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New data on brittle stars (Echinodermata: Ophiuroidea) from the Persian Gulf and Oman Sea, Iran

Mona Goharimanesh[1,4], Omid Mirshamsi[1,3], Sabine Stöhr[2], Fereshteh Ghassemzadeh[1,3]*, Dominique Adriaens[4]

[1] *Ferdowsi University of Mashhad, Faculty of Science, Department of Biology, Mashhad, Iran*
[2] *Swedish Museum of Natural History, Department of Zoology, Stockholm, Sweden*
[3] *Research Department of Zoological Innovations (RDZI), Institute of Applied Zoology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran*
[4] *Ghent University, Research Group Evolutionary Morphology of Vertebrates, Gent, Belgium*

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Abstract
Brittle stars are one of the most diverse classes of echinoderms distributed worldwide in marine habitats. In this study, brittle stars were sampled by hand from the intertidal zone of the Persian Gulf's western part to the Oman Sea, from locations accessible without the need of a boat or diving equipment. Sampling time was set in the first days of the lunar month or at least the time of lowest tide in each day. The specimens were first immobilized in freshwater, then fixed in neutralized buffered formalin, and finally preserved in 70% ethanol after one week of fixation. Of 22 sampling points, seven localities yielded intertidal brittle stars (*Macrophiothrix hirsuta cheneyi*, *Macrophiothrix elongata*, and *Ophiocoma scolopendrina*) during the sampling period (December 2017–March 2018). *Ophiocoma scolopendrina* is reported for the first time from Dayyer and Nayband in the Persian Gulf. We also re-evaluated recently reported data on ophiuroids from the studied area.

Key words: *intertidal, identification, Macrophiothrix, Ophiocoma, ophiuroid*

INTRODUCTION

The Persian Gulf is located between the Arabian Peninsula and Iran, extending from the Shatt al Arab delta to the Strait of Hormuz, connecting to the Indian Ocean via the Oman Sea, where both Persian Gulf and Oman Sea include different sandy, muddy and rocky habitats. Ophiuroidea, commonly named brittle stars, is one of the most diverse classes of the phylum Echinodermata (Stöhr et al., 2012), and in total, includes about 260 genera and 2,110 species (Stöhr et al., 2021). Generally, the marine habitats from the intertidal to hadal depths are inhabited by ophiuroids. They are living on the sea floor, on/inside other organisms, buried in mud, or hidden in/under rocks (Stöhr et al., 2012). In the Persian Gulf and Oman Sea, 20 genera and 38 species of brittle stars are known, probably five of them endemic to the region [compiled by Fatemi and Stöhr (2019)], and a recent study reported two additional records (*Ophionereis dubia* and *Ophiothrix savignyi*) for Abu Musa Island (Abdollahi et al., 2020), which cannot be evaluated due to the lack of images in the publication. Beigmoradi and Attaran-Fariman (2020) reported 11 species of ophiuroids from the Oman Sea, but a critical evaluation of the images and descriptions indicated that some specimens were misidentified.

*Corresponding Author: *ghasemzd@um.ac.ir*

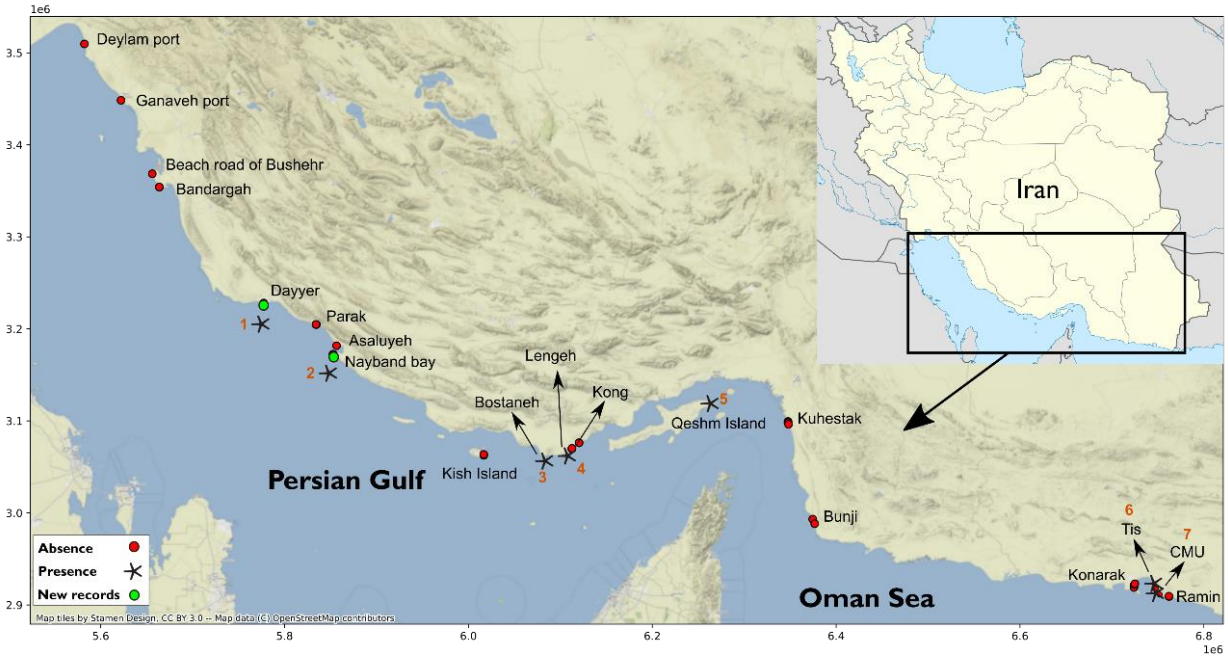

FIGURE 1. Sampling localities at the coast of the Persian Gulf and the Gulf of Oman. At localities marked by red circles no brittle stars were found, stars indicate the presence of brittle stars, and green circles mark new geographical records. At seven stations out of 22, the brittle stars were collected during the sampling time. The presence of *O. scolopendrina* from two stations is reported for the first time. Each locality includes several sampling points.

The majority of reported species from the Persian Gulf and Oman Sea occur in subtidal zones. However, little attention has been paid to their occurrence along the Iranian coast, especially in the intertidal zone. In this work, we examined the intertidal ophiuroid species along the Iranian coastline of the Persian Gulf to the Oman Sea, from habitats that were likely to be inhabited by specimens. We also aimed to update the latest data on ophiuroids of the Persian Gulf and Oman Sea, by examining the recently (after Fatemi and Stöhr, 2019) published papers from that area.

MATERIAL AND METHODS

Study area

We chose the stratified sampling method to classify the likely habitats for brittle stars according to the available data in Naderloo and Türkay (2017) and then sampled the specimens randomly from each location. Brittle stars were collected by hand from the intertidal areas of southern Iran, from locations accessible without the need of a boat or diving equipment. This research was carried out in two stages from December 16th, 2017 till March 25th, 2018. The first survey was primarily aimed to sample from the westernmost parts of the Persian Gulf to Bushehr (Fig. 1). The second one focused on the continuation of the initial sampling station (Parak) to Chabahar, a coastline of about 6000 km. The coasts of Khuzestan are muddy and are not a very likely habitat to find intertidal brittle stars, as these are usually seen in rocky and rocky-sandy habitats in Iranian waters (Fatemi and Stöhr, 2019). Deylam Port (sandy coast) was selected as the starting point of the survey, a habitat for which the presence/absence of brittle stars had not been reported yet.

The 50 sampling points along the Iranian coast of the Persian Gulf and Oman Sea were geographically divided into 22 sampling areas as follows: Deylam Port, Ganaveh Port, Beach Road of Bushehr, Bandargah, Halileh, Dayyer, Parak, Asaluyeh, Nayband Bay, Kish Island, Bostaneh Port, Lengeh Port, Kong, Qeshm Island, Kuhestak, Bunji, Konarak, Tis, the beach of Lipar Hotel, the beach of Chabahar Maritime and Marine University (CMU), Darya bozorg and Ramin Port. The main coordinates

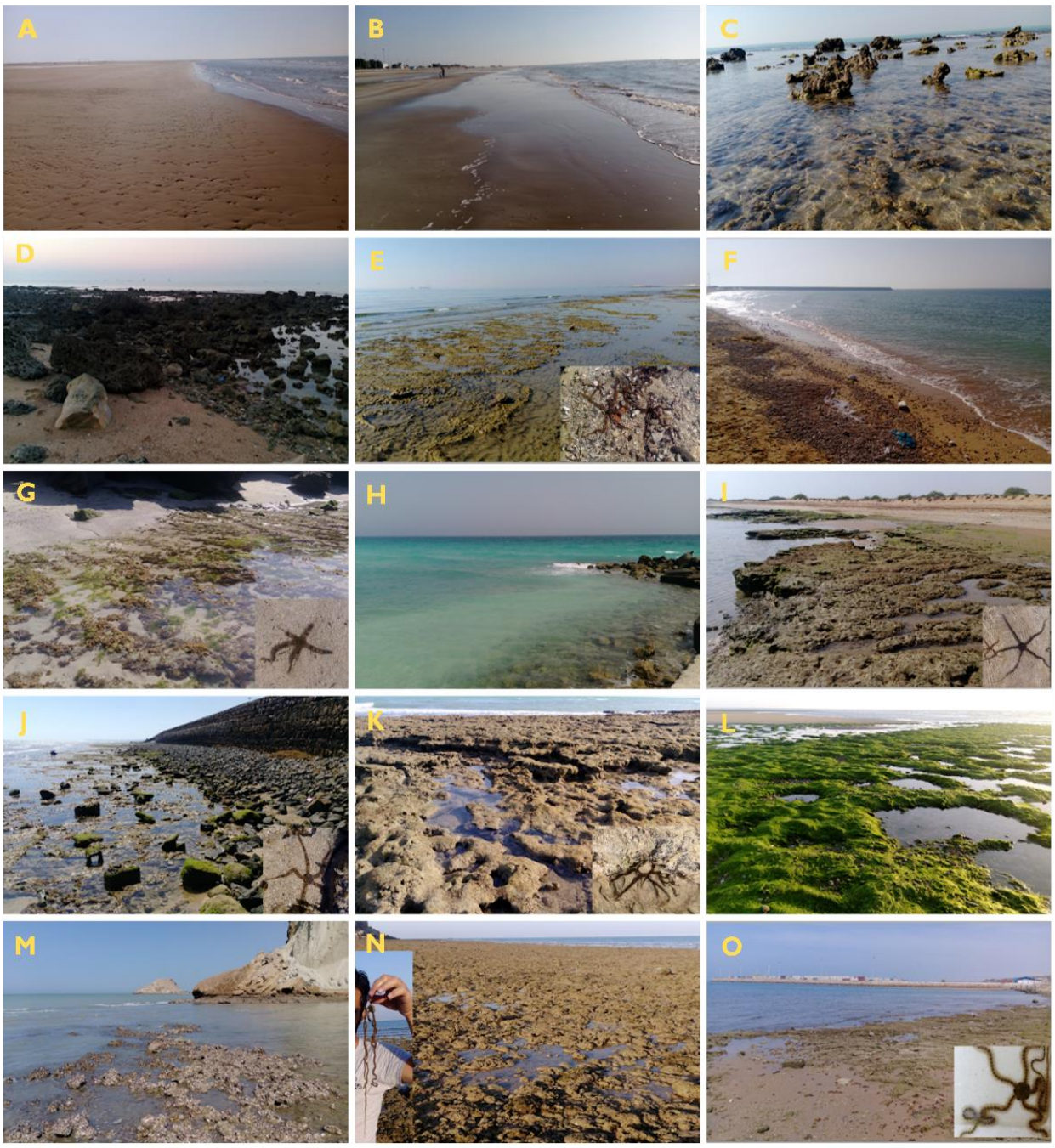

FIGURE 2. Various habitats at some of the sampling locations. A) Deylam Port, B) Ganaveh Port, C) Beach Road of Boushehr, D) Halileh, E) Dayyer, F) Parak, G) Nayband Bay, H) Kish Island, I) Bostaneh Port, J) Lengeh Port, K) Qeshm Island, I) Kuhestak, M) Bunji, N) Tis, and O) Chabahar university. The locations where brittle stars were found are marked by a photo of a specimen.

TABLE 1. The geographical coordinates of the sampling localities in the Persian Gulf and the Oman Sea.

Locality	Geographical coordinates	Habitat characteristics
Deylam Port	30.047, 50.146	Sandy
Ganaveh Port	29.570, 50.504	Sandy
Beach road of Bushehr	28.944, 50.879	Rocky cobble/dead corals
Bandargah	28.830, 50.879	Rocky/rock pool/Sandy
Halileh	28.831, 50.878	Rock pool/ cobble/Sandy
Dayyer	27.834, 51.898	Rock pool/dead corals/Sandy
Parak (4 sites)	27.648, 52.412	Sandy
Asaluyeh	27.465, 52.610	Sandy
Nayband Bay (4 sites)	27.390, 52.577	Rocky cliff/Sandy
Kish Island (4 sites)	26.517, 54.048	Rocky/rock pools
Bostaneh Port (3 sites)	26.502, 54.641	Rock pools/dead corals/Sandy
Lengeh Port (5 sites)	26.544, 54.879	Rocky cobble/dead corals/sandy
Kong (2 sites)	26.621, 54.979	Rocky/rock pools
Qeshm Island (2 sites)	26.929, 56.266	Rock pools/dead coral
Kuhestak (3 sites)	26.806, 57.021	Cobble/rock pools/Sandy
Bunji (2 sites)	25.953, 57.263	Dead corals/Sandy
Konarak (5 sites)	25.371, 60.403	Sandy
Tis (3 sites)	25.367, 60.609	Rocky/dead corals/Sandy
Lipar Hotel (2 sites)	25.321, 60.619	Rocky-Sandy
Chabahar University (CMU)	25.309, 60.625	Rocky/dead coral/Sandy
Darya bozorg	25.276, 60.665	Rocky/rock pools
Ramin Port (3 sites)	25.271, 60.744	Sandy

are listed in table 1 and the total sampling points were plotted using Geopandas and Stamen's Terrain map style (Fig. 1). The habitats of sampling stations and specimen numbers are illustrated in figures 2 and 3.

Data collection

Generally, the lowest tide is the best collecting time because it exposes the maximum area of the seafloor. The lowest tides usually occur during the early days of a lunar month. When the waters are receding, the intertidal flats are exposed and the animals can be collected before they have had a chance to hide. Therefore, sampling time was set in the first days of the lunar month or at least the time of lowest tide in each day. Sample size and habitat information (rocky, sandy, and sandy) were recorded. In total, 225 individuals were collected.

Morphological study

The specimens were first immobilized in freshwater, then fixed in neutralized buffered formalin, and finally preserved in 70% ethanol after one week of fixation (Batley and Simpson, 2016). Initial identification was performed based on the available identification keys (Gondim et al., 2013, Pomory, 2007, Goharimanesh et al., 2021). The samples were photographed with a digital camera attached to a stereomicroscope (model Olympus, SZH 10) located at the Faculty of Science, Ferdowsi University of Mashhad (FUM). Some of the specimens were later used for evolutionary morphological studies (Goharimanesh et al., 2020; Goharimanesh et al., in press).

RESULTS

The specimens (two genera) belonging to the two families Ophiotrichidae and Ophiocomidae were collected [for a detailed explanation of the family characters, see Goharimanesh et al. (2021)].

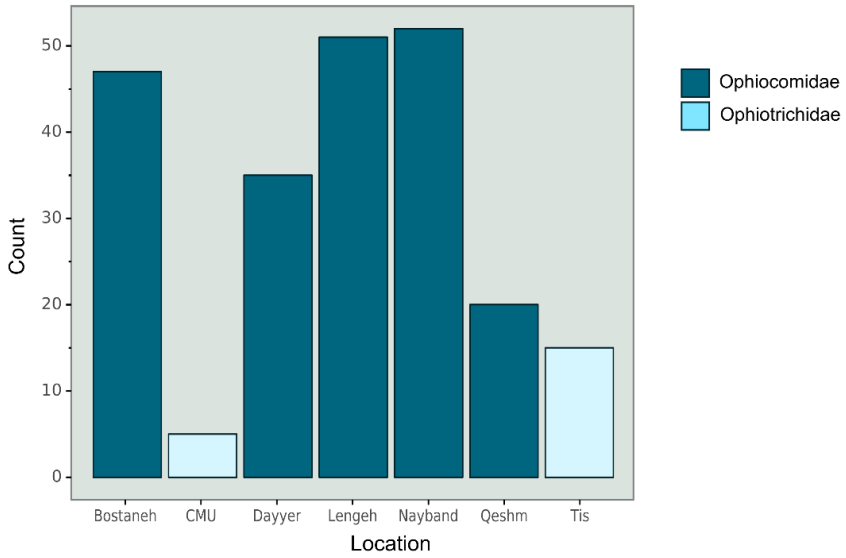

FIGURE 3. The number of collected specimens from each location.

The brittle stars were found in Dayyer, Nayband bay, Bostaneh port, Lengeh port, Qeshm Island, Tis, and CMU. Figure 3 shows the specimen number for each location. Intertidal brittle stars were only observed when the water was receding in rocky or rocky-sandy habitats and under rocks. Yet, they may have been missed in other rocky habitats such as Boushehr, Halileh, and Kish Island, due to their cryptic life-style, and hiding in crevices, or the sampling time may have been inappropriate.
The identified species, their occurrence, habitat, and diagnostic morphological characters are provided below.

Taxonomic account
Class Ophiuroidea Gray, 1840
Order Amphilepidida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017
Suborder Gnathophiurina Matsumoto, 1915
Superfamily Ophiactoidea Ljungman, 1867
Family Ophiotrichidae Ljungman, 1867

Genus *Macrophiothrix* H.L. Clark, 1938
***Macrophiothrix hirsuta cheneyi* (Lyman, 1861)**
Occurrence: Reported from the Persian Gulf and Oman Sea: Price, 1983, Khaleghi et al., 2015, Fariman and Beigmohammadi, 2016, Fatemi and Stöhr, 2019; Beigmoradi and Attaran-Fariman, 2020 and the present study from Tis and CMU (Fig. 2O).
Habitat in Oman Sea: Under rocks in rocky/sandy intertidal zone.
Diagnosis: Disc covered with short spines/stumps, more condensed or only seen between radial shields extending to ventral disc, disc, and arms without tubercles; dorsal and ventral color grey and dark blue or purple; dorsal arms with a longitudinal light line bordered by two dark blue stripes, ventral arms with wider median longitudinal stripe. Radial shields triangular covering two-thirds of the disc diameter. Oral shield much broader than long, covering less than one-third of interradius. Adoral shields separated. Several tooth papillae on the dental plate, but no lateral oral papillae on oral plate. Madreporite one, with one pore (Pourvali, 2015 and Goharimanesh et al., 2021).

***Macrophiothrix elongata* H.L. Clark, 1938**

Occurrence: Reported from the Persian Gulf and Oman Sea: Clark and Bowen, 1949, Price, 1981, Price, 1983, Khaleghi et al., 2017, Pourvali 2015, Fariman and Beigmohammadi, 2016, Beigmoradi and Attaran-Fariman, 2020 and by the present study from Tis (Fig. 2N) and CMU.

Habitat in Oman Sea: Under rocks in rocky/sandy intertidal area.

Diagnosis: *M. hirsuta cheneyi* and *M. elongata* are very similar in morphology and geographical distribution (Hoggett, 1990 and Clark, 1968), but the dorsal arm plates in *M. h. cheneyi* are rugose (Hoggett, 1990) and according to Clark (1968), *M. elongata* has much longer arms (about 20x disc diameter in *M. elongata*, and 10x in *M. h. cheneyi*).

Suborder Ophiodermatina Ljungman, 1867
Superfamily Ophiocomoidea Ljungman, 1867
Family Ophiocomidae Ljungman, 1867

Genus *Ophiocoma* l. Agassiz, 1836 sensu stricto O'Hara et al. 2019
***Ophiocoma scolopendrina* (Lamarck, 1816)**

Occurrence: Reported from the Persian Gulf and the Gulf of Oman: Mortensen, 1940, Fatemi et al. 2010, Pourvali 2015, Fatemi and Stöhr, 2019 and also the present study provides two new geographical records from Dayyer Port and Nayband Bay (Fig. 2, E, G, I, J, K, N, and O).

Habitat in Persian Gulf: Rocky and rocky-sandy intertidal area.

Diagnosis: Disc round or pentagonal. Dorsal disc fully covered by granules, covering the whole disc, including the radial shields. The disc colors range from light to dark brown, sometimes spotted patterns. Skin obscuring plates and scales. Ventral disc with granules, but less dense than on dorsal disc. Oral shields oval, shorter than wide. Adoral shields not meeting in front of the oral shield. Oral papillae five. Dorsal arm plates all fan-shaped, wider than long. Tentacle scales two, oval, arm spines alternatingly three and four (Fig. 4). Madreporite one, with one pore. Color in life variable, light and dark brown mottled, and changes in correlation with light intensity, but never completely black (Olbers et al., 2019, Goharimanesh et al., 2021). The specimens of Dayyer, Nayband and Qeshm were the darkest amongst the specimens collected (Fig. 5).

DISCUSSION

In this study, three intertidal species of ophiuroid from the Persian Gulf and Oman Sea were identified. In addition to recent studies (Fatemi and Stöhr, 2019), the results of the present study confirmed the misidentification of *Ophiothrix savignyi* as *Macrophiothrix hirsuta cheneyi* published in Fariman and Beigmohammadi (2016). The disc in *O. savignyi* is covered by long spines, but the animals in their images lack these, and they have dorsal arm plates that are wider than long and look rugose, which fit the description of *M. hirsuta cheneyi*. Moreover, we discovered that a recent report by Beigmoradi and Attaran-Fariman (2020) misidentified several ophiuroid species from the Oman Sea. In their study, specimens identified as *Ophiothela tigris* and *Ophiothela* sp. are actually *Ophiothela venusta*. As mentioned in Clark and Rowe (1971), *O. tigris* is naked on the disc and arm, but the images presented by Beigmoradi and Attaran-Fariman (2020) showed a disc covered with granules. Also, the coloration did not fit that of *O. tigris*. The *Macrophiothrix* sp 1. and sp 2. are not two different species as mentioned in their study (Beigmoradi and Attaran-Fariman 2020), but the images show *M. hirsuta* instead. *Ophiothrix* sp. and *Ophiothrix savignyi*, presented on two figures with identical images but different captions, were also *M. hirsuta* as there are no spines on the dorsal arm plates and the arms are much shorter. *Macrophiothrix longipeda*, another species reported by Beigmoradi and Attaran-Fariman (2020) from the Gulf of Oman, was probably misidentified. According to Clark and Rowe (1971) and Martin et al. (2005), *M. longipeda* has radial shields covered by granules, and the coloration is spotted. It also has a disc diameter of up to 40 mm and arms that can be up to 80 cm long (Davie, 1998). Hence, *M. longipeda* may have been confused with *M. elongata* by Beigmoradi and Attaran-Fariman (2020), however, the images

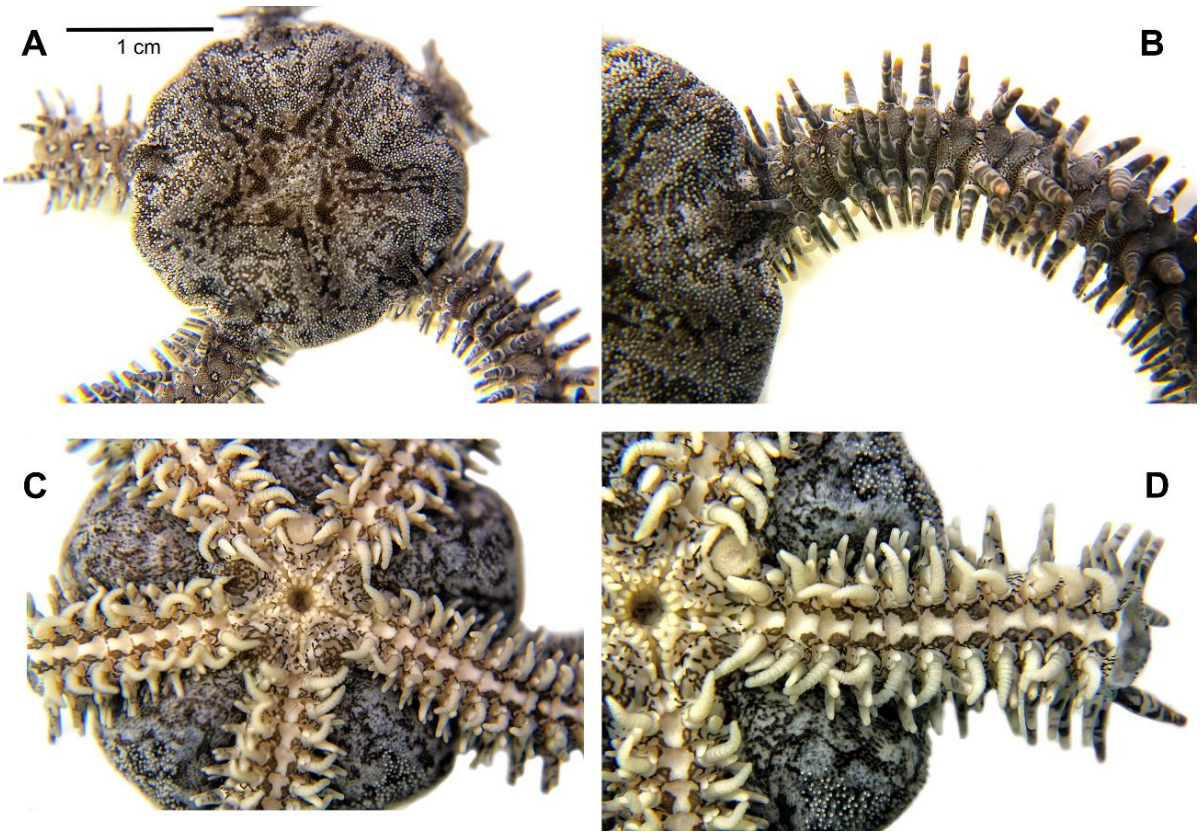

Figure 4. *Ophiocoma scolopendrina* dorsal (A & B) and ventral view (C & D), collected at Bostaneh.

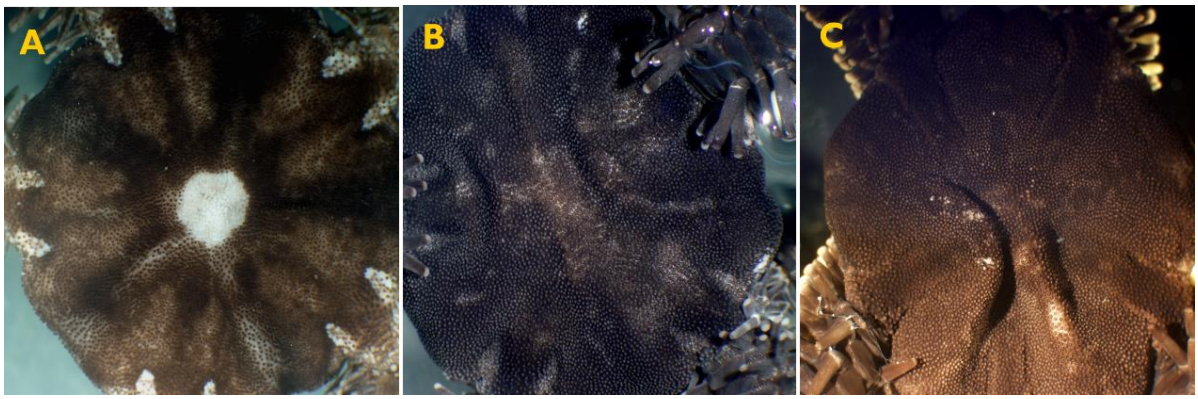

FIGURE 5. Dorsal disc color variation of *Ophiocoma scolopendrina* from A. Dayyer Port, B. Nayband Bay, and C. Qeshm Island.

are not clear enough to decide, as the arm length is the main difference between *M. elongata* and *M. hirsuta* (Clark, 1968). Currently, there are no records of *M. longipeda* in the Persian Gulf nor the Indian Ocean. As pointed out by Fatemi and Stöhr (2019), Attaran-Fariman and Beigmoradi (2016) misidentified *Amphipholis* and published the same erroneous record a second time (Beigmoradi and Attaran-Fariman, 2020). According to Clark and Rowe (1971), in *Amphiopholis* the outermost oral papillae are operculiform, and the oral papillae cover the oral slit. The images of Beigmoradi and Attaran-Fariman (2020) do not show such features. Instead, the figured disc lacks tubercles; three oral papillae arise from the oral plate, of which the outermost is not operculiform, and the oral papillae do not close the oral slit. These characters all fit the description of the genus *Amphiodia*. It also seems to have a single tentacle scale, a naked ventral disc, and the radial shield almost fully covered by scales (similar to *A. obtecta*). The

pair of thorns on the radial shield, as mentioned in Clark and Rowe (1971) and shown in Stöhr et al. (2010) regarding *A. obtecta*, could not be detected on the published images (Attaran-Fariman and Beigmoradi, 2016; Beigmoradi and Attaran-Fariman, 2020), which makes identification to species level impossible. This re-evaluation implies that instead of 11 species reported by Beigmoradi and Attaran-Fariman (2020), there were only five species, and none of them were new records for the studied area.

New geographical records have been reported for *Ophionereis dubia* and *Ophiothrix savignyi* in Abu Musa Island (Abdollahi et al., 2020). However, the identification cannot be verified since the animals were neither figured nor described. *Ophiothrix savignyi* has been misidentified in previous studies (see Fatemi and Stöhr, 2019) and therefore, any records of this species should be treated with caution. In contrast, *Ophionereis dubia* has a characteristic and unique color pattern and should not be subject to confusion.

To conclude, apart from reporting the absence and presence of three intertidal species along the Iranian coast of the Persian Gulf and Oman Sea, two new geographical records are here reported for the species *O. scolopendrina* from Dayyer Port and Nayband Bay. Yet, they may have been missed in other rocky habitats such as Bushehr, Halileh, and Kish Island, due to their cryptic life-style, hiding under rocks or in crevices, or the sampling time may have been inappropriate. We suspect that the fluctuation of physical factors and stress exposure associated with tidal emersion (Knox, 2000) might affect diversity in the intertidal zone more than in the subtidal zone. This could explain the higher number of species of ophiuroid occurring in the subtidal rather than in the intertidal zone. Further studies on the subtidal zone along the studied areas are needed to understand these patterns.

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