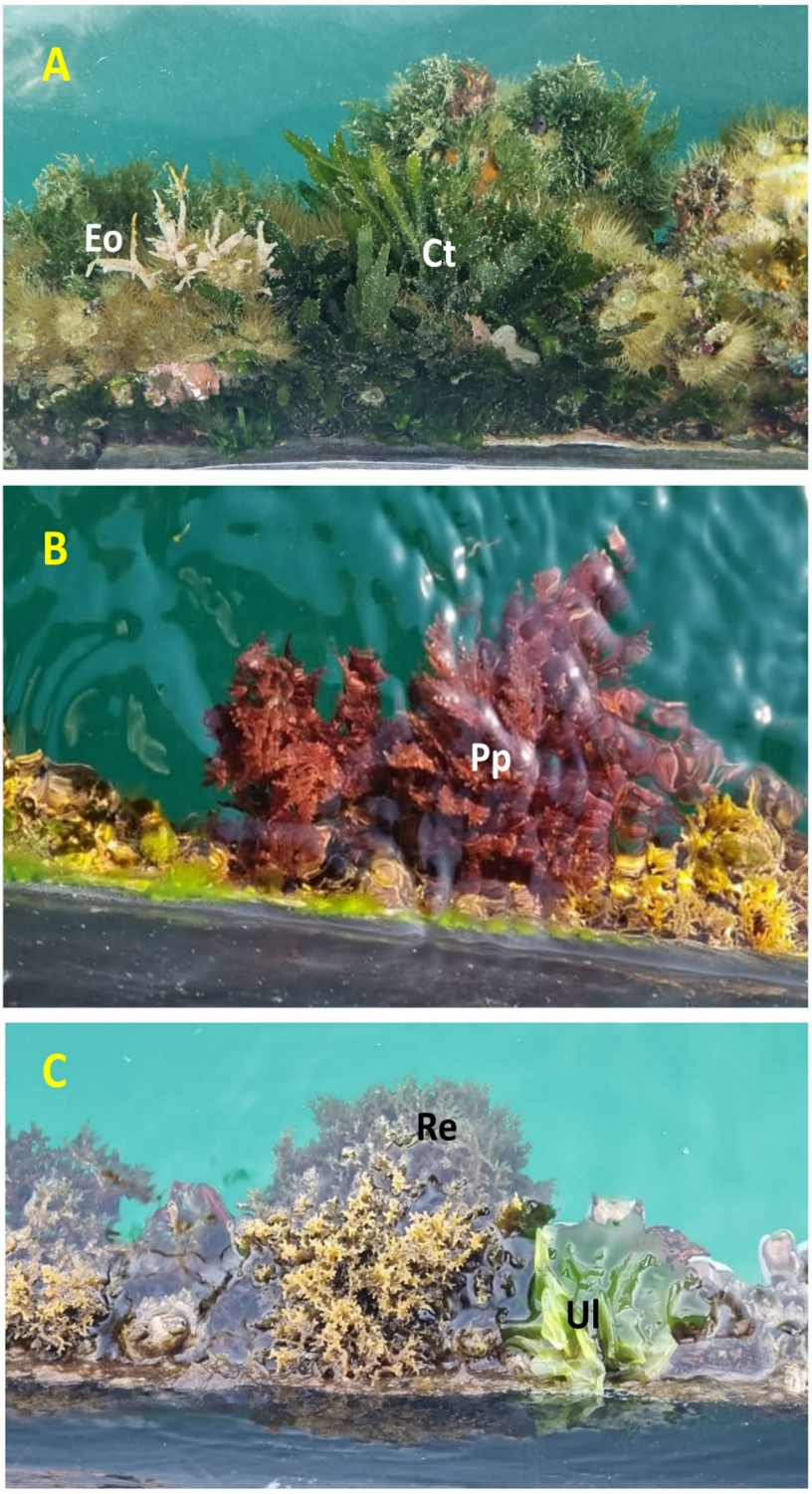

Fig. 2. Assemblages of seaweeds and fouling animals growing on the side of a floating pontoon at Dadna. (**A**) *Eucheuma odontophorum* (Eo), *Caulerpa taxifolia* (Ct); (**B**) *Palisada perforatae* (pp), (**C**) *Rosenvingea endiviifolia* (Re), *Ulva lacinulata* (Ul). Photos Per O.Olsson.

2 Forming mats, 2–30 cm long, with filaments 10–30 µm in diam.; plurilocular sporangia corn cob-shaped ..... *Feldmannia irregularis*
3 Filaments forming stiff, upright epiphytic tufts, composed of multicellular segments; propagules having a stalk bearing slender, cylindrical to tapering arms ..... *Sphacelaria rigidula*
3 Otherwise 4

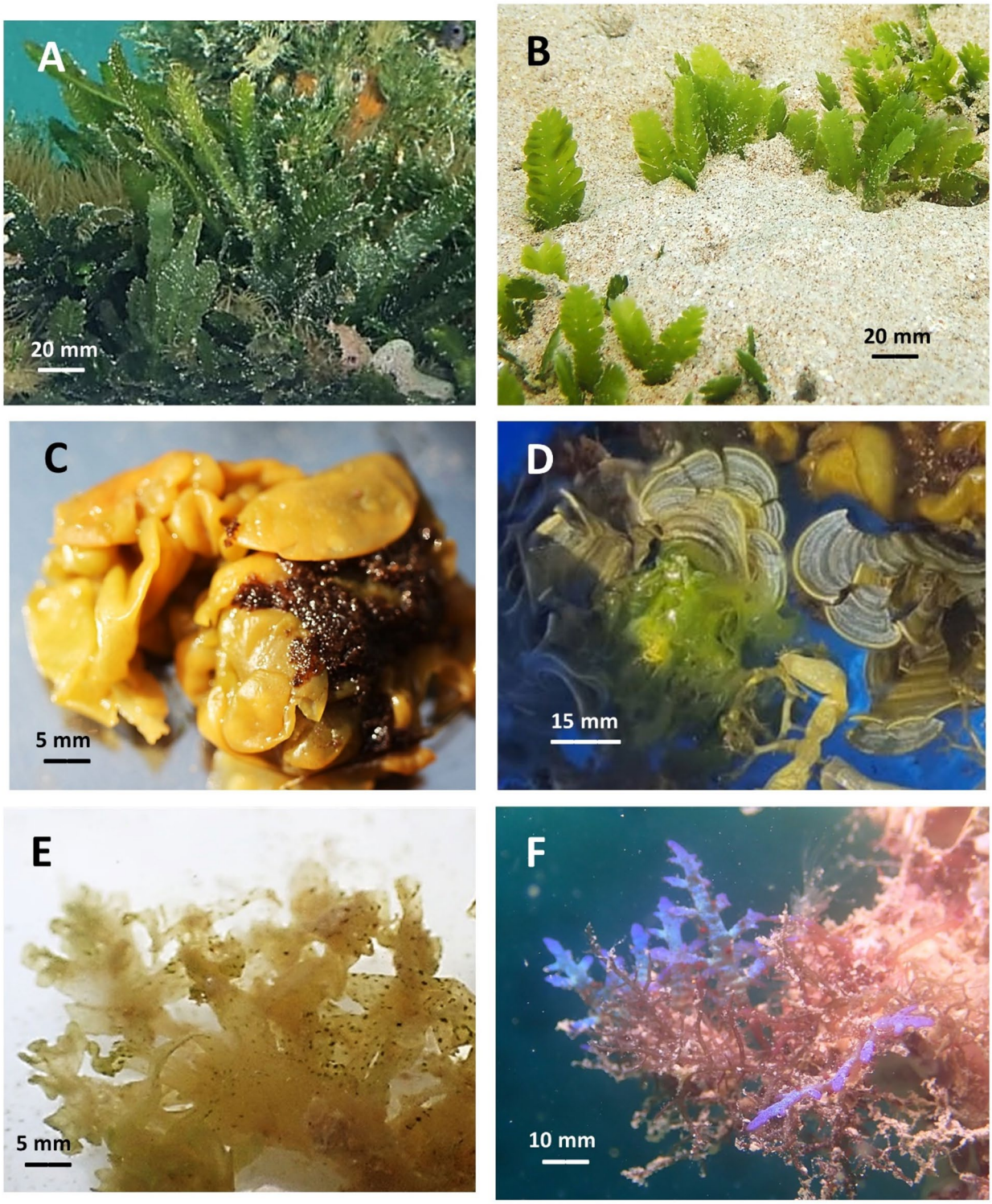

Fig. 3. *Caulerpa taxifolia.* (**A**) Clumps growing on side of a floating structure, (**B**) Creeping through sand with the erect branches arising from a stoloniferous base; (**C**) *Colpomenia sinuosa.* Surface partially covered with a dark coloured mat of the rhodophyte *Tolypiocladia glomerulata*; (**D**) *Padina gymnospora;* (**E**) *Rosenvingea endiviifolia;* (**F**) *Champia compressa.*

4 Cushions globose, irregularly lobed, convoluted and hollow……*Colpomenia sinuosa*
4 Otherwise …… 5
5 Fronds strongly compressed, composed of dichotomously divided branches or fan-shaped lobes …… 6

5 Otherwise 8
6 Branches dichotomously divided at wide angles, entangled, about 3 mm wide below and narrowing above ..... *Dictyota implexa*
6 Fan-shaped fronds bearing concentric rows of hairs and having an inrolled margin 7
7 Fronds four cells thick throughout ..... *Padina antillarum*
7 Fronds mostly 3 cells thick ..... *Padina gymnospora*
8 Composed of hollow, fused, cylindrical branches, 2–3 mm in diam., irregularly divided, with narrower branchlets ..... *Rosenvingea endiviifolia*
8 Composed of creeping branches giving rise to erect ones bearing roughly triangular or irregularly rounded lateral branches, with margins smooth or coarsely toothed ..... *Turbinaria conoides*

Class Phaeophyceae
Order Ectocarpales
Family Acinetosporaceae
Feldmannia irregularis (Kützing) G.Hamel

Forming medium to dark brown tufts, up to 15 mm high, usually epiphytic, consisting of very narrow filaments (10–30 µm in diam) of cells up to 6 times longer than broad above the shorter celled upper meristematic regions. Characteristic plurilocular sporangia, sessile, single or in a series, somewhat corn cob-shaped.

Feldmannia mitchelliae (Harvey) H.S.Kim

Forming soft light brown to yellowish-brown, low mats, from about 5–30 cm in length, with filaments alternately divided filaments, often lateral above, narrow (30–60 µm in diam.), tapering to a hair-like tip above where cells 4–6 times longer than broad. Distinctive plurilocular sporangia. sessile or rarely stalked, usually in series, typically elongate and cylindrical to ellipsoidal, with base and apex rounded,

Family Scytosiphonaceae
****Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier*** (Fig. 3C)

Initially forming sack-like crinkled balls, later becoming irregularly lobed, convoluted and brain-like, occasionally somewhat compressed, pale to medium brown, 3–20(–30) cm across, attached by lower surface. Growing with mats or turfs of seaweeds along the vertical sides of floating structures at Dadna farm.

****Rosenvingea endiviifolia (Martius) M.J.Wynne*** (Figs. 2C, 3E)

Forning yellow–brown, entangled masses of often fused branches, 2–3 mm in diam., with these branches abruptly narrowing towards the last order of branchlets. Associated with other low growing mat or turf-forming seaweeds on the shallow sides of floating structures.

Order Dictyotales
Family Dictyophyceae
Dictyota implexa (Desfontaines) J.V.Lamouroux

Forming erect, medium brown, with branches frequently entangled, 3–8 cm high, dichotomously divided at wide angles (90°–120°), about 3 mm wide below and narrowing abruptly above to 0.1–0.2 mm, with apices blunt or rounded.

Padina antillarum (Kützing) Piccone

Consisting of deeply divided wedge- to fan-shaped fronds, usually 2–3 cm wide and to about 10 cm long, four cell thick althougj up to 6 in lower parts, distinctly corrugated and having concentric hair zones on upper and lower surfaces, with frond margin inrolled. Organs of asexual reproduction, known as sporangia, develop as dark lines close to and on each side of a hair zone.

****Padina gymnospora (Kützing) Sonder*** (Fig. 3D)

The distinctive fan-shaped blades bear concentric rows of hairs and dark coloured reproductive organs. Superficially resembles *Padina antillarum* but differs principally in having blades three rather than four cells thick.

Order Sphacelariales
Family Sphacelariaceae
Sphacelaria rigidula Kützing

Forming medium to dark brown, tufts or compact cushions, to 5 cm high, consisting of erect filaments of segments 30–45 µm in diam. and 1–2 times longer than broad, sparingly and irregularly divided. Characteristic propagules, consisting of slender, cylindrical to slightly tapering arms borne on a stalk.

Order Fucales

Family Sargassaceae
Turbinaria conoides (J.Agardh) Kützing

Forming low, medium brown cushions, consisting of creeping basal branches bearing compressed branches, slender, simple or divided, roughly surfaced stalks and each with a funnel-shaped lateral branch, roughly triangular or irregularly rounded, margins smooth or coarsely toothed, 3.5–9 mm across, sometimes deeply cut on one side.

RHODOPHYTA

Key to species

1 Calcareous and hard, consisting of a smooth crust or wrinkly, warty or bearing projections including coral-like, unsegmented branches 2
1 Uncalcified or having calcified branches consisting of segments with flexible joints 4
2 Crusts thin (< 5 mm thick) and smooth; cells without secondary pit connections and trichocytes (hairs); sporangial conceptacles having distinctive spiky filaments around the pore canal and protrude through it ..... *Spongites tunicatus*
2 Crust usually more 5 mm thick, often surface wrinkled, warty, through to having various projections including branches; secondary pit connections and trichocytes present 3
3 Crusts minutely wrinkled through to having low cone-like projections to cylindrical to compressed, repeatedly subdichotomously or regularly divided branches, with apices rounded or truncate ..... *Neogoniolithon brassica-florida*
3 Crust bearing cylindrical to blunt or tapering branches, or forming brain-like clumps of interweaving, flattened, fan-shaped branches ..... *Lithophyllum kotschyanum*
4 Calcareous branches, composed of calcified segments connected by uncalcified, flexible joints 5
4 Generally uncalcified and of another form 6
5 Segments cylindrical, 1–2 mm in diam.; conceptacles hemispherical, lateral and scattered over segments; ..... *Amphiroa rigida*
5 Segments cylindrical, ca 0.1 mm in diam.; conceptacles axial and terminal on segments ..... *Jania pumila*
6 Minute epiphyte, uniseriate, unbranched filaments, about 20 µm in diam. ..... *Erythrotrichia carnea*
6 Otherwise 7
7 Composed of branches regularly constricted into long or shorter than broad segments, with a transverse septum at each constriction 8
7 Otherwise 9
8 Branches cylindrical, 0.5–1.5 mm in diam., with segments as long as broad near base and shorter above ..... *Champia parvula*
8 Branches flattened, 2–4 mm across, with segments < 0.5 times longer than broad throughout ..... *Champia compressa*
9 Composed of filaments having a single axial row of cells and completely or incompletely covered by cortical cells 10
9 Otherwise 14
10 Axial cells completely or partially corticated by a single layer of cells, usually cells much shorter than the axial cells 11
10 Axial cells completely corticate and cortical cells large and of similar length to the axial cells (pericentral cells) 12
11 Outer cells completely cover the axial filament; cortical cells aligned in vertical rows; spines present in whorls at nodes ..... *Centroceras gasparrinii*
11 Outer covering of cells restricted to nodes; nodal cells distinctly transversely elongate, with a clear separation between cells; spines absent ..... *Gayliella flaccida*
12 Branches flattened, at least in ultimate divisions, with lateral pericentral cells flanked by two cells, with branches terminating in two or three hair-like filaments ..... *Taenioma nanum*
12 Branches cylindrical and otherwise 13
13 Branches < 120 µm in diam., consisting of creeping filaments with incurved apices, bearing simple erect branches lying between three, short, divided branches that frequently terminate in hairs ..... *Herposiphonia secunda*
13 Branches > 120 µm in diam., consisting of many rows of pericentral cells and bearing short, spirally disposed lateral branchlets, each tapering to a pointed apical cell ..... *Tolypiocladia glomerulata*
14 Forming low mats, < 2 cm high, consisting of markedly compressed erect branches (at least in upper parts) arising from a creeping system of branches, with side branches constricted at base and apically rounded ..... *Gelidium pusillum*
14 Generally greater than 2 cm high, consisting of mostly cylindrical or just occasionally slightly compressed branches 15
15 Forming decumbent clumps, sometimes cushion-like or as low mats 16
15 Forming often large bushy clumps 19

16 Consisting of low mats of irregularly or oppositely divided branches arising from a system of creeping branches, with branches < 300 µm in diam ..... *Wurdemannia miniata*
16 Consisting of often entangled, sometimes decumbent branches, > 300 µm in diam 17
17 Forming dense, decumbent clumps of cylindrical to slightly compressed branches, with branches 2–5 mm across and regularly dichotomously divided ..... *Gracilaria canaliculata*
17 Otherwise with branches about 1 mm in diam 18
18 Forming dense clumps of intertwined branches, irregularly divided, covered by spines and having spine-like apices, with numerous secondary discoid holdfasts; branches solid ..... *Caulacanthus ustulatus*
18 Forming decumbent clumps of creeping and erect branches, often side branches in lateral series, sometimes erect branches arching and apically attached; branches mostly filled with mucilage ..... *Lomentaria strumosa*
19 Branches cylindrical and bearing of radially or unilaterally arranged branchlets, with apices characteristically blunt and having a pit-like apical depression containing a tuft of hairs ..... *Palisada perforata*
19 Otherwise 20
20 Branches cylindrical and branchlets often spine-like with acute apices 21
20 Otherwise 22
21 Branches densely covered by short, spine-like branchlets; without awl-shaped propagules ..... *H. hamulosa*
21 Branches without a dense covering of branchlets, loosely branched; characteristic star-shaped propagules sometimes present ..... *Hypnea cornuta*
22 Consisting of flattened and irregularly constricted fronds, up to 10 cm in length, covered by tooth-like projections ..... *Eucheuma odontophorum*
22 Consisting of cylindrical branches divided into lightly calcified segments. di- or trichotomously divided and blunt-tipped ..... *Tricleocarpa fragilis*

Class Floridiophyceae
Order Gigartinales
Family Caulacanthaceae
Caulacanthus ustulatus (Mertens ex Turner) Kützing (Fig. 4)

Forming dense, somewhat mossy, reddish-brown to blackish clumps of intertwined branches, 2–5 cm high and several cm in diam., consisting of cylindrical branches, about 1 mm in diam., frequently irregularly branched, beset covered by spines and having spine-like apices, attached by numerous secondary discoid holdfasts. Cystocarps present. Growing in the shallow subtidal on rocks and sides of pontoons and other floating structures. Also associated with other low growing mat or turf-forming seaweeds in the lower littoral zone.

Family Cystocloniaceae
Hypnea cornuta (Kützing) J.Agardh (Figs. 3F, 5E)

Forming bushy clumps, supple, reddish to straw-coloured, 10–20 cm high, consisting of several cylindrical branches, about 2 mm in diam., sparingly alternately divided,
bearing opposite or unilaterally arranged, upwardly curved branchlets, usually simple and spine-like; propagules frequent, anvil- or star-shaped but so far not observed in the specimens examined. Often clumps associated with other seaweeds growing along the vertical side of floating structures and sometimes associated with *Champia compressa* (Fig. 3F).

Hypnea hamulosa (Esper) Lamouroux (Fig. 5D)

Forming dense tufts, varying from dark red to sometimes greenish tufts, about 10 cm high, branching at short intervals and branches covered by short, spine-like branchlets with some side having haptera-like growths. Asexual organs of reproduction (tetrasporangia) densely grouped at base of spiny branchlets.

Family Solieriaceae
Eucheuma odontophorum Børgesen (Fig. 4C,G)

Forming clumps consisting of flattened and regularly constricted branches, about 10 cm long, with tooth-like projections on branchlets more commonly distributed along the margins. associated with other seaweeds growing on the sides of floating structures.
An interesting discovery since not previous reported from the Northern Arabian Sea although known from several East African countries, South Africa and the islands of Mauritius and Zanzibar[12]. The genus is a commercially important tropical seaweeds since a valuable source of phycocolloid.

Wurdemannia miniata (Draparnaud) Feldmann & Hamel

Forming dark brownish-red, wiry clumps or mats, to 3 cm in high, consisting of erect and often entangled cylindrical branches, up to 300 µm in diam., irregularly to unilaterally divided, terminating in a row of apical cells, arising from a creeping system of branches.

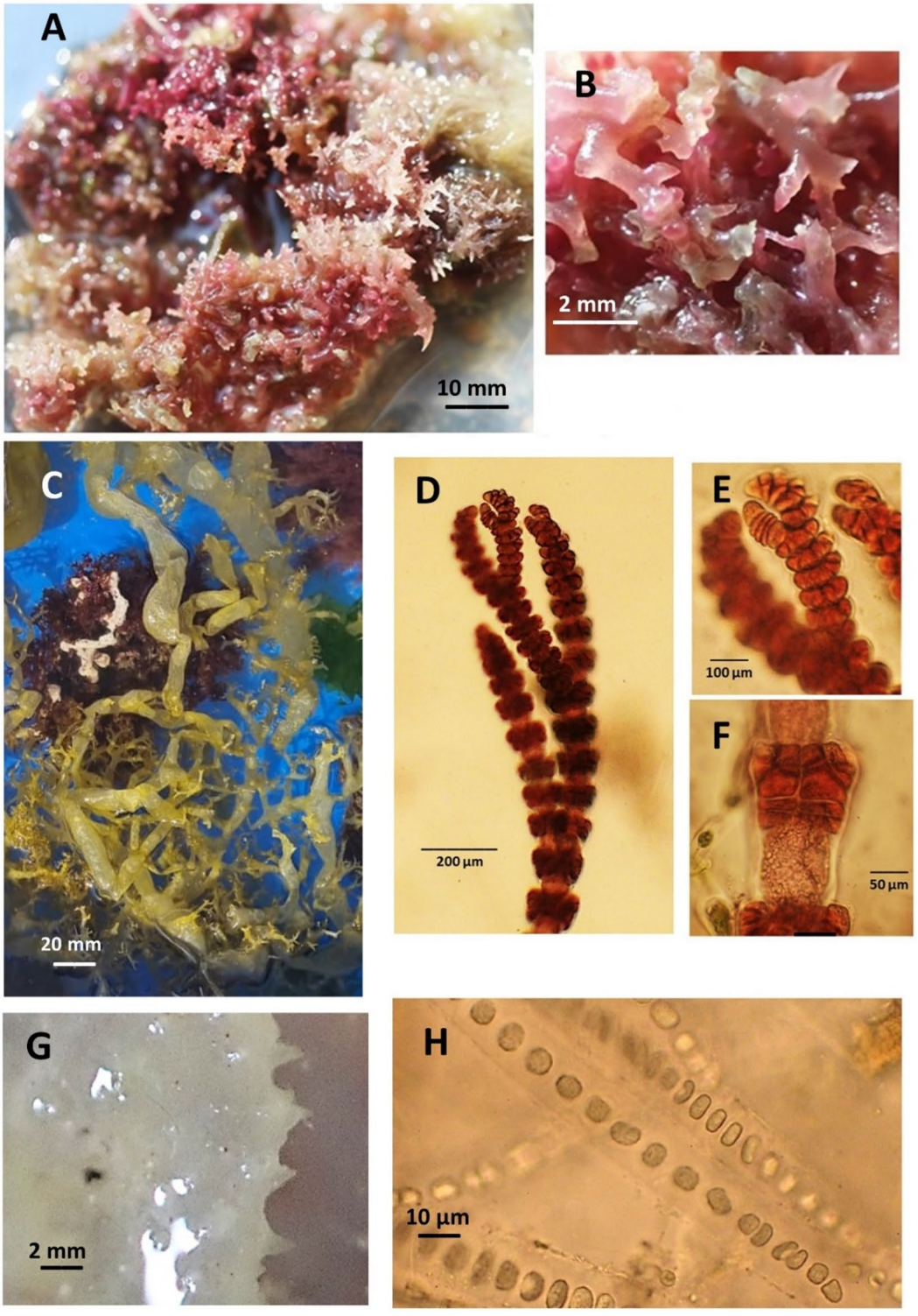

Fig. 4. *Caulacanthus ustulatus.* (**A**) Dense intertwined clump of cylindrical, spiny branches, (**B**) Close view with swollen spiny branches bearing cystocarps; (**C**,**G**) *Eucheuma odontophorum*. (**C**) Irregularly contorted branches, bearing tooth-like side branchlets, (**G**) Close view of teeth along margin of a branchlet; (**D**–**F**) *Gayliella flaccida*. Branches often having a claw-like apical portion and corticated nodes often distinctly transversely elongated cells with cells clearly separated; (**H**) *Erythrotrichia carnea.* Very minute unbranched filaments, with cells separated and having a thick sheath. Photos D.M.John.

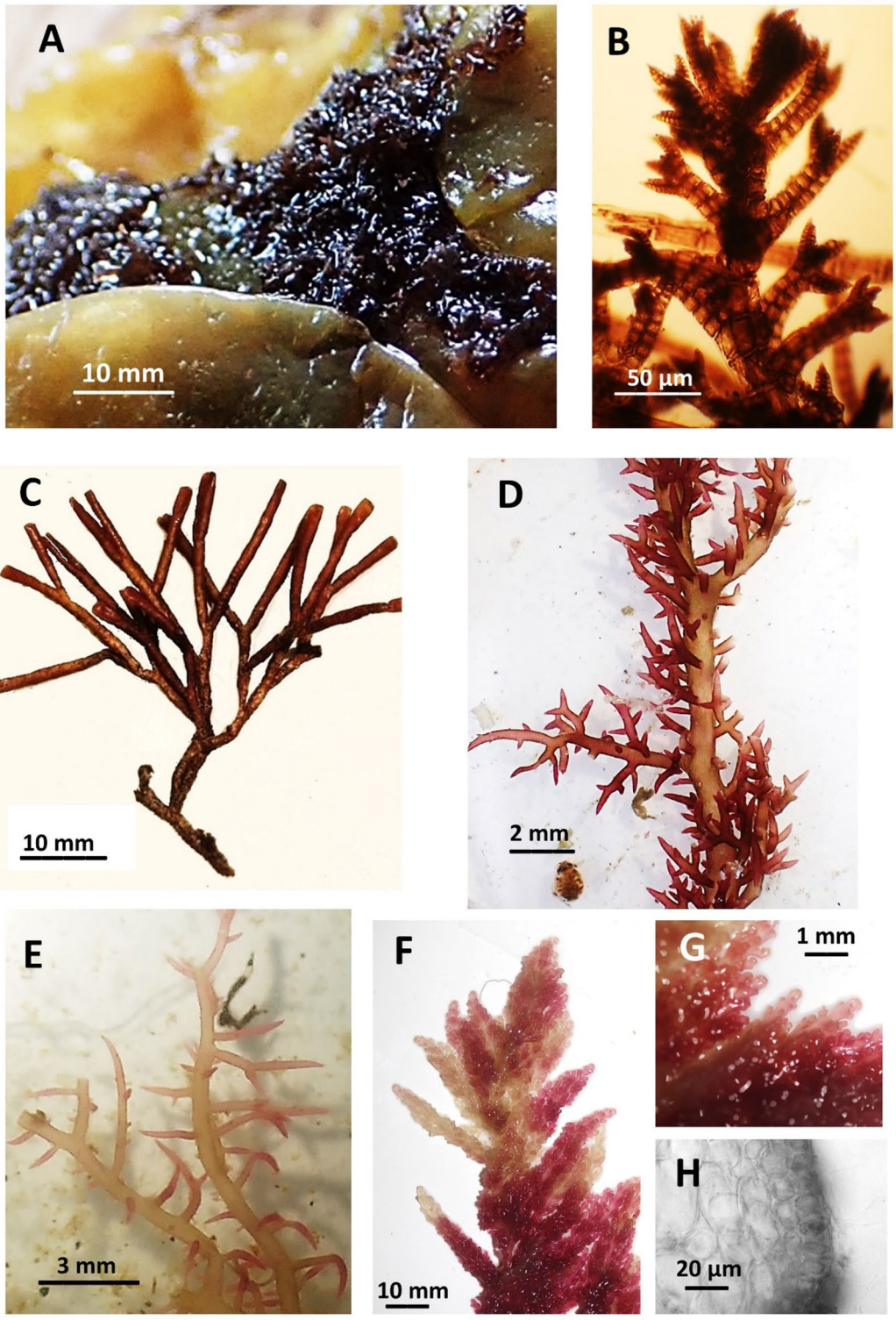

Fig. 5. *Tolypiocladia glomerulata.* (**A**) Dense, reddish-brown clumps growing on *Colpomenia sinuosa*, (**B**) Close view of segmented branches bearing short lateral branchlets, with each abruptly tapering; (**C**) *Tricleocarpa fragilis;* (**D**) *Hypnea hamulosa.* Dense clumps of branches covered by short spine-like branchlets*;* (**E**) *Hypnea cornuta.* Branches sparingly divided with some often upwardly curved; (**F**–**H**) *Palisada perforata.* (**F**) Showing somewhat pyramidal outline of the branches; (**G**) Close view of dense and often club-shaped branchlets; (**H**) Section of branch showing almost quadrate epidermal cells and with cortical cells increasing in size towards centre. Photos D.M.John.

Order Ceramiales
Family Ceramiaceae
Centroceras gasparrinii (Meneghini) Kützing

Forming rose-red to purplish mats or tufts, 3–6 cm high, consisting of creeping and erect cylindrical filaments, up to 0.2 mm in diam., completely corticated, characteristically bearing whorls of 3-celled spines at each node, dichotomously or trichotomously divided, terminate in claw-like apices.

****Gayliella flaccida (Harvey ex Kützing) T.O.Chou & L.J.McIvor*** (Fig. 4D–F)

Forming pinkish to straw-coloured tufts, 5–20 mm high, consisting of branches having corticated nodes arising from similarly structured creeping ones attached by rhizoids; nodes of lower branches having 6 of so-called pericentral cells, each cell producing two base to apically directed cells and one apical to basally directed ones, each node has distinctly transversely elongate cells throughout and a clear separation between the cells. Commonly grows epiphytically on larger seaweeds.

****Herposiphonia secunda (Agardh) Ambronn***

Consisting of minute segmented filaments, reddish-purple, less than 10 mm long, consisting of creeping filaments, 90–120 µm in diam., segments 1.5–2 times longer than broad, with apices incurved, bearing simple erect branches, up to 2 mm long, often three erect branches lying between one short branch of indeterminate growth, terminate in hairs, attached by unicellular rhizoids; branch segments consist of nine pericentral cells surrounding the axial cell.

Order Rhodymeniales
Family Champiaceae
****Champia compressa Harvey*** (Fig. 3F)

Forming distinctive bluish or greenish iridescent clumps of flattened, more or less procumbent branches, sometimes downwardly curved and anastomosing; branches up to 4 mm across, segmented with each segment less than 0.5 times longer than broad, separated by a septum, hollow and mucilage-filled, lateral branches arising alternately and subopposite.

Clumps growing on a variety of artificial surfaces such as rope and on metal frames in the sea at Dibba. Sometime larger in stature (up to 6 cm high) and wider than the type variety and therefore showing some resemblance to the more robust variety *scindica* Børgesen.

Champia parvula (Agardh) Harvey

Forming pinkish-red to straw- coloured clumps, 2–10 cm high, consisting of cylindrical branches, 0.5–1.5 mm in diam., opposite or whorled, segmented, with each segment barrel-shaped, separated by diaphragms, about as long as broad near base and shorter towards apices. Branches hollow and mucilage filled.

Family Lomentariaceae
Lomentaria strumosa M.J.Wynne

Forming reddish, often tangled and somewhat decumbent clumps, to about 4 cm high, consisting of creeping and erect branches, cylindrical, to 1 mm in diam., irregularly or oppositely divided, often in a lateral series, with erect branches sometimes arching and attached apically. Asexual organs of reproduction (tetrasporangia) confined to pits in swollen, with inversely conical terminal branches, contracted towards tip. Branches mostly mucilage-filled above and walls several cells thick.

Discovered growing along with low turf-forming seaweeds on a lower rocky mainland shore, near Snoopy Island. First described from wave-exposed shores in the neighbouring Sultanate of Oman[15].

Order Gelidiales
Family Gelidiellaceae
Gelidium pusillum (Stackhouse) Le Jolis

Forming brownish to reddish-purple, felty and creeping mats, less than 2 cm high, with branches creeping and erect, cylindrical near base and flattened above, to 1.5 mm wide, irregularly to bilaterally divided, side branches typically constricted at base, apices rounded and terminating in a single cell.

Order Gracilariales
Family Ceramiaceae
Centroceras gasparrinii (Meneghini) Kützing

Forming rose-red to purplish mats or tufts, 3–6 cm high, consisting of creeping and erect cylindrical filaments, up to 0.2 mm in diam., completely corticated, characteristically bearing whorls of 3-celled spines at each node, dichotomously or trichotomously divided, terminate in claw-like apices.

Family Delesseriaceae
****Taenioma nanum (Kützing) Papenfuss***

Minute, greenish red, to about 1 mm in high, consisting of erect branches arising at intervals of 2–9 segments from creeping branches, 46–80 µm in diameter, bearing flattened branchlets, usually 18–23 segments long, each terminates in two long hairs. Collected in March 1996 growing with a mat of *Centroceras gasparrinii* on a gently seaward sloping rocky platform lying about 2 km south of Ras Dibba.

Family Gracilariaceae
Gracilaria canaliculata Sonder

Forming dense, commonly decumbent clumps, up to 10 cm across, cartilaginous to supple, deep red especially if shaded, consisting of cylindrical to slightly compressed branches, 2–5 mm across, regularly subdichotomously divided several times, often branches downwardly bent and attached by a disc or bundles of rhizoids, terminating in broadly rounded apices..

Family Rhodomelaceae
Palisada perforata (Bory de Saint-Vincent) K.W.Nam (Figs. 2B, 5F–H)

Forming relatively stiff to cartilaginous clumps, commonly olive-brown to reddish-brown, about 5–15 cm high, consisting of prostrate and erect cylindrical branches, 1.5–2 mm in diam., irregularly or alternately divided, densely beset by radially or unilaterally arranged branchlets, knobbly or club-shaped, decreasing in length towards apices so branches having narrowly pyramidal outline.

****Tolypiocladia glomerulata (C.Agardh) Schmitz*** (Figs. 3C, 5A,B)

Forming densely branched, reddish-brown clumps about 5 cm high, consisting of erect, segmented branches bearing spirally disposed, short lateral branchlets, each abruptly tapering to a pointed apical cell, with rhizoids arising at base of the branchlets. So far sampled on the vertical sides of floating structures, often growing over the brown seaweed *Colpomenia sinuosa*.

Order Nemalionales
Family Galaxauraceae
****Tricleocarpa fragilis (Linnaeus) Huisman & R.A.Townsend*** (Fig. 5C)

Forming stiff, bushy, pink to creamy red clumps, 5–10 cm high, consisting of cylindrical, di- or trichotomously divided branches, up to 4 mm in diam., often the branches constricted at joints to form segment from 1 to 10 or more times longer than broad, lightly calcified and uncalcified at flexible joint, with branches having a blunt apex. Known from tidepools but usually most common in the shallow subtidal zone, including on the side of floating structures.

Order Corallinales
Family Corallinaceae
Jania pumila Lamouroux

Forming low growing, often partially prostrate turfs or cushions, usually to 2 cm high, consisting branches formed of calcified, cylindrical segments, about 0.1 mm in diam. and 3–5 times longer than broad, widely subdichotomously divided, terminating in tapering and rounded segments, occasionally two small segments at end of terminal one, frequently attached by rhizoids at branch tips.

Family Lithophyllaceae
Amphiroa rigida Lamouroux

Forms loose clumps, ivory to pinkish-red n colour, to 10 cm across, with branches consisting of calcified segments, cylindrical, 1–2 mm in diam., articulations dark coloured, widely and irregular to unequally forked, usually terminate in bluntly rounded apices. Conceptacles conspicuous, hemispherical, lateral on segments, each having a central pore.

Lithophyllum kotschyanum Unger

Morphologically ranging from often light pinkish-red hemispherical clumps, often about 6 cm high, formed cylindrical branches, simple or divided at wide angles, sometimes fused, and having blunt or tapering apices through to often larger brain-like clumps, about 5–10 cm high, consisting of interweaving, flattened and somewhat fan-shaped branches; cells having secondary pit connections often joining contiguous filaments, with cell fusions and trichocytes rare.

Family Spongitaceae
Neogoniolithon brassica-florida (Harvey) Setchell & Mason

Extremely variable, often light pink, ranging from extensive crust, up to 5 mm thick, with surface minutely wrinkled or warty, through to crusts bearing low projections or dense, repeatedly divided, cylindrical to compressed branches, often 1–3 mm across, with rounded or truncated apices; cell fusions connecting filaments common, pit connections common, trichocytes single and in series or clusters.

Spongites tunicatus D.L.Penrose

Forming thin, smooth or warty crusts, up to 0.3 mm thick, often covered with slightly raised conceptacles; cell fusions common, no secondary pit connections or trichocytes (hairs) present. Sporangial conceptacle having single-spored, characterised by having spiky filaments developed from canal and protrude through the pore. .

Class Compsopogonophyceae
Order Erythropeltales
Family Erythrotrichiaceae
Erythrotrichia carnea (Dillwyn) J.Agardh (Fig. 4H)

Simple, minute (< 100 µm high), uniseriate filaments, usually epiphytic on larger seaweeds; cells about 20 µm in diam., quadrate or slightly longer than broad and with a thick sheath.

Discussion

The seaweed flora of Fujairah appears to be very depauperate (< 40 spp) compared to that of the neighbouring Sultanate of Oman where over 400 species have been recorded[11]. The majority of the Omani seaweeds are restricted to the province of Dhofar that borders the Arabian Sea and where seaweed diversity as well as abundance are exceptionally high during the summer monsoon (the 'khareef'). During this period there are constantly blowing strong south-easterly winds that lead to considerable wave action, upwelling of colder water and elevated nutrient levels[16]. The part of the Omani coast bordering the Gulf of Oman resembles in many respects that of Fujairah and here intertidal seaweed diversity is also low and has been attributed to high air temperatures, desiccation and low nutrient levels[17].

About 68% of the seaweeds recorded from Fujairah also occur in those emirates bordering the southern basin of the Arabian Gulf where seasonal fluctuations in sea temperature and salinity, as well as maximum sea temperature, are exceptionally high so making the environment very inhospitable for marine life.

The rhodophyte *Eucheuma odontophorum* and the crustose coralline red algae (CCA) *Spongites tunicatus* and *Neogoniothon brassica-florida* are the few seaweeds reported from Fujairah but have yet to be discovered in southern Oman. Most of the seaweeds reported from Fujairah are widely distributed within the Indian Ocean, with most found along the coast of East Africa[3,6]. It is not possible at present to know whether the low seaweed diversity of Fujairah reflects under collecting or because it is genuinely a diversity 'cold spot'. The publication by Price et al.[18] remains the only detailed analysis of seaweed diversity patterns within the Indian Ocean. The analysis was based on the seaweed records published in Silva et al.[3] but Fujairah was not mentioned since in 1996 its seaweed flora was unknown unlike southern Oman.

Still much remains to be discovered concerning the seaweed flora of Fujairah with still no account yet taken of any seasonal differences. Some seasonality is to be expected but is unlikely to be anything like as dramatic as observed within the southern basin of the Arabian Gulf[19] or along the southern coast of Oman[20] and of Yemen[21]. Scarcely studied in Fujairah are subtidal seaweeds and *Neogoniolithon brassica-florida* and *Lithophyllum kotschyanum* are the only ones mentioned from deeper water by John[5]. These crustose coralline algae (CCA) were collected in the late 1990s when corals were still healthy and thriving. Since the turn of the century there has been an up to 80% loss of corals in Fujairah due to two major events, the so-called super cyclone Gonu in 2007 that was followed by a very harmful algal bloom[22]. The demise of the corals might well have favoured the development of seaweeds, at least until such a time as the corals completely recover.

Still to be identified are some seaweeds lacking reproductive stages or too small and fragmentary to name with any certainty. A molecular systematic study of the Fujairah seaweeds is required as DNA-information may well reveal 'cryptic diversity' since morphologically similar specimens sometimes prove to belong to different taxa. The increasing recognition of cryptic diversity is resulting in much uncertainty about the status of many species[23]. Such molecular studies are only just beginning to be undertaken in the nearby Arabian Gulf and are leading to the discovery of species not previously recorded for the region. One of the few such studies carried out to date in the Arabian Gulf has been on Kuwaiti seaweeds[24] but none of the species analysed are known from Fujairah.

Finally, it is possible that seaweeds growing within the sheltered lagoon system of the Khor Kalba Conservation Reserve might well be carried into the sea and occasionally become caste up on beaches along the coasts of neighbouring Fujairah and Oman. The need to comprehensively investigate the little or unknown seaweed floras of Fujairah, Khor Kalba in Sharjah and neighbouring Northern Oman has never been more urgent at a time when climate change is beginning to have a major impact upon marine ecosystems worldwide.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. Most of the specimens of seaweeds from Fujairah are housed in the herbarium at London's Natural History Museum (BM).and information on specimens can be obtained from the corresponding author.

Received: 21 October 2024; Accepted: 23 June 2025
Published online: 06 August 2025

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Acknowledgements

We wish to thank Dr Ahmed Gharieb for facilitating the sampling of offshore floating structures, Jessica Helliwell (Freestyle Divers of Project REEFrame) for the photographs of *Champia* and *Caulerpa*, the late Dr Yvonne Chamberlain (University of Portsmouth) for identifying the crustose red seaweeds, Prof. Michael Wynne (University Michigan) for confirming the identity of *Lomentaria strumosa*, Fadi Mohammad Akram (Environment and Protected Area Authority, Sharjah, UAE) for photographs of seaweeds from the Khor Kalba Conservation Reserve, and the Natural History Museum, London for provision of research facilities for one of the authors (DMJ).

Author contributions

P.O.O. organised, collected and prepared the samples for the project. DMJ identified the seaweed samples, carried out the analysis, prepared the figures and wrote the manuscript. All authors reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-08714-8.

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