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# Morphological and molecular investigation of some xanthid crabs from the Egyptian coast of the Red Sea

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## Abstract

Family Xanthidae comprises 15 subfamilies and over 600 accepted species; they are represented well in the foreshore marine environments. Members of family Xanthidae are multi-colored crabs, usually inhabiting rocky coasts, coral reefs, and mud flats, all of which are well represented along the Egyptian coast of the Red Sea. Here, we utilized cytochrome oxidase subunit I (*COI*) sequences combined with morphology to provide information on some xanthid specimens collected from the Egyptian coast of the Red Sea. Six species within four genera (*Leptodius*, *Etisus*, *Cyclodius*, *Chlorodiella*) were collected. Genetic distances combined with morphological analyses showed intraspecific variations between two morphotypes of *Leptodius exaratus*. Two *Etisus* species were examined, *E. laevimanus* and *E.* sp. The latter *Etisus* sp. was close to *E. frontalis*, especially with regard to frontal lobe morphology, but different in male's first gonopod, with interspecific genetic distances. We also identified *Chlorodiella nigra* and *C. laevissima*. Obtained genetic distances between two morphotypes of *Cyclodius granulatus* revealed that these morphotypes are also likely cases of intraspecific variation. The results of this study should provide a basis for future work on family Xanthidae along the coasts of the Red Sea, which is needed as data remain scant.


**Keywords** Decapoda · Xanthidae · Crabs · Red Sea · DNA barcode · *COI*

## Introduction

The true crabs of the infraorder Brachyura are among the most well-known and intensely studied groups of all crustaceans, and their ecological success is reflected by their colonization of almost every marine and terrestrial habitat (Warner 1977; Ng et al. 2008). Thus, they are an important group of aquatic organisms, and over 7400 species have been described to date (Ng et al. 2008). Among Brachyura, crabs of the family Xanthidea MacLeay, 1838 are the most species-rich family, with 15 subfamilies and more than 600 species known worldwide (Ng et al. 2008; Lai et al. 2011; Mendoza and Guinot 2011; Mendoza and Manuel-Santos 2012; Naruse et al. 2021).

In the Red Sea, marine life is considered as an assemblage of generally Indo-Pacific species, and comprises a wide variety of many aquatic groups, including decapod crustaceans (Vine 1986). The Egyptian coasts represent a significant portion of the northern Red Sea coasts, including the coasts of the Suez Gulf and the western coasts of the Gulf of Aqaba (Head 1987). These Egyptian Red Sea coasts include many habitats such as sandy and rocky shores, and coral reefs, all of which are inhabited by various species of family Xanthidea that utilize these ecosystems for refuge, breeding, and feeding.

Red Sea crustaceans have been studied and documented by many authors, and among the oldest are works by Heller (1861a, b), who recorded over 100 species, and by Paulson (1875), who published a magnificent monograph on Red Sea Crustacea. Other important subsequent faunal studies were carried out by Klunzinger (1913), who provided translation of some of Paulson's text, as well as Nobili (1906), Laurie (1915), Balss (1924, 1929, 1934), and Guinot (1962, 1967),

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while several papers have either reviewed some families or have dealt with biological and ecological aspects of brachyurans (Ramadan 1936; Fishelson 1971; Griffin and Tranter 1974; Lewinsohn 1977; Türkay 1986; Vine 1986). Some more recent studies have focused on xanthid crabs from the Red Sea; for example, on *Leptodius exaratus*, with research focusing on ecology and biology (El-Sayed 2004), larval stages and male gonopods (Al-Aidaroos et al. 2017), and parasitism (Hassan et al. 2021). Other recent studies have examined molecular phylogenies (Abbas et al. 2016), larval stages (Al-Haj and Al-Aidaroos 2017), and the taxonomy of some xanthid crabs (Ahmed 2019; El-Sayed et al. 2019).

Using traditional morphology as the basis of identification for many brachyuran crab species can be time-consuming (Hebert et al. 2003; Plaisance et al. 2009). However, DNA barcoding via the use of mitochondrial cytochrome oxidase subunit I sequences can speed up the rate of identification and lower the rate of misidentified species (Lefébure et al. 2006; Costa et al. 2007; Plaisance et al. 2009).

The use of cytochrome oxidase subunit I (*COI*) sequences for DNA barcoding has increased as this marker can be easily amplified with the universal primer pair LCO1490 and HCO2198 (Hebert et al. 2003). There are approximately 9000 sequences of brachyuran crabs available in GenBank (as of April 2022); evidence of the importance of acquiring molecular data to aid in baseline biodiversity studies and better understanding species delineations (Chu et al. 2015). In this study, we utilized mitochondrial marker *COI* sequences to confirm the morphological identification of some confusing xanthid crab specimens collected recently from the Egyptian coasts of the Red Sea. This work thus provides a specimen-based *COI* database for xanthid crabs from this region, an increasingly important reference given increasing utilization of *COI* sequences in environmental DNA (eDNA) surveys in the region (e.g. DiBattista et al. 2017).

## Materials and Methods

### Collection Sites

The materials examined were collected from four sites along the Egyptian coasts of the Red Sea. These sites are, from north to south: 1) northwestern coast of the Gulf of Suez (29º 50′ 43.8" N, 32º 30′ 0.5" E), 2) Ras Mohamed Protectorate Area, Sharm-Elsheikh (27º 47′ 22.6" N, 34º 13′ 9.85" E, 3) the National Institute of Oceanography and Fisheries at Hurgada City (27º 17′ 18.9″ N, 33º 45′ 46.6″ E), and 4) Safaga (mangrove stand) (26º 37′ 05″ N, 34º 00′ 35″ E). Specimens were collected by hand between September 2017 to April 2018 and are stored in 95% ethanol filled containers in the Marine Invertebrates Laboratory, Faculty of Science, Al-Azhar University. In addition, two specimens of *Leptodius gracilis* (Dana, 1852) and *Leptodius affinis* (De Haan 1833–1850) were obtained from Okinawa, Japan for further molecular comparisons (Table 1). These specimens are deposited in the Ryukyu University Museum, Fujukan (RUMF), University of the Ryukyus, Okinawa, Japan. Measurements provided are carapace length (CL) and Carapace Width (CW).

**Abbreviations** G1: first male pleopod; mtCOI: mitochondrial cytochrome oxidase subunit I; PCR: Polymerase Chain Reaction; ML: Maximum Likelihood; RCAZUE: Reference Collection at Al-Azhar University, Egypt; ZRC, Zoological Reference Collection of the Lee Kong Chian Natural History Museum, National University of Singapore.

### Molecular Analyses

Genomic DNA was extracted from small pieces of xanthid crab pereopod tissues from each specimen using a Qiagen DNeasy Blood and tissue extraction kit (Qiagen, Tokyo). The resulting DNA concentrations observed with a nanodrop ranged from 9.0–37.1 ng/µl. Sequences were amplified with the primer pair LCO1490-HCO2198 (Folmer et al. 1994). PCR amplification of mtCOI was performed using 40 standard PCR cycles (reaction volume 20 µl) as follows: 94º C for 45 s (denaturation), 47-48º C for 70 s (annealing), and 72ºC for 90 s (extension). Bands of PCR products were observed on 1.5 % agarose gels. Positive single band PCR products were purified used a mixture of SAP (Shrimp Alkaline phosphate) and EXO1 (Exonuclease) under 37º C for 20 min. followed by 83º C for 30 min. Sequences were obtained by FASMAC (Kanagawa, Japan) in both directions. The acquired sequences were assembled using Bioedit software (Hall 1999), and then aligned and analyzed using Mega 7 software (Kumar et al. 2016).

For phylogenetic analyses, a phylogenetic tree was inferred by using the Maximum Likelihood (ML). All studied crabs' sequences from the present study and other sequences retrieved from GenBank were aligned with Muscle within MEGA v7 (Kumar et al. 2016) and trimmed to the same length. The Tamura 3-parameter model (Tamura 1992; Kumar et al. 2016) was selected as the best fitting model for the COI marker region (performed in MEGA v7; Kumar et al. 2016). A ML phylogenetic tree was constructed within MEGA v7 configured to use Gamma distribution 1/4, 1000 bootstrap replicates and maximum parsimony. All positions containing gaps and missing data were eliminated. *Menaethius monoceros* MW291632 was used as the outgroup in the ML tree. The sequences were deposited in National Center for Biotechnology Information (NCBI) GenBank.

**Table 1** Specimen information for newly collected xanthid crab material in this study from the Egyptian Red Sea and Japan

| Species | Museum specimen # | Sex | Analyses conducted | D | Month/year of collection | Locality |
|---|---|---|---|---|---|---|
| *Leptodius exaratus* | RCAZUE-Crus-Br.91864.17 | ♂ | Morphological & molecular | ON246985 | Feb. 2018 | Egypt: northwestern coast of Suez Gulf |
| *Leptodius exaratus* | RCAZUE-Crus-Br.91864.18 | ♂ | | ON246986 | Apr. 2018 | Egypt: Safaga, Red Sea |
| *Leptodius exaratus* | RCAZUE-Crus-Br.91864.19 | 2♀ | | ON246345 | Apr. 2018 | Egypt: northwestern coast of Suez Gulf |
| *Leptodius gracilis* | RUMF-ZC-5237 | | Molecular | ON260955 | Oct. 2014 | Japan: Okinawa, Pacific |
| *Leptodius affinis* | | | | ON246984 | | |
| *Etisus* sp. | RCAZUE-Crus-Br.914111.21 | ♀ | Morphological | | Feb. 2018 | Egypt: Hurgada, Red Sea |
| | RCAZUE-Crus-Br.914111.21 | ♂ | Morphological & molecular | ON260936 | | |
| *Etisus laevimanus* | RCAZUE-Crus-Br.914114.300 | ♂ | | ON246340 | Apr. 2018 | Egypt: Safaga, Red Sea |
| | RCAZUE-Crus-Br.914114.20 | 2♀ | | ON246338 | Feb. 2018 | Egypt: Hurgada, Red Sea |
| *Cyclodius granulatus* | RCAZUE-Crus-Br.91222.1 | ♂ | Morphological & molecular | ON246249 | | Egypt: northwestern coast of Suez Gulf |
| | RCAZUE-Crus-Br.91222.1 | ♂ | | ON246262 | | |
| | RCAZUE-Crus-Br.91222.1 | ♀ | | ON246263 | | |
| | RCAZUE-Crus-Br.91222.2 | ♂ | | ON254171 | | Egypt: Hurgada, Red Sea |
| | RCAZUE-Crus-Br.91222.6 | ♂ | | ON254172 | | Egypt: northwestern coast of Suez Gulf |
| | RCAZUE-Crus-Br.91222.6 | ♂ | | ON261186 | | |
| | RCAZUE-Crus-Br.91222.6 | ♀ | | ON246264 | | |
| | RCAZUE-Crus-Br.91222.6 | ♀ | | ON261167 | | |
| *Chlorodiella nigra* | RCAZUE-Crus-Br.91218.23 | 5♂ | Morphological & molecular | ON246335 | Feb. 2018 | Egypt: Hurgada, Red Sea |
| | RCAZUE-Crus-Br.91218.23 | 2♀ | | ON246339 | | |
| *Chlorodiella laevissima* | RCAZUE-Crus-Br.91216.30 | ♀ | Morphological & molecular | ON332813 | Sep. 2017 | Egypt: Sharm-Elsheikh, Red Sea |
| | RCAZUE-Crus-Br.91216.30 | ♂ | Morphological | | Sep. 2017 | |

## Results and Discussion

**Family Xanthidae MacLeay, 1838**
**Subfamily Xanthinae MacLeay, 1838**
**Genus *Leptodius* A. Milne-Edwards, 1863**
***Leptodius exaratus* (H. Milne Edwards, 1834**
(Fig. 1)

**Materials examined** RCAZUE-Crus-Br. 91,864.17, 1♂, 14.8 × 22.5 mm, Northwestern coast of Suez Gulf, Feb. 2018. RCAZUE-Crus-Br. 91,864.18, 1♂,15.1 × 21.8 mm, Safaga, Apr. 2018. RCAZUE-Crus-Br.91864.19, 2♀♀, 10.0 × 14.5, 11.5 × 17.2 mm, northwestern coast of Suez Gulf, Apr. 2018.

**Diagnosis** Carapace (Fig. 1A, B) broader than long, 1.44–1.52 width/length; regions well defined and projected; surface granular or smooth, sometimes finely punctate. Front separated from supraorbital angle by deep notch, front slightly exceeding supraorbital angles in dorsal view (Fig. 1A, B); frontal margin with median


**Fig. 1** *Leptodius exaratus* (H. Milne Edwards 1834). **A**, **C**, RCAZUE-Crus-Br.91864.18, male, 15.1 × 22.8 mm; **B**, RCAZUE-Crus-Br.91864.19, female, 11.5 × 17.2 mm; **D**, RCAZUE-Crus-Br.91864.17, male, 14.8 × 22.5 mm. **A**, **B**, whole animal, dorsal view; **C**, **D**, left G1, ventral view

notch. Anterolateral margins convex, smooth or feebly granulated, with four pointed lobes; posterolateral margins concave and smooth. Chelipeds stout, unequal in males, subequal in females; palm with rough upper surface; both fingers cutting margins with obtuse teeth, distal ends of both fingers hoof-shaped. Ambulatory legs without special dactyl-propodal articulation. Male pleonal somites 3–5 functionally fused but sutures sometimes visible. G1 (Fig. 1C, D) long, slender, proximal third oblique, rest of G1 almost straight except for gently curved distal third, of which apical lobe slightly directed mesially; apical lobe about 0.08–0.1 times as total length of G1 with 5–6 mushroom-like tubercles on mesial margin, 6–9 curved spines on mesial margin proximal to apical process.

There were only 0.000–0.008 genetic distance differences between *COI* sequences between all Egyptian *Leptodius* specimens examined in this study (Tables 1 and 2), indicating that all are conspecific. A male specimen from Safaga, Red Sea Egyptian coast (RCAZUE-Crus-Br.91864.18, 15.1 × 22.8 mm) was identified as *L. exaratus*, as it matches the neotype and redescription of *L. exaratus* (Lee et al. 2013) very well, especially with regards to the sub-distal spines, angle between apical lobe and rest of G1, with a slight difference in the number of mushroom-like tubercles,

**Table 2** Calculated pairwise distances (*COI*) between the studied *Leptodius* specimens from the Red Sea, Egypt, Japan and sequences from GenBank

| # | Taxa | 1 | 2 | 3 | 4[x] | 5[x] | 6* | 7* | 8* |
|---|---|---|---|---|---|---|---|---|---|
| **1** | *L.* cf. *affinis* HM751002 (Natuna, Indonesia) | | | | | | | | |
| **2** | *L. nigromaculatus* HM751003 (Singapore) | 0.178 | | | | | | | |
| **3** | *L. exaratus* LC071451 (Iran) | 0.163 | 0.135 | | | | | | |
| **4** | *L. gracilis* RUMZ-ZC-5237 (Japan)[x] | 0.164 | 0.220 | 0.186 | | | | | |
| **5** | *L. affinis* (Okinawa, Japan)[x] | 0.181 | 0.005 | 0.139 | 0.231 | | | | |
| **6** | *L. exaratus* RCAZUE-Crus-Br.91864.18 (Egypt)* | 0.154 | 0.141 | 0.000 | 0.200 | 0.144 | | | |
| **7** | *L. exaratus* RCAZUE-Crus-Br.91864.19 (Egypt)* | 0.160 | 0.138 | 0.005 | 0.179 | 0.130 | 0.006 | | |
| **8** | *L. exaratus* RCAZUE-Crus-Br.91864.17 (Egypt) * | 0.165 | 0.142 | 0.006 | 0.185 | 0.130 | 0.008 | 0.000 | |

* Refers to Egyptian species, [x] present study from another locality (Japan)

being 6 in the present specimens vs. 8–10 in specimens of Lee et al. (2013). Another male specimen (RCAZUE-Crus-Br.91864.17, 14.8 × 22.5 mm) has a slightly less curved (wider angle) distal end of G1 (Fig. 1D), but this was still in the range of infraspecific variation (see Lee et al. 2013: fig. 4B–D).

***Remarks***: Lee et al. (2013: fig. 7) indicated that the color patterns of *Leptodius affinis* (De Haan, 1833–1850) are extremely variable. Colorations of *L. exaratus* examined in the present study were pale brownish to yellowish, and one of our female specimens (RCAZUE-Crus-Br.91864.19, 11.5 × 17.2 mm) has an anterior large red spot on the dorsal surface of the carapace (Fig. 1B).

Three species of *Leptodius* have been recorded from the Red Sea: *L. exaratus, L. gracilis* (Dana, 1852) and *L. sanguineus* H. Milne Edwards, 1834 (Serène 1984). *Leptodius sanguineus* can be easily identified by possessing five anterolateral teeth behind the exorbital angle, while *L. exaratus* and *L. gracilis* have four anterolateral teeth (Barnard 1950: 220; Serène 1984: 182). Although *L. exaratus* and *L. gracilis* are morphologically very close to each other, they can be distinguished by the number of mushroom-like tubercules at the apical lobe of male pleopod (G1) (8–10 in *L. exaratus* vs. 5–6 in *gracilis*) Serène (1984: 182).

Chenari et al. (2019) studied eight specimens with different colorations of *Leptodius* from the Persian Gulf. They identified them as *L. exaratus* morphologically, but they claimed that all eight specimens were not conspecific due to their non-identical COI sequences and G1 terminal structures (indicated as *Leptodius* sp. FC). Further supporting this was that their phylogenetic analyses placed their specimens in a different clade from that of "*L. exaratus*" registered in GenBank (HM751002) from Pulau Salor, Natuna, Indonesia. However, Lee et al. (2013: fig. 7) indicated that *Leptodius* species can have a wide range of color variation. The present study also recognized such variations in the coloration as well as G1 structures in *L. exaratus*. The genetic distances between Chenari's et al. (2019) specimens are very small; they could belong to a single species. One of their sequences (LC071451) indeed was in the same clade as *L. exaratus* from Egypt. The specimens that Chenari's et al. (2019) regarded as multiple species (*Leptodius* sp. FC) most probably belong to *L. exaratus*. The sequence of "*L. exaratus*" registered in GenBank (HM751002) was of the specimen collected from Natuna, Indonesia (ZRC 2003.0549, see Lai et al. 2011), where *L. exaratus* appears to be not distributed (see Lee et al. 2013). The Natuna specimen may be close to *L. affinis* instead (see Lee et al. 2013). In any case, examination of the specimen is needed to confirm its identity.

**Habitat** Founded under small rocks in intertidal rocky habitat.

**Live coloration:** Varies from yellow to brown, some specimens have an anterior large red spot on the dorsal surface of the carapace.

**Subfamily Etisinae Ortmann, 1893**
**Genus *Etisus* H. Milne Edwards, 1834**
***Etisus* sp.**
(Figure 2)

**Materials examined** RCAZUE-Crus-Br.914111.21, 1♂, 9.1 × 11.5 mm, 1 juvenile, 5.1 × 6.9 mm, 1♀, 8.6 × 11.6 mm, Hurgada (NIOF), Feb. 2018.

**Diagnosis** Carapace (Fig. 2A, B) convex transversally and longitudinally, relatively narrow, 1.26–1.35 width/length; regions well defined by narrow, deep furrows, regions 1 M, 2F and 1F strongly convex; surface smooth to finely granular. Front separated from surpraorbital angle by deep notch, exceeding supraorbital angle in dorsal view, frontal margin separated into median and lateral lobes, median lobes slightly wider and exceeding lateral lobes. Anterolateral margins convex, with four distinct teeth. Thoracic sternites bearing scattered setae, fifth thoracic sternite in male have rounded sternal press-button. Chelipeds unequal in both male and female; extensor surface of carpus rough and punctate; outer surface of palm rough with fine granules and ridges; both fingers curved flexor-ward, tips rounded, spoon-shaped, setose, leaving wide gaps when closed. Ambulatory legs have numerous scattered setae, propodus and dactylus with short spinules on extensor surface; special dactyl-propodal articulation present. G1 elongated, slender, glabrous, short subdistal spinules with long pre-apical setae at tip (Fig. 2C).

***Remarks*** Our examined specimens are morphologically close to *Etisus frontalis* (Dana, 1852) (type locality: Sulu Sea) with regards to the shape of front, relatively narrow carapace, the presence of four smooth teeth behind the external orbital angle at anterolateral margins, and the black coloration of cheliped fixed finger being extended slightly to the palm (Dana 1852: 187; 1855: pl. 9, fig. 3 a–d; Serène 1984: pl. 31, fig. E). The G1 of our male specimen (RCAZUE-Crus-Br.914111.21, 9.1 × 11.5 mm; Fig. 2C), however, differs markedly from that shown by Serène (1984: fig. 139) based on a male from Aldabra. The genetic distances of the specimens examined (Table 3, Fig. 6) showed dissimilarity among the examined specimens when compared to sequences from *E. electra* (HM750978, Hawaii) and *E. frontalis* (JN107934, French Polynesia), with differences of 10.3% and 11.1%, respectively, strongly indicating these are all different species. Further study is needed to ascertain the correct identification of our specimens.

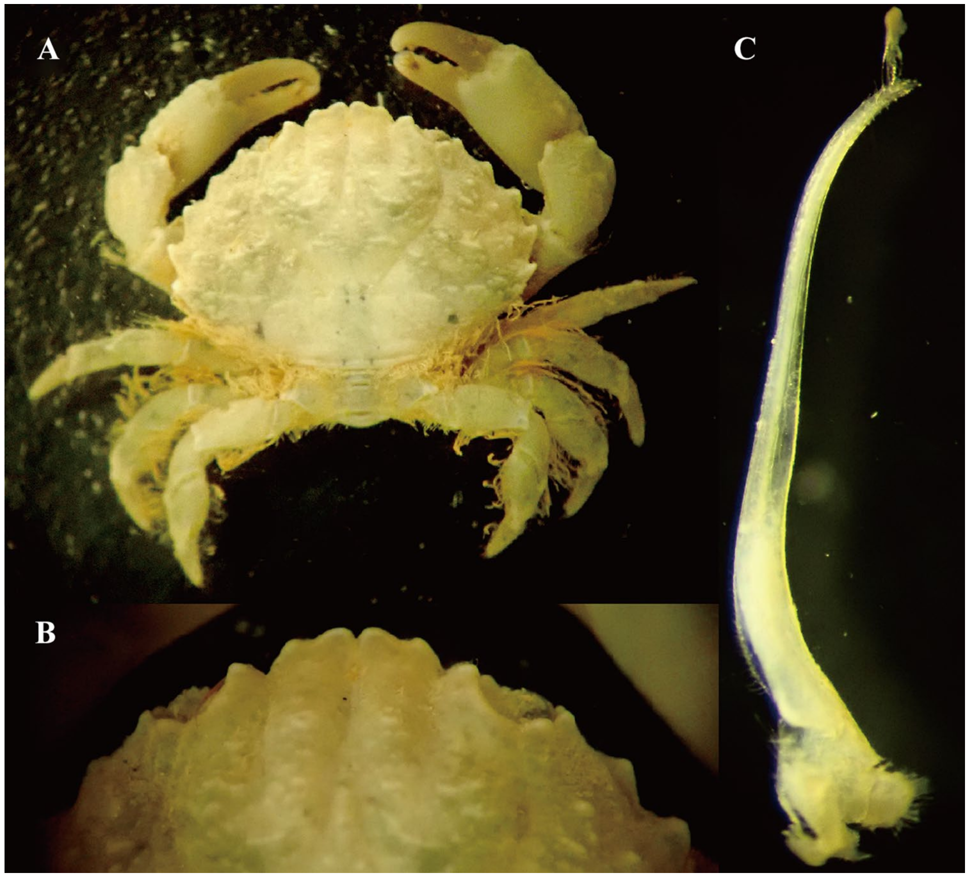


**Fig. 2** *Etisus* sp. RCAZUE-Crus-Br.914111.21, male, 9.1 × 11.5 mm. **A**, whole animal, dorsal view; **B**, anterior part of cephalothorax; **C**, left G1

**Habitat** Found in rocky habitat under rocks and dead corals.

**Live coloration** Beige to pale brown on whole body except cheliped fingers, has dark brown and whitish extremities.

### *Etisus laevimanus* Randall, 1840

(Figure 3)

**Materials examined** RCAZUE-Crus-Br.914114.20, 2♀♀, 10.8 × 15.2 mm, 11.3 × 16.1 mm, Hurgada (NIOF), Feb. 2018; RCAZUE-Crus-Br.914114.300, 1♂ 21.7 × 32.6 mm, Safaga, Apr. 2018.

**Diagnosis** Carapace (Fig. 3A) feebly convex, broader than long, 1.40–1.53 width/length; regions slightly developed, nearly glabrous; summit of regions L without ornamentation. Frontal margins feebly sinuous (Fig. 3A), slightly exceeding supraorbital angles. Anterolateral margins of carapace with four smooth teeth

**Table 3** Calculated pairwise distances (*COI*) between the studied *Etisus* specimens from the Red Sea, Egypt, Japan and sequences from GenBank

| # | Taxa | 1 | 2 | 3* | 4 | 5* | 6* |
|---|---|---|---|---|---|---|---|
| **1** | *E. electra* HM750978 (Hawaii) | | | | | | |
| **2** | *E. frontalis* JN107934 (Freanch Polynesia) | 0.022 | | | | | |
| **3** | *E.* sp. RCAZUE-Crus-Br.914111.21 (Egypt)* | 0.103 | 0.111 | | | | |
| **4** | *E. laevimanus* MW277689 (Hawaii) | 0.237 | 0.248 | 0.230 | | | |
| **5** | *E. laevimanus* RCAZUE-Crus-Br.914111.300 (Egypt)* | 0.231 | 0.225 | 0.229 | 0.037 | | |
| **6** | *E. laevimanus* RCAZUE-Crus-Br.914111.20 (Egypt)* | 0.228 | 0.233 | 0.229 | 0.042 | 0.008 | |

* Refers to Egyptian species

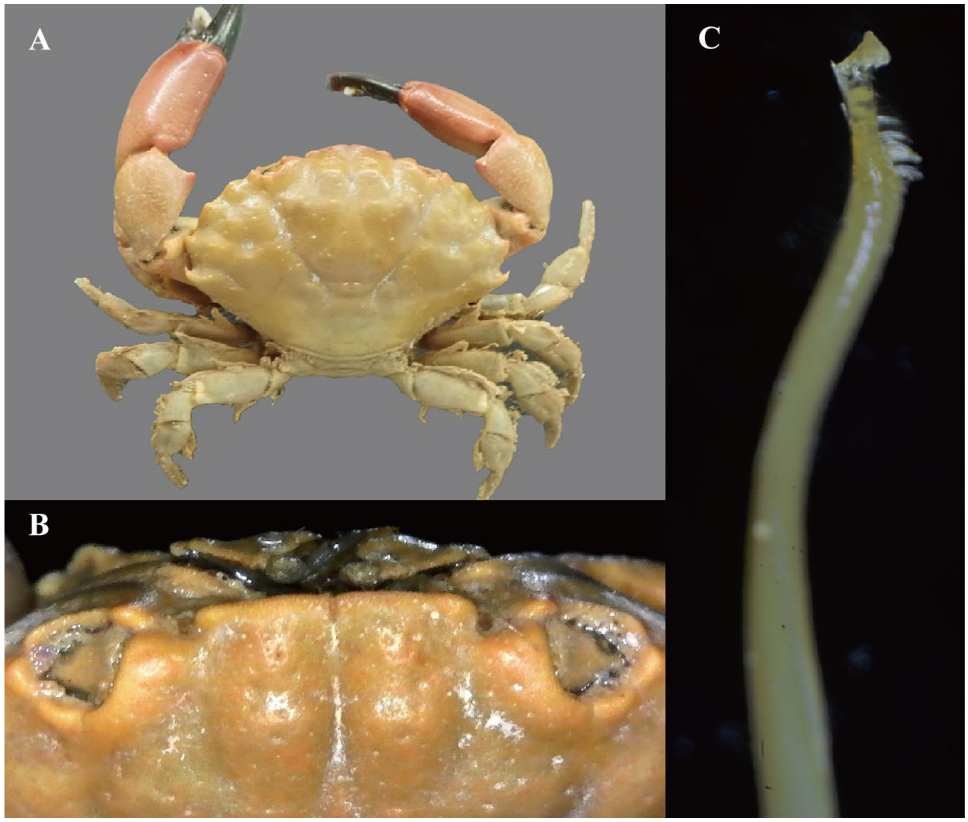

**Fig. 3** *Etisus laevimanus* Randall, 1840 (RCAZUE-Crus-Br.914114.300). **A**, whole animal dorsal view; **B**, anterodorsal view of cephalothorax, anterior view; **C**, left G1

behind exorbital angles, fourth tooth pointed, curved anteriorly. Chelipeds slightly unequal, especially in male; height of palm of major chela about two-thirds of length of superior margin of palm; minor cheliped similar to major cheliped, except for shorter palm; dactylus of cheliped slightly curved distally, spoon shaped. Ambulatory legs elongated; lateral margins of propodi and dactyli with small granules; special dactyl-propodal articulation present. G1 thin, elongate; tip strongly curved, rounded and serrated; with subdistal short setae (Fig. 3C).

***Remarks:*** The present specimens (Fig. 3) agree well with the original description of *Etisus laevimanus* by Randall (1840: 115) from the Sandwich Islands (= Hawai'i), one of the black-fingered xanthid crabs, as it has a slightly bilobed front, depressed carapace regions, with spoon-shaped cheala extremities. Moreover, spoon-tipped chelae appear to be a mutual morphological character between some xanthin and etisine genera (Lai et al. 2011), which can cause confusion in distinguishing between some genera for non-experts. However, some of these mutual characters, in addition to dactyl-propodal locks on the ambulatory legs (Sèrene 1984), have been discussed by others (Ng et al. 2008; Lai et al. 2011; Lasley et al. 2015) as ways to distinguish between Etisinae and Chlorodielinae. The pairwise genetic distances (Table 3) between our specimens and a sequence from a specimen identified as *Etisus laevimanus* (KP163570, Hawaii) ranged from 3.7% to 4.2%, possibly indicating geographic genetic differences within the same species.

**Habitat** Founded in coral reef habitat among dead corals and rocks.

**Live coloration** Yellow to brown in whole body with dark small spots and cheliped fingers black.

**Subfamily Chlorodiellinae Ng and Holthuis, 2007**
**Genus *Cyclodius* Dana, 1851**
***Cyclodius granulatus* (Targioni-Tozzetti, 1877)**
(Figure 4)

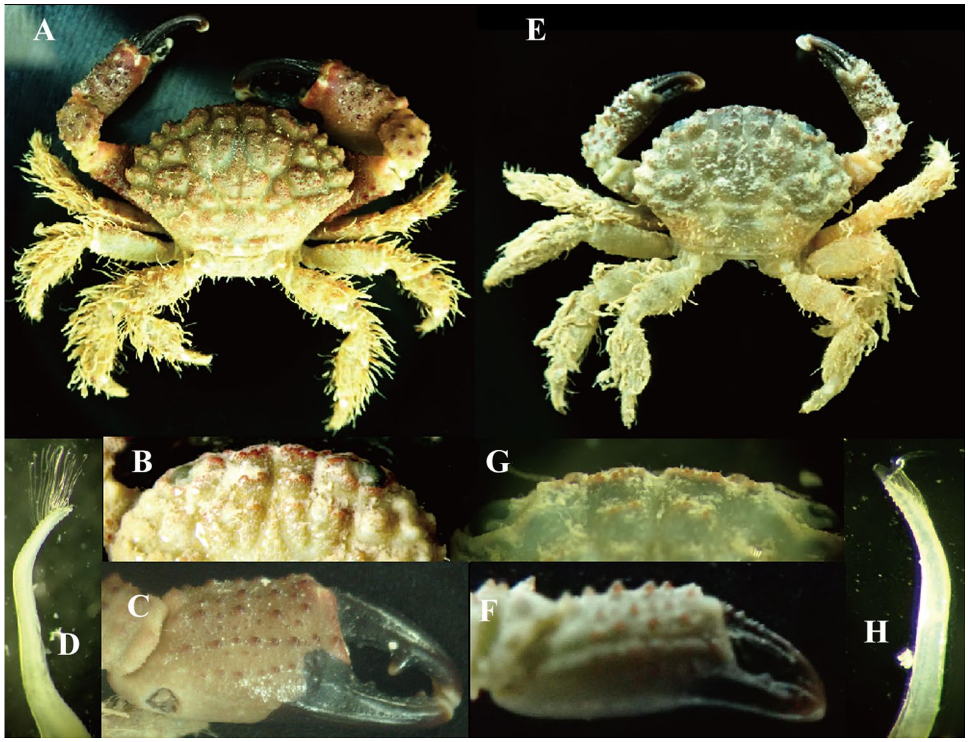


**Fig. 4** *Cyclodius granulatus* (Targioni-Tozzetti, 1877). **A**–**D**, RCAZUE-Crus-Br.91222.2, male, 12.0 × 17.7 mm; **E**–**H**, RCAZUE-Crus-Br.91222.6, male, 6.1 × 7.7 mm. **A**, **E**, whole animal dorsal view; **B**, **G**, front and anterior part of carapace, dorsal view; **C**, **F**, right cheliped palms, outer view; **D**, **H**, left GI

**Material examined** RCAZUE-Crus-Br.91222.1, 2♂♂, 9.5 × 12.2, 11.2 × 15.6 mm, 1♀, 4.6 × 6.1 mm, northwestern coast of Suez Gulf, Feb. 2018; RCAZUE-Crus-Br.91222.6, 3♂♂ 4.6 × 5.7, 5.1 × 6.7, 6.1 × 7.7 mm, 2♀♀, 5.1 × 6.6, 6.2 × 8.6, northwestern coast of Suez Gulf, Feb. 2018; RCAZUE-Crus-Br.91222.2, 1♂, 12.0 × 17.7 mm, Hurgada (NIOF), Feb. 2018.

**Diagnosis** Carapace (Fig. 4A, E) subhexagonal, broader than long, dorsal surface granulated, with prominent and projecting regions; 2 M and 3 M always well defined, regions 5L, 2 M always longitudinally divided. Frontal margin with 2 wide median and 2 narrow lateral lobes, median lobes slightly exceeding lateral lobes; a small notch present between supraorbital angle and lateral lobe of front. Anterolateral margins of carapace with four teeth behind exorbital angles, feebly convex; posterolateral margins straight, posteriorly convergent. Chela elongated, outer surface of palm with distinct, rounded granules, arranged in rows, distal extremity of merus extends beyond lateral margin of carapace when stretched laterally; finger as long as superior margin of palm and without brushes of setae near cutting margins. Ambulatory legs with numerous setae on anterior and posterior margins; merus about twice as long as broad; special dactyl-propodal articulation present. G1 elongated, smooth and glabrous with long plumose pre-apical setae; tip slightly curved.

***Remarks*** Five *Cyclodius* species have been recorded from the Red Sea: *C. drachi* (Guinot, 1964); *C. granulatus* (Targioni-Tozzetti, 1877); *C. nitidus* (Dana, 1852); *C. obscurus* (Hombron and Jacquinot, 1842–1854), and *C. ungulates* (H. Milne Edwards 1834). *Cyclodius granulatus* was originally described as *Pilodius granulatus* Targioni-Tozzetti, 1877 from the Red Sea, and recorded from Djibouti by Nobili (1906: 265), Klunzinger (1913: 227), Ramadan (1936: 33), Guinot (1964: 82), Sèrene (1984: 250), and Galil and Vannini (1990: 44) as *Phymodius granulatus*. Recently, this species was transferred to *Cyclodius granulatus* (Ng et al. 2008). The present specimens agree well with *C. granulatus* (Targioni-Tozzetti, 1877) in the following characteristics: 1) carapace strongly granular, 2) frontal median lobes separated by narrow furrow, 3) ambulatory legs have numerous setae, and 4) G1 with pre-apical long plumose setae (Fig. 4). Smaller specimens on hand (RCAZUE-Crus-Br.91222.6) tend to have deeper median furrow of the front, sharper granules on the outer surface of the palm of chelae, and less setose ambulatory legs (Fig. 4E–G). The morphological differences are, however, very

**Table 4** Calculated pairwise distances (*COI*) between the studied specimens of subfamily Chlorodiellinae collected from the Red Sea, Egypt. *Cy*, *Cyclodius*; *Ch*, *Chlorodiella*

| # | Taxa | 1 | 2 | 3 | 4* | 5* | 6* | 7* | 8* | 9* | 10* | 11* | 12 | 13* | 14* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Cy. granulatus* KP163588 (KSA, Red Sea) | | | | | | | | | | | | | | |
| 2 | *Cy.* cf. *granulosus* GQ260921 (Palmyra Atoll) | 0.099 | | | | | | | | | | | | | |
| 3 | *Cy. granulatus* RCAZUE-Crus-Br.91222.1(Egypt) * | 0.000 | 0.102 | | | | | | | | | | | | |
| 4 | *Cy. granulatus* RCAZUE-Crus-Br.91222.2(Egypt)* | 0.000 | 0.099 | 0.00 | | | | | | | | | | | |
| 5 | *Cy. granulatus* RCAZUE-Crus-Br.91222.1(Egypt) * | 0.000 | 0.102 | 0.000 | 0.00 | | | | | | | | | | |
| 6 | *Cy. granulatus* RCAZUE-Crus-Br.91222.1(Egypt) * | 0.000 | 0.102 | 0.000 | 0.00 | 0.00 | | | | | | | | | |
| 7 | *Cy. granulatus* RCAZUE-Crus-Br.91222.6(Egypt)* | 0.000 | 0.099 | 0.000 | 0.00 | 0.00 | 0.00 | | | | | | | | |
| 8 | *Cy. granulatus* RCAZUE-Crus-Br.91222.6(Egypt)* | 0.000 | 0.099 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | | |
| 9 | *Cy. granulatus* RCAZUE-Crus-Br.91222.6(Egypt)* | 0.000 | 0.099 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | |
| 10 | *Cy. granulatus* RCAZUE-Crus-Br.91222.6(Egypt)* | 0.000 | 0.099 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | |
| 11 | *Ch. nigra* MZ900924 (China) | 0.192 | 0.231 | 0.199 | 0.192 | 0.193 | 0.199 | 0.199 | 0.192 | 0.194 | 0.193 | | | | |
| 12 | *Ch. laevissima* MZ559824 (Papua New Guinea) | 0.201 | 0.234 | 0.199 | 0.195 | 0.196 | 0.199 | 0.199 | 0.199 | 0.195 | 0.196 | 0.145 | | | |
| 13 | *Ch. nigra* RCAZUE-Crus-Br.91218.23 (Egypt)* | 0.172 | 0.221 | 0.175 | 0.172 | 0.174 | 0.175 | 0.175 | 0.172 | 0.174 | 0.175 | 0.023 | 0.152 | | |
| 14 | *Ch. nigra* RCAZUE-Crus-Br.91218.23 (Egypt)* | 0.172 | 0.222 | 0.177 | 0.172 | 0.174 | 0.177 | 0.177 | 0.172 | 0.174 | 0.173 | 0.023 | 0.153 | 0.0.002 | |
| 15 | *Ch. laevissima* RCAZUE-Crus-Br.91218.30 (Egypt)* | 0.159 | 0.206 | 0.156 | 0.156 | 0.156 | 0.156 | 0.156 | 0.156 | 0.156 | 0.156 | 0.027 | 0.147 | 0.0.002 | 0.002 |

* Refers to Egyptian species

subtle, and due to the lack of pairwise genetic differences between large and small individuals (Table 4, RCAZUE-Crus-Br.91222.1, 91,222.2 vs. 91,222.6), all specimens examined in this study are identified as *C. granulatus*.

**Habitat** The present specimens were collected in association with the zooxanthellate scleractinian coral *Stylophora pistillata* (Esper, 1792).

**Live coloration** Brown to dark brown of carapace and chelipeds, black cheliped fingers and pale brown ambulatory legs.

**Subfamily Chlorodiellinae Ng and Holthuis, 2007**
**Genus *Chlorodiella* Rathbun, 1897**
***Chlorodiella nigra* (Forskål, 1775)**
(Figure 5A–C)

**Materials examined** RCAZUE-Crus-Br.91218.23, 5♂♂, 3.1 × 4.1, 3.2 × 4.6, 4.9 × 7.3, 5.0 × 7.2, 7.3 × 11.3, 2♀♀ 4.5 × 6.3, 4.5 × 6.3 mm, Hurgada (NIOF), Feb. 2018.

**Diagnosis** Carapace (Fig. 5A, B) subhexagonal, dorsal surface smooth, feebly convex longitudinally, branchial regions well defined. Front truncate, comparatively broader. Anterolateral margins with four teeth behind orbital angle, first tooth often reduced but three others well developed. Chelipeds fingers with rounded, spoon-shaped tips; anterior margin of merus smooth or granular, with 1 subproximal spine; palms not very elongated. Ambulatory legs with sparse plumose setae, and with dactyl-propodal articulation. G1 (Fig. 5C) slender, curved distally (pre-apical), with long apical setae.

***Remarks*** *Chlorodiella nigra* (Forskål, 1775) was originally described based on material from Djiddah (= Jeddah, Saudi Arabia), the Red Sea. The present specimens agree well with the Serène's (1984) description of *C. nigra* and previous records from the Red Sea by Kossmann (1877) and Klunzinger (1913).

**Habitat** The present specimens were obtained from dead corals in coral reef habitat.

**Life coloration** Reddish brown to brown on whole body, with black fingers of chelipeds.

***Chlorodiella laevissima* (Dana, 1852)**
(Figure 5D, E)

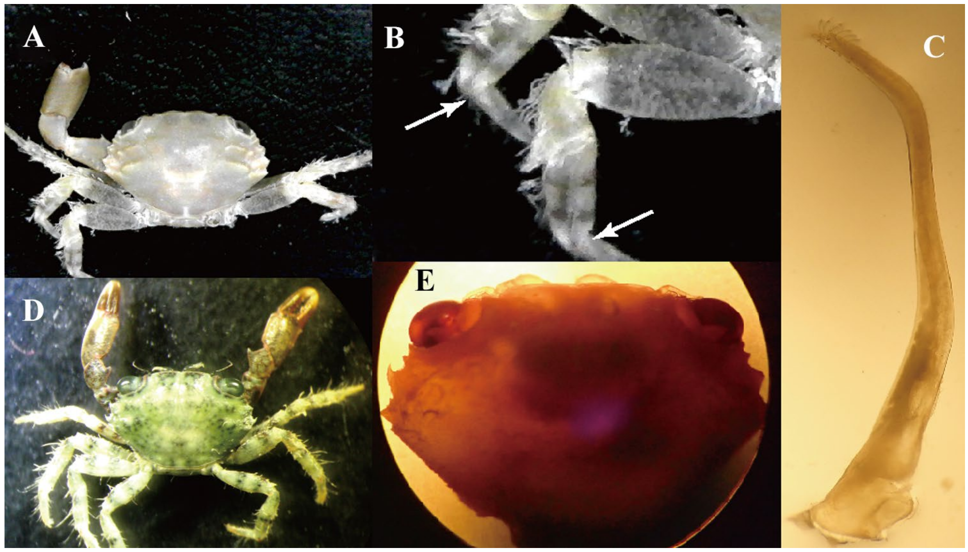


**Fig. 5** **A**–**C**, *Chlorodiella nigra* (Forskål, 1775) RCAZUE-Crus-Br.91218.23, ♂, 7.2, 7.3 × 11.3 mm; **D**, **E**, *Ch. laevissima* RCAZUE-Crus-Br.91218.30, 1♀, 3.3 × 5.1 mm. **A**, **D**, whole animal dorsal view; **B**, third and fourth ambulatory leg, left, showing dactyl-propodal articulation (arrows); **C**, right G1; **E**, carapace dorsal view

**Materials examined** RCAZUE-Crus-Br.91218.30, 1♂, 2.2 × 3.3 mm, 1♀ 3.3 × 5.1 mm, Sharm-Elsheikh, Sep. 2017.

**Diagnosis** Carapace (Fig. 5D, E) subhexagonal, dorsal surface smooth, regions feebly or not defined. Front nearly straight without defined furrow. Anterolateral margins with four teeth behind orbital angle, pointed, first and last teeth often reduced, second and third teeth sharp, well developed. Chelipeds similar to *C. nigra* (present study). Ambulatory legs setose, with special dactylo-propodal articulation.

***Remarks*** *Chlorodiella laevissima* was originally described from the Sandwich Islands (= Hawai'i), by Dana (1852). The only record of this species from the Red Sea was in a list by Vine (1986). The specimens examined in this species are very small and are morphologically close to *C. laevissima* (Dana, 1852) in the following characteristics: **1)** Anterolateral margins have teeth 1 and 4 very small and teeth 2, 3 sharp, well developed; **2)** straight frontal margin without median furrow; and **3)** the ambulatory legs have sparse, plumose setae. There is a sequence of *C. laevissima* from Papua New Guinea (MZ559824) in GenBank, but the genetic distances between it and our material is 14.7%, which is much larger than the distances between our *C. nigra* and *C. laevissima* from Egypt (0.2%; Table 4). However, the use of *COI* barcode in this case may fails alone without morphological characteristics to distinguish some crab species (Schubart et al. 2008; Chu et al. 2015). The identity of the specimen of Papua New Guinea also needs to be confirmed (Fig. 6).

**Habitat** Coral reef habitat, from branches of *Acropora* spp.

**Live coloration** Carapace is gray to greenish, chelipeds are brown becoming darker at the palm and fingers, and ambulatory legs pale brown with greenish bands.

## Discussion

The present study investigated identities of xanthid specimens collected from the Egyptian coast of the Red Sea based on detailed morphological observation and *COI* marker sequences due to their high informative content and use as a standard marker for species identification (Hebert et al. 2003; Chu et al. 2015). It was found from genetic distances that there were intraspecific variations in taxonomically important G1 and carapace characters in *Leptodius exaratus* and *Cyclodius granulatus*, respectively. Moreover, the present variation observed between *C. granulatus* individuals was supported by other previous works (Gordon 1934: 32; Lasley et al. 2015:173), showing that *Cyclodius granulosus* and small individuals of other *Cyclodius* species have some degree of variation in carapace tuberculation.

Other variations were noticed in our specimens of *Etisus* sp., which morphologically was close to *E. frontalis*, but different in G1 characters, with interspecific genetic distances. Unfortunately, we could examine only a limited number of small specimens; further collection of the species should help in its precise identification. It is important to mention the findings of Lai et al. (2011), who found that the two congeners *Etisus electra* and *E. frontalis* are very similar morphologically. As well, Lasley et al. (2015) concluded from their molecular analyses and morphological observations that

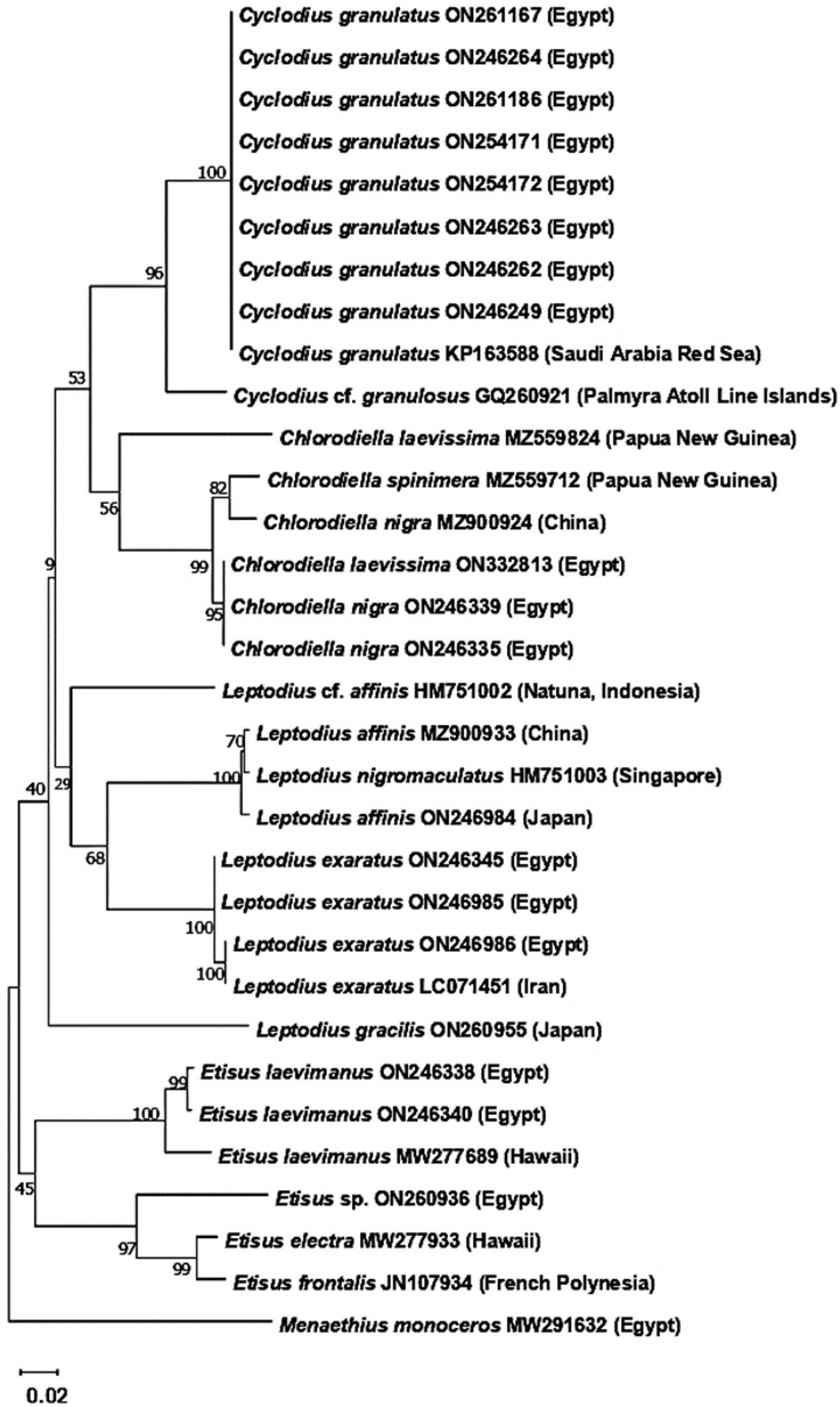


**Fig. 6** Phylogenetic tree using Maximum Likelihood analyses of partial sequences of the mt *COI* marker for xanthid crabs. *Leptodius* cf. *affinis* HM51002 Natuna, Indonesia (GenBank ID: *L. exaratus*); *Leptodius exaratus* LC071451 Iran (GenBank ID: *Leptodius* sp.)

members of subfamily Etisinae are not monophyletic and need extensive revision. The results of the present study advance the molecular investigations of this group in the Red Sea by providing mitochondrial (*COI*, 16S) combined with nuclear (e.g. Histone, 18 s) sequences on the most diverse crab of family (Xanthidae) for future classification and environmental DNA analyses.

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**Authors' Contributions** All authors contributed to the study conception and design. Material preparation and specimens' collection were performed by [Mohamed A. Amer] and analyses by [Mohamed A. Amer], [James D. Reimer] and [Tohru Naruse]. The first draft of the manuscript was written by [Mohamed A. Amer] and all authors commented on the manuscript. All authors read and approved the final manuscript.

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**Data Availability** The datasets generated and analyzed during the current study are included in this article, DNA sequences for studied species available at National Center for Biotechnology Information (NCBI) GenBank. And the alignment is available upon request from the corresponding author.

## Declarations

**Ethical Approval and Animal Ethics** Not applicable.

**Consent for Publication** Not applicable.

**Competing Interests** The authors have no competing interests to declare that are relevant to the content of this article.



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