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The diversity of acorn barnacles (Cirripedia, Balanomorpha) across Thailand's coasts: The Andaman Sea and the Gulf of Thailand

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Abstract

The acorn barnacle is a sessile crustacean, inhabiting the intertidal areas of tropical and temperate regions worldwide. According to current practices on Cirripedia morphology, shell, opercular valves, and arthropodal characters including cirri and mouthparts are used as a tool for taxonomic classification, and using these characteristics the present study aimed to provide better resolution for the barnacle diversity and geographical distribution within coastlines of Thailand: the Andaman Sea and the Gulf of Thailand. A total of ten species belonging to three families (Chthamalidae, Tetraclitidae, and Balanidae) were identified in this study. Subsequently, five species were newly recorded for the first time from Thailand's coasts: *Newmanella spinosus* Chan & Cheang, 2016, *Euraphia hembeli* Conrad, 1837, *Euraphia depressa* (Poli, 1795), *Tetraclita kuroshioensis* Chan, Tsang & Chu, 2007, and *Tetraclita singaporensis* Chan, Tsang & Chu, 2007. The others, already mentioned in previous records, include: *Tetraclita squamosa* (Bruguière, 1789), *Chthamalus malayensis* Pilsbry, 1916, *Amphibalanus amphitrite* (Darwin, 1854), *Amphibalanus reticulatus* (Utinomi, 1967), and *Megabalanus tintinnabulum* (Linnaeus, 1758). Interestingly, acorn barnacles along the Andaman Sea occur abundantly, and are much higher in number of species (up to 8 species) than those found in the Gulf of Thailand's coast (up to 6 species). This biased trend of species' preferences is possibly due to the differences in oceanographic nature between two coastlines and the history of barnacle colonization.

Introduction

Acorn barnacles, a member of marine crustaceans, inhabit a diverse array of substrates (e.g. calcareous rock or limestone, mollusk shells, corals, sponges, mangrove roots, turtle shells, and whale skins) along intertidal zones of temperate and tropical coastlines worldwide, as sessile form throughout their adulthood (Frith et al. 1976; Sophia Rani et al. 2010; Brickner and Høeg 2010; Brickner et al. 2010; Chen et al. 2012; Hayashi 2013; Chen et al. 2014; Yu et al. 2016). It is known as a marine fouling or biofouling organism and it has been considered as a problematic or invasive species for oyster farming, aquaculture, the reforestation of mangrove swamps, and for the support structures of offshore oil rig platforms and ship transport (Santhakumaran and Sawant 1991; Rawangkul et al. 1995; Molnar et al. 2008; Sophia Rani et al. 2010; Holm 2012). Although the presence of hard calcareous plates covering acorn barnacles' bodies limits abilities to search for food and new habitats, the species are still tremendously successful in occupying the coastline of tropical and temperate regions due to their free-swimming and planktonic larval stages: high-feeding nauplius and non-feeding cyprid. The nauplius larva develops in successive manner with ecdysis or molting to shed their exoskeleton and allow growth of larva, a characteristic used to classify acorn barnacles into Ecdysozoa of Protostomia clade. The metamorphosis (settlement process) alters a cyprid larva to a sessile juvenile and subsequently an adult form growing inside the ring of shell plates (4–8 in number depending on the species), homologous structure to carapace of other crustaceans (Høeg and Møller 2006; Maruzzo et al. 2012; Martin et al. 2014). The sessile body of adult barnacles has six

pairs of featherly throracic appendages called cirri (legs or feeding appendages), so named suborder Cirripedia constituted inside order Sessilia and superorder Thoracica. With highly suitable habitats and temperature ranges, diverse forms of acorn barnacles occur along coastlines in both the Andaman Sea and the Gulf of Thailand. However, the taxonomic classification alongside geographical distribution information of acorn barnacles has received little attention in Thailand. Here we aim to investigate taxonomy, shell morphology, and geographical distribution by firstly relating the taxonomic key of acorn barnacles to their distribution records along the Andaman Sea and the Gulf of Thailand coasts to elucidate the diversity of the species across the coastlines of Thailand.

Material and methods

Study sites

Acorn barnacles were collected from the rocky coastal areas of two distinct geographic regions of Thailand: the Andaman Sea and the Gulf of Thailand, during May 2015-July 2016.

The Andaman Sea located in the eastern part of the Indian Ocean is bordered by the coastlines of Myanmar, Thailand, Malaysia, Indonesia and India. In the Andaman Sea, the tide is semidiurnal. Its water temperature and salinity range 25.9–30.4˚C and 29–33 ppt, respectively (Limpsaichol et al. 1991). Five sampling sites along the Andaman Sea coast comprised of (1) Ao Khoei beach, Khura Buri district, Phang-nga province, (2) Na Tai beach, Takua Thung district, Phang-nga province, (3) Kalim beach, Katu district, Phuket province, (4) Ao Yon beach, Mueang Phuket district, Phuket province, and (5) Panwa beach, Mueang Phuket district, Phuket province.

The Gulf of Thailand, a semi-enclosed sea, is bordered by the coastlines of Vietnam, Cambodia, Thailand, and Malaysia with a connection to the South China Sea in the south. In the Gulf of Thailand, the tide is mixed diurnal. Its water temperature and salinity range 29–32˚C and 30–33 ppt, respectively (Pollution Control Department 2001). Five sampling sites along the coastline of the Gulf of Thailand were investigated, comprising (1) Khao Sam Muk beach, Mueang Chon Buri district, Chon Buri province, (2) Si Racha beach, Si Racha district, Chon Buri province, (3) Ko Kham Yai beach, Ko Si Chang district, Chon Buri province, (4) Ban Krut beach, Bang Saphan district, Prachuap Khiri Khan province, and (5) Hin Ngam beach, Sichon district, Nakhon Si Thammarat province.

A synopsis and illustration of all the sampling locations are given in Table 1 and Figure 1.

Table 1. Sampling locations, arranged from north to south.

Locality		Habitat characteristics	Coordinates
Andaman Sea coast			
Ao Khoei	AK	Large boulders on sandy shores	09°16’44.18”N 98°22’07.01”E
Na Tai	NT	Rocky shores	08°14’15.39”N 98°16’51.22”E
Kalim	KL	Small to large rocks on sandy shores	07°55’25.47”N 98°15’47.68”E
Ao Yon	AY	Rocky shores	07°52’09.79”N 98°26’08.29”E
Panwa	PW	Large boulders on sandy shores	07°48’05.09”N 98°24’28.80”E
Gulf of Thailand coast			
Khao Sam Muk	KS	Rocky shores	013°18’38.88”N 100°54’07.81”E
Si Racha	SR	Large boulders on sandy shores	013°10’33.92”N 100°55’33.74”E
Ko Kham Yai	KK	Small rocks on sandy shores	013°09’59.30”N 100°49’18.00”E
Ban Krut	BK	Rocky shores	011°21’26.07”N 099°34’42.86”E
Hin Ngam	HN	Rocky shores	009°00’00.68”N 099°55’09.45”E

Sampling collection

The barnacles were collected from each station by surveying along rocky shores of an intertidal zone during both low and high tides. Whole acorn barnacle individuals were removed from the substratum and immediately preserved in ethyl alcohol (95%v/v) for further examination. All work was done under certified supervision of S.K. (Certificate from Institute of Animal for Scientific Purposes Development-IAD, Royal Thai Government: U1-03104-2559).

Morphology analysis

Samples were primarily identified based on their shell morphology using an Olympus SZ51 stereomicroscope and was photographed with digital camera. For better species identification in some families, arthropodal characters were observed. Soft bodies were removed from the shells and dissected. Cirri and mouthparts were mounted onto slides for light microscopy observation and imaging using digital camera. Taxonomic identification was performed using keys of Newman and Ross (1976) and Chan et al. (2009). The general terminology of shell morphology and the important characters used in this paper follow Chan et al. (2009). All voucher specimens from each station were deposited in the collection of Laboratory of Zoology, Department of Biology, Faculty of Science, Burapha University, Thailand.

Results

Based on shell morphology, total ten species (6 genera) of acorn barnacles along the coastlines of Thailand in both the Andaman Sea and the Gulf of Thailand were identified and are categorized into three families: Chthamalidae (2 subfamilies: Chthamalinae and Euraphiinae), Tetraclitidae (2 subfamilies: Newmanellinae and Tetraclitinae), and Balanidae (2 subfamilies: Amphibalaninae and Megabalaninae). The descriptions of the identified barnacles are as follows:

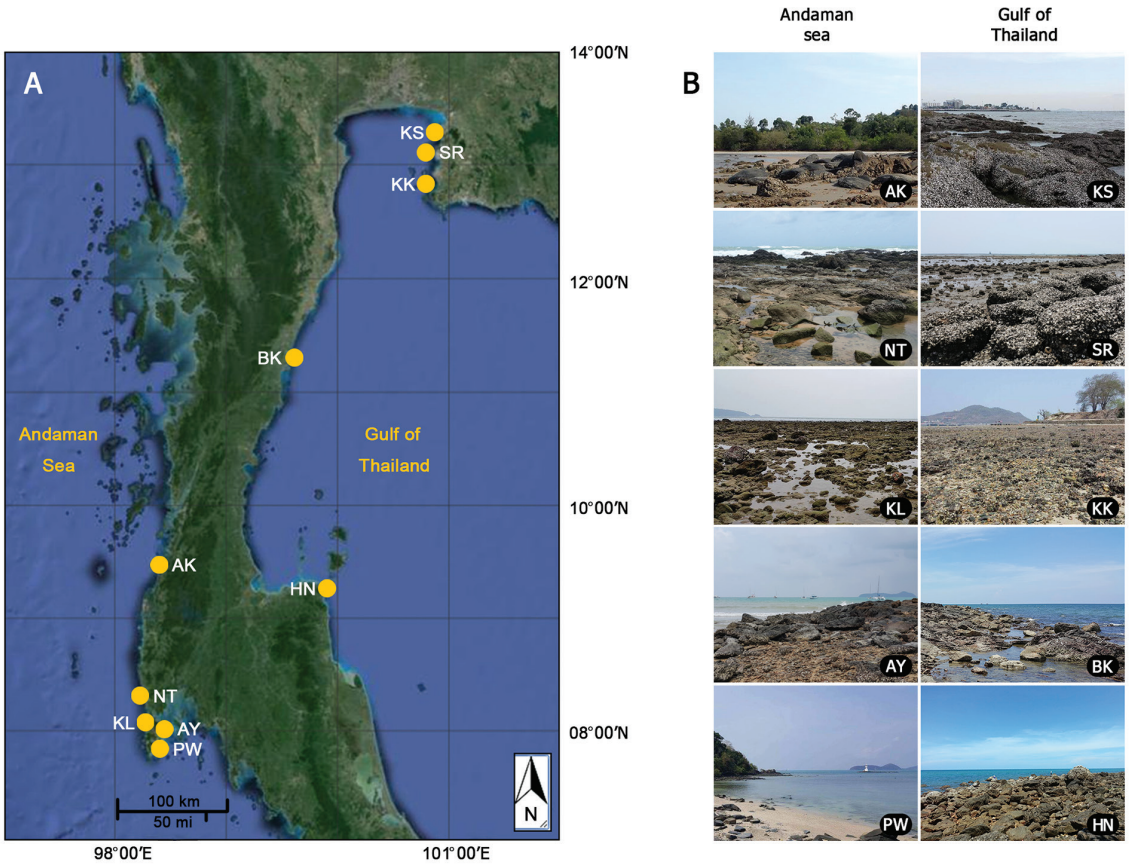

Figure 1. Map showing all sampling locations (**A**) and habitat characteristics (**B**) of acorn barnacles found along the coastlines of the Andaman Sea and the Gulf of Thailand. See Table 1 for acronyms of sampling sites. (modified from http://marinegiscenter.dmcr.go.th/gis/)

Systematic taxonomy

Superorder Thoracica Darwin, 1854
Order Sessilia Lamarck, 1818
Suborder Balanomorpha Pilsbry, 1916
Superfamily Chthamaloidea Darwin, 1854
Family Chthamalidae Pilsbry, 1916
Subfamily Chthamalinae Darwin, 1854

Genus *Chthamalus* Ranzani, 1817

Type species. *Chthamalus stellatus* (Poli, 1791)

1 genus, 1 species recorded: *Chthamalus malayensis* Pilsbry, 1916.

Chthamalus malayensis Pilsbry, 1916

Figure 2; Tables 2–3

Chthamalus malayensis Pilsbry, 1916: 310–311; Hiro, 1939: 249–251; Utinomi, 1954: 18; Karande & Palekar, 1963: 231; Pope, 1965: 51–63; Newman & Ross, 1976: 42; Dong et al., 1980: 125; Ren, 1984: 151–153; Southward et al., 1998: 123.
Chthamalus stellatus: Hoek, 1913: 267–269.
Chthamalus challenger: Broch, 1931: 53–55; 1947: 5.
Chthamalus antennatus: Rossel, 1972: 174, pl. 13, figs. 1–7, pl. 14, fig. 1–5.

Non-type material examined. Andaman Sea: 3 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.CH.CM01-03). 2 specimens, Phuket province, Mueang Phuket district, Ao Yon beach, 15.VII.2015, A. Pochai (BUU16.CH.CM04-05). 1 specimen, Phuket province, Mueang Phuket district, Panwa beach, 16.VII.2015, S. Khachonpisitsak (BUU16.CH.CM06). 3 specimens, Phuket province, Katu district, Kalim beach, 15.VII.2015, A. Pochai (BUU16.CH.CM07-09).

Gulf of Thailand: 2 specimens, Chon Buri province, Ko Si Chang district, Ko Kham Yai beach, 05.VII.2015, S. Khachonpisitsak (BUU16.CH.CM10-11).

Description. Peduncle absent; body length 3–10 mm; base membranous. Shell elongated oval/shield-shaped, shell white to grey with 6 plates (1 carina, 2 carinal latus, 2 latus and 1 rostrum), carina bigger than rostrum, parietes symmetrical, calcareous and solid, radii solid, inner surface of parietes smooth and white-grey to pale-violet; orifice kite-shaped. Operculum plates symmetrical, articulation of opercular valves deep, scutum and tergum separable. Tergum smaller than scutum, tergum higher than wide, tergum with 4 distinct crests for lateral depressor muscles. Scutum elongated and triangular, adductor pit deep. Mandible with 4 teeth, lower margin pectinated, three large setae at the edge; cirri I with conical spines; cirri II with multi-cuspidate setae and basal guard.

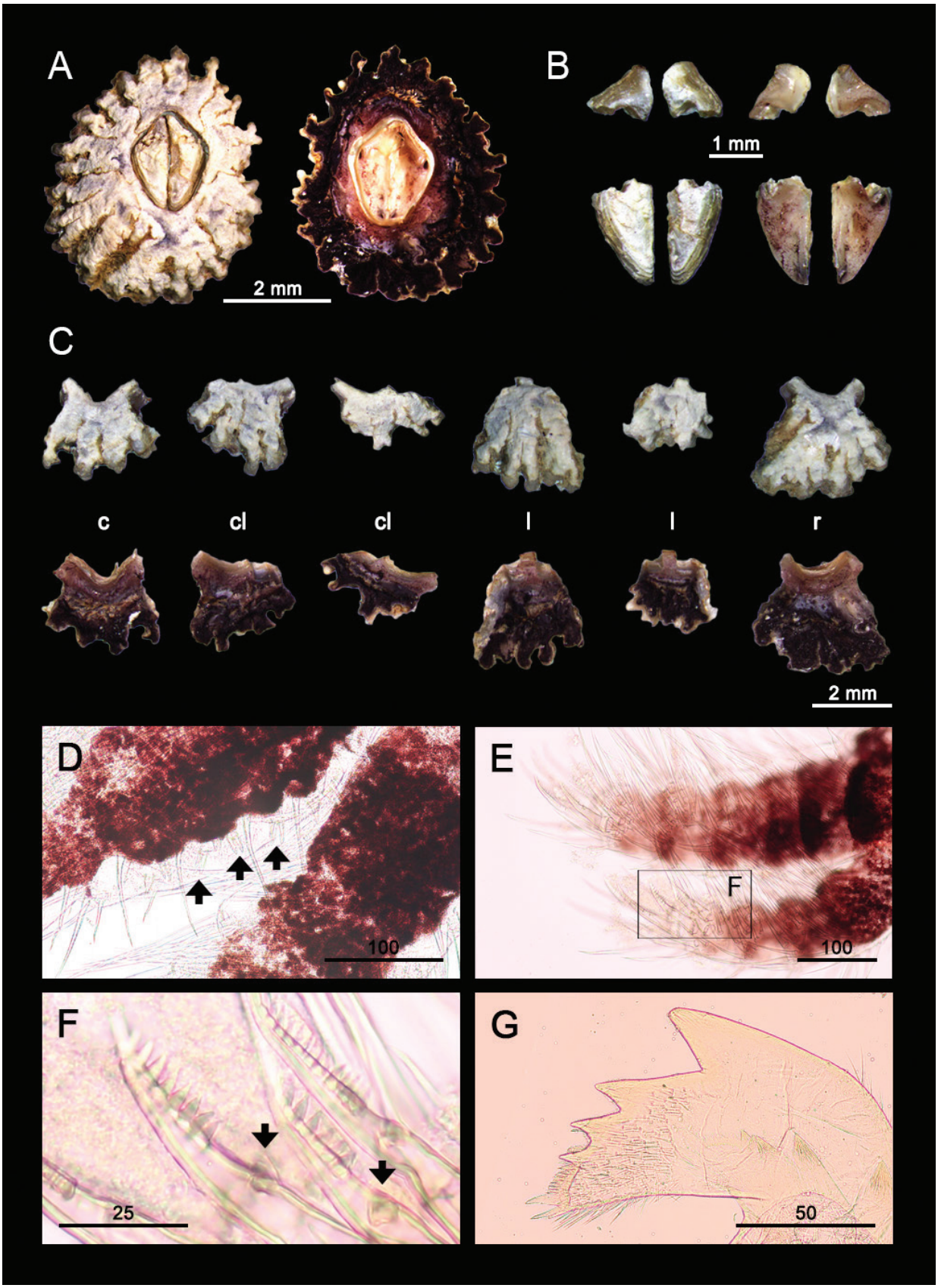

Figure 2. *Chthamalus malayensis* collected from Ka Lim beach, Phuket (BUU16.CH.CM07). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates, **D–G.** Light microscopy on mouthparts, **D.** Close up of cirri I showing conical spines(↑), **E.** Cirri II, **F.** Close up on cirri II showing multi-cuspidate setae with basal guard(↓), **G.** Mandible with four large teeth. **D-G.** Scale bars in µm. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

Table 2. Species list and distribution of acorn barnacles found in ten sampling sites along the coastlines of the Andaman Sea and the Gulf of Thailand. Abbreviations: +, presence; abs, absence. See Table 1 for acronyms of sampling sites.

Species	Sampling sites									
	Andaman Sea					Gulf of Thailand				
	AK	NT	KL	AY	PW	KS	SR	KK	BK	HN
Chthamalus malayensis	abs	+	+	+	+	abs	abs	+	abs	abs
Euraphia depressa	abs	abs	abs	abs	abs	+	abs	abs	abs	abs
Euraphia hembeli	abs	+	abs	abs	abs	abs	abs	abs	abs	abs
Newmanella spinosus	abs	+	abs	abs	abs	abs	abs	abs	abs	abs
Tetraclita kuroshioensis	+	+	+	+	abs	abs	abs	+	+	abs
Tetraclita singaporensis	abs	+	abs	abs	abs	abs	abs	abs	abs	abs
Tetraclita squamosa	abs	abs	abs	abs	abs	abs	abs	abs	abs	+
Amphibalanus amphitrite	+	+	+	+	+	+	+	+	+	+
Amphibalanus reticulatus	abs	+	abs	abs	abs	+	+	+	abs	abs
Megabalanus tintinnabulum	abs	+	abs	abs	abs	abs	abs	abs	abs	abs
Total number of species	**2**	**8**	**3**	**3**	**2**	**3**	**2**	**4**	**2**	**2**

Distribution. *Chthamalus malayensis* is widely distributed in the Indo-West Pacific region. It has been previously recorded in Taiwan, Thailand, China, Philippines, Vietnam, Malaysia, India and Australia (Jones 2004; Tsang et al. 2008; Tsang et al. 2012). From the previous observation, *C. malayensis* presented in both the Andaman Sea (Phuket) and the Gulf of Thailand (Si Chang and Samui Islands) (Tsang et al. 2012). In this study, *C. malayensis* were also found in both coastlines: the Andaman Sea (Na Tai, Kalim, Ao Yon, Panwa) and the Gulf of Thailand (Ko Kham Yai) (Table 2).

Remarks. *Chthamalus malayensis* has usually 4 crests for lateral depressor muscles while *Euraphia hembeli* and *Euraphia depressa* contains distinct 10–12 crests at the tergum and 3 small crests, respectively. The size of *C. malayensis* ranges from 3–10 mm similar to *E. depressa* while that of *Euraphia hembeli* is much bigger (10–33 mm). In addition, *C. malayensis* differs from *E. depressa* in two main characters diagnosed in this study: shape of external shell and jointing pattern of tergum and scutum. The shape of the external shell of *C. malayensis* shows a distinct and rather uniform ribbed surface from the lower region to the apex; on the other hand, *E. depressa* exhibits smooth surface that is never ribbed. Secondly, marked articulation and sinous jointing of tergum and scutum can be clearly noticed in *C. malayensis* while *E. depressa* shows less articulation. However, these shell morphology is not reliable tool for species identification among Chthamalids; hence, we further investigate arthropodal characters. It is clear that *Chthamalus* has four teeth on the mandible while *Euraphia* has three teeth on the mandible. In addition, to further identify *Chthamalus* into the correct species, setae on cirri I and cirri II were observed. Our specimens of Chthamalids have conical spines on cirri I and multi-cuspidate setae with basal guard on cirri II (Figure 2F); hence, our specimens are confirmed as *C. malayensis*.

Moreover, *C. malayensis* distributes above the vertical zonation of *Tetraclita* population. The overlapping of habitats can be seen among these species and even *C. malayensis* were found to attach to *Tetraclita* at the overlapping regions of high shore and middle shore.

Subfamily Euraphiinae Newman & Ross, 1976

Genus *Euraphia* Conrad, 1837

Type species. *Euraphia hembeli* Conrad, 1837

1 genus, 2 species recorded: *Euraphia depressa* (Poli, 1795) and *Euraphia hembeli* Conrad, 1837.

Euraphia depressa (Poli, 1795)

Figure 3; Tables 2–3

Chthamalus depressus Poli, 1791
Chthamalus stellatus var. *depressus*: Darwin, 1854.
Euraphia depressa: Utinomi (1959); Southward (1964).

Non-type material examined. Gulf of Thailand: 2 specimens, Chon Buri province, Mueang Chon Buri district, Khao Sam Muk beach, 05.VII.2016, W. Sukparangsi (BUU16.CM.ED01-02).

Description. Peduncle absent; body length 3–10 mm; base membranous. Shell light brown-yellowish brown with 6 plates (1 carina, 2 carinal latus, 2 latus and 1 rostrum), shell flatted and thin-walled; parietes symmetrical and solid, external surface of shell without ribbed, inner surface of parietes smooth and light brown and white with small horizontal striations around aperture, parietes separable, suture distinct and easily parted; orifice rhomboidal. Opercular plates symmetrical, tergum smaller than scutum, scutum and tergum separable jointing between tergum and scutum with slightly sinous. Scutum triangular with slightly curved basal margin, external surface with shallow and horizontal striations from occludent margin to tergal margin, occludent margin of scutum without teeth, tergal margin slightly sinous from interior view; tergum with 2–3 lateral depressor crests. Mandible with 3 teeth, lower margin pectinated with 8 setae, three

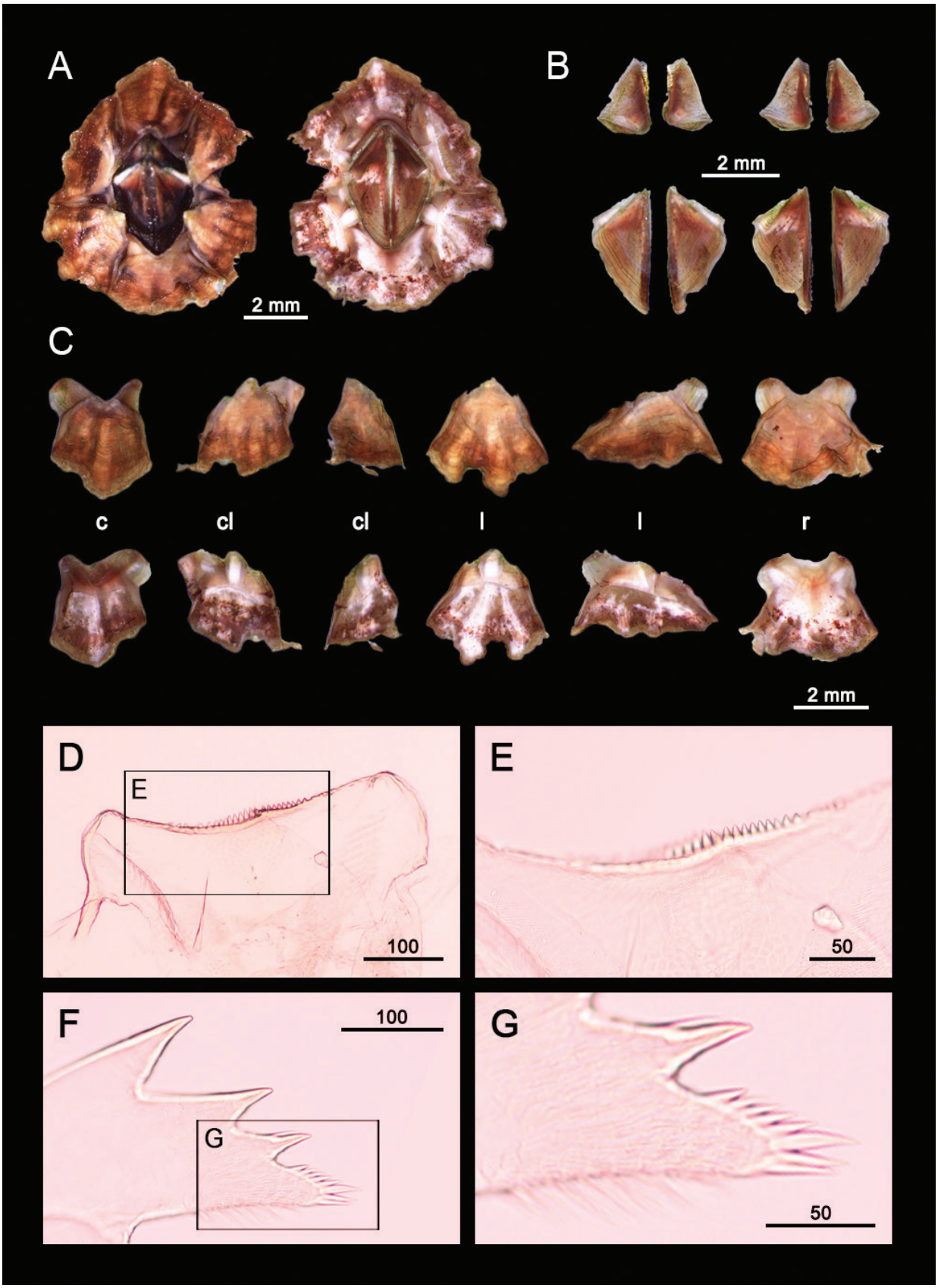

Figure 3. *Euraphia depressa* collected from Khao Sam Muk beach, Chon Buri (BUU16.CH.ED01). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates, **D-G.** Light microscopy on mouthparts, **D.** Labrum, **E.** Close up on the teeth of the labrum, **F.** Mandible with three large teeth, **G.** Close up on the pectinated lower margin of mandible. **D–G.** Scale bars in µm. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

Table 3. Distribution of acorn barnacles on different habitat types of intertidal zone (vertical zonation): low shores/ sublittoral zone (LS), middle Shores/ littoral zone (MS), and high shores/ supralittoral zone (HS).

Scientific name	Habitat type			Settlement pattern on habitats
	LS	MS	HS	
Family Chthamalidae				
Chthamalus malayensis			+	Attached to rock platform, shell of *Tetraclita* spp. and other substrates
Euraphia depressa			+	Attached to sheltered sites of rock
Euraphia hembeli	+	+		Attached to rocky shore exposed to heavy wave action
Family Tetraclitidae				
Newmanella spinosus	+			Attached to rocks on a wave exposed shore
Tetraclita kuroshioensis		+		Attached to rock platform and sheltered sites of rock
Tetraclita singaporensis		+		Attached to rock platform and sheltered sites of rock
Tetraclita squamosa		+		Attached to rock platform and sheltered sites of rock
Family Balanidae				
Amphibalanus amphitrite	+	+	+	Attached to rocks on a wave exposed shore, shell of oyster and Asian green mussel, offshore vessel and various substrates
Amphibalanus reticulatus	+	+		Attached to shell of Asian green mussel, oyster, ridged Venus clam and other substrates
Megabalanus tintinnabulum	+			Attached to rocky shore exposed to heavy wave action

large setae at the edge; labrum with obvious teeth; caudal appendage absent.

Distribution. In previous records, *Euraphia depressa* was found to inhabit along Mediteranean localities, including Spain (Punta Carnero, Punta de la Chullera, Malago, Salobrena and Calpe), France (Cap Bear, La Couronne, and Cassis), Italy (Pegli and Lido), Greece (Amnisso), the Black Sea and Suez canal (Utinomi 1959; Southward 1964; Achituv and Safriel 1980; Crisp 1981). In this study, the presence of *E. depressa* in Khao Sam Muk station (Chon Buri) in Thailand was unexpected as it was previously unrecorded along Thailand's coastal areas. They were found along rocky shores exposed to heavy wave action inhabiting sheltered crevices of the rocky platform and high shore. The abundance of *E. depressa* is much less than that of the cosmopolitan barnacle *Amphibalanus amphitrite* in the same area of observation.

Remarks. *Euraphia depressa* (Poli, 1795) was the reassigned name from *Chthamalus depressus* (Poli, 1795). According to Southward (1964), *Euraphia depressa* can be distinguished from *Chthamalus stellatus*, based on the shell morphology showing smooth unribbed shell on the external surface from younger specimens to more adult stage and the operculum characters, showing joints between tergum and scutum without sinous or slightly sinous, and smaller tergum. In addition, a barnacle of the genus *Euraphia* is distinguished from the genus *Chthamalus* based on the number of teeth on mandible and as described in Southward (1964) our specimens have mandible with three large teeth and three large setae on the lower edge (Figure 3F & G) and lacking of caudal appendages, leading to species identification of our specimens as *Euraphia depressa*. However, the number of setae at the pectinated margin of mandible in our specimens is different. Only small 5 setae after larger three setae were found in our specimens while up to 12 setae were mentioned in Southward (1964).

Euraphia hembeli Conrad, 1837

Figure 4; Tables 2–3

Euraphia hembeli Conrad, 1837: 261.

Non-type material examined. Andaman Sea: 2 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.CH.EH01-02).

Description. Peduncle absent; base membranous; body length larger than *Chthamalus* and range from 10–30 mm. Shell brownish grey with 6 plates (1 carina, 2 carinal latus, 2 latus and 1 rostrum), carina bigger than rostrum, carinal latus bigger than latus. External surface of shell irregularly ribbed around basal margin, inner surface of parietes smooth and white with dark brown and pale violet horizontal striations around aperture. Parietes symmetrical, calcareous and solid, parietes separable, sutures coarsely serrate or with interlocking toothed structure. Orifice rhomboidal. Operculum plates symmetrical, tergum smaller than scutum, tergum and scutum separable. Scutum triangular, occludent margin of scutum with strong teeth. Tergum strongly marked with 10–12 lateral depressor crests, scutal margin strongly articulated.

Distribution. Barnacles in the genus *Euraphia* were recorded in several regions including West Africa, the Mediterranean, Hawaii and Southern Japan (Newman and Ross 1976). *Euraphia hembeli* was previously recorded in California around San Diego (Barrett and Freeman 2016). In this study, we report the presence of *Euraphia hembeli* distributing along low and middle shore of the intertidal zone, which was only found at Na Tai station, the Andaman Sea (Tables 2 and 3). In addition, this is the first report of its presence in Thailand.

Remarks. Based on the shell and opercular valve morphology (Newman and Ross 1976; Kim and Yamaguchi 1996), two candidates: *Euraphia hembeli* Conrad, 1837 and *Euraphia*

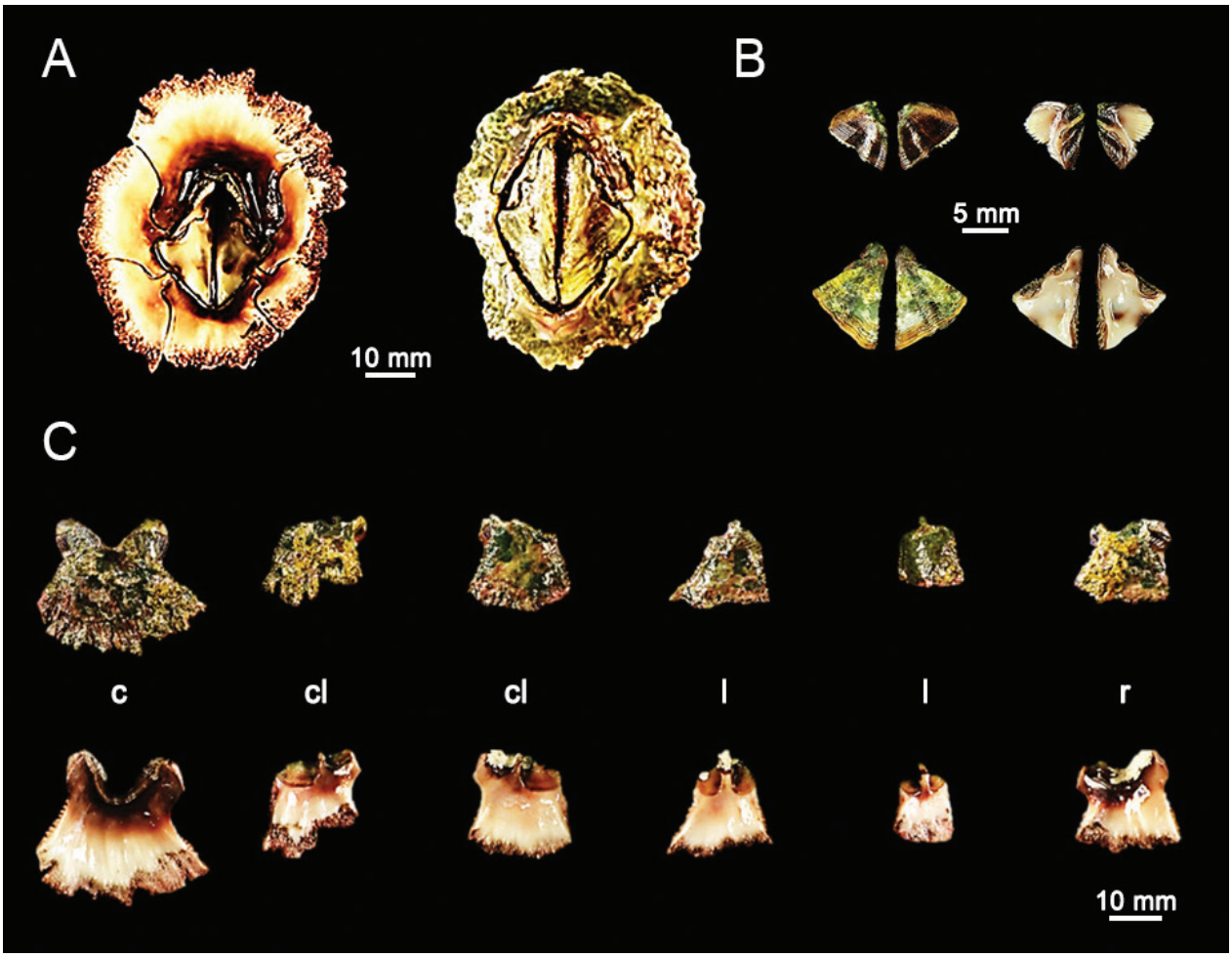

Figure 4. *Euraphia hembeli* collected from Na Tai beach, Phang-nga (BUU16.CH.CH01). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

pilsbryi Hiro, 1936 (reassigned as *Hexechamaesipho pilsbryi* (Hiro, 1936)) show similar patterns of opercular plates to our collected specimens. Based on Newman and Ross (1976), description of *Euraphia hembeli* in Barrett and Freeman (2016) and Chan et al. (2008), our specimens fit more into *E. hembeli* and differ from other *Euraphia* in its gigantic appearance (up to 30 mm) and the presence of strong marked lateral depressor crests (10–12 in number, less in *H. pilsbryi*).

Superfamily Tetraclitoidea Gruvel, 1903
Family Tetraclitidae Gruvel, 1903
Subfamily Newmanellinae Ross & Perreault, 1999

Genus *Newmanella* Ross, 1969

Type species. *Newmanella radiata* (Bruguiere, 1789)

1 genus, 1 species recorded: *Newmanella spinosus* Chan & Cheang, 2016.

***Newmanella spinosus* Chan & Cheang, 2016**

Figure 5; Tables 2–3

Newmanella spinosus Chan & Cheang, 2016: 212–220, figs 9–15.

Non-type material examined. Andaman Sea: 4 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.TC.NS01-04).

Description. Peduncle absent; base calcareous. Shell greyish green, shell with 4 plates (1 carina, 2 latus, 1 rostrum); parietes low conical, 3–4 rows of irregular parietal tubes (parietes multiple tubiferous), radii board with horizontal striation and summit oblique. External surface with deep longitudinal/radiating lines from base to apex, internal surface of parietes smooth and white with greyish green striations close to operculum. Orifice pentagonal, diamond-shaped. External surface of operculum brownish grey, internal surface of operculum white. Scutum triangular, external surface of scutum with horizontal striations; tergum high and narrow, tergum with numerous depressor crests.

Distribution. *Newmanella spinosus* was previously recorded from low intertidal to subtidal levels on rock shores along the coastlines of Taiwan and the Philippines and they were also collected from the surfaces of buoys

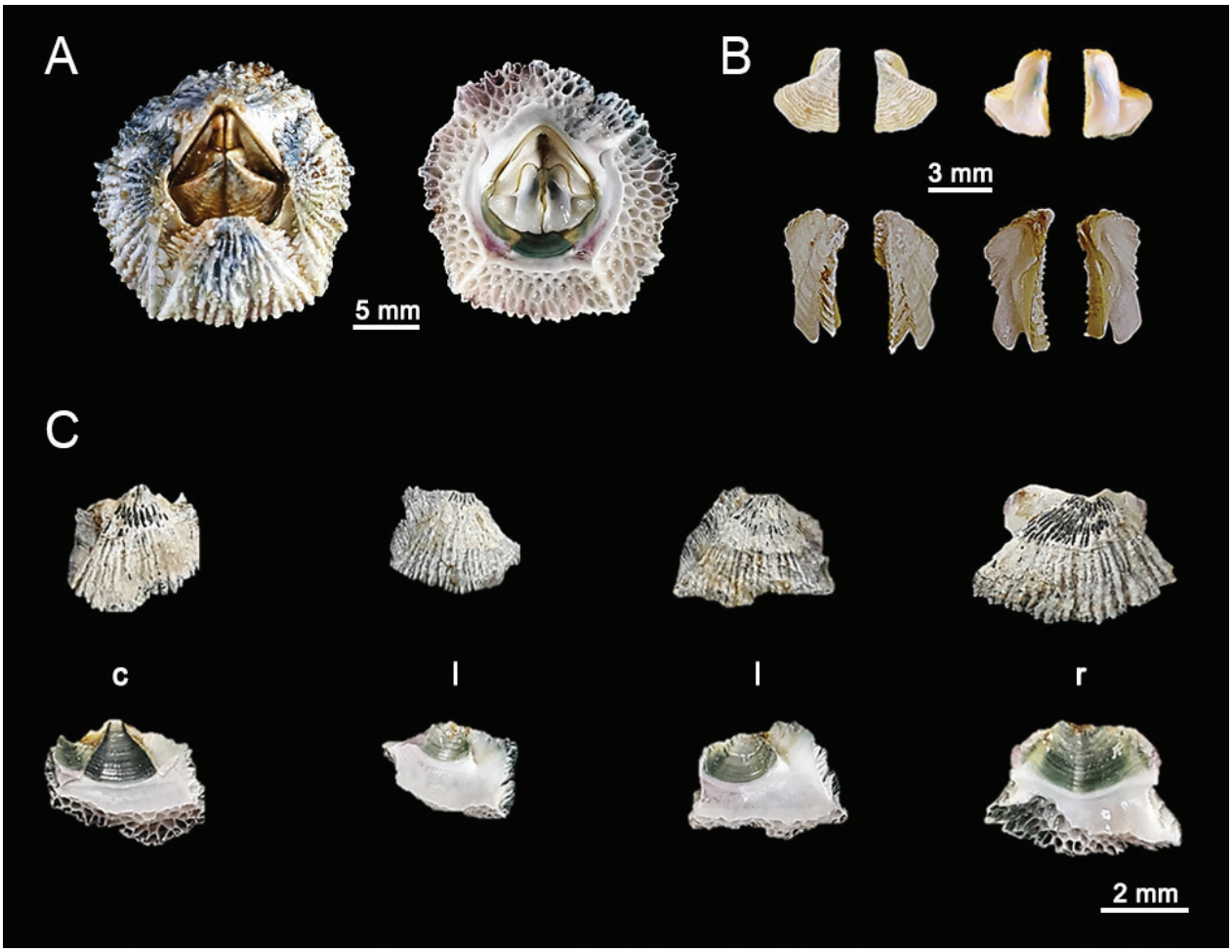

Figure 5. *Newmanella spinosus* collected from Na Tai beach, Phang-nga (BUU16.TC.NS01). **A**. Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates. Abbreviations: c, carina; l, latus; r, rostrum.

used in fishing cages in the open sea (Chan and Cheang 2016). In this present study, *N. spinosus* specifically distributes along low shores, and the intertidal zones of Na Tai beach, Takua Thung District, Phang-nga (the Andaman Sea).

Remarks. *N. spinosus* is morphologically similar to *N. radiata,* based on shell and scutum. The shell of *N. spinosus* is green while those of *N. radiata* is white. In addition, lateral scutal depressor muscle crest is shallow in the scutum of *N. radiata*, but deep in *N. spinosus*. The distribution of *N. spinosus* is around the North Pacific Ocean, from Okinawan Japan to Taiwan and the Philippines (Chan and Cheang 2016). The presence of *N. spinosus* in Thailand is surprising in our study, and creates the first record of this species distributing specifically in Na Tai beach, Takua Thung district, Phang-nga province.

Subfamily Tetraclitinae Newman & Ross, 1976

Genus *Tetraclita* Schumacher, 1817

Type species. *Tetraclita squamosa* (Bruguiére, 1789)

1 genus, 3 species recorded: *Tetraclita kuroshioensis* Chan, Tsang & Chu, 2007, *Tetraclita singaporensis* Chan, Tsang & Chu, 2007 and *Tetraclita squamosa* (Bruguiere, 1789).

Tetraclita kuroshioensis Chan, Tsang & Chu, 2007

Figure 6; Suppl. material 1; Tables 2–3

Tetraclita squamosa viridis: Hiro, 1936: 635; 1937: 469; 1939: 271.
Tetraclita squamosa squamosal: Utinomi, 1968: 178.
Tetraclita pacifica Chan et al., 2007b: 88.

Non-type material examined. Andaman Sea: 2 specimens, Phang-nga province, Khura Buri district, Ao Khoei beach, 30.VII.2015, A. Pochai (BUU16.TC.TK01-02). 3 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.TC.TK03-05). 2 specimens, Phuket province, Mueang Phuket district, Ao Yon beach, 15.VII.2015, A. Pochai (BUU16.TC.TK06-07). 3 specimens, Phuket province, Katu district, Kalim beach, 15.VII.2015, A. Pochai (BUU16.TC.TK08-10).

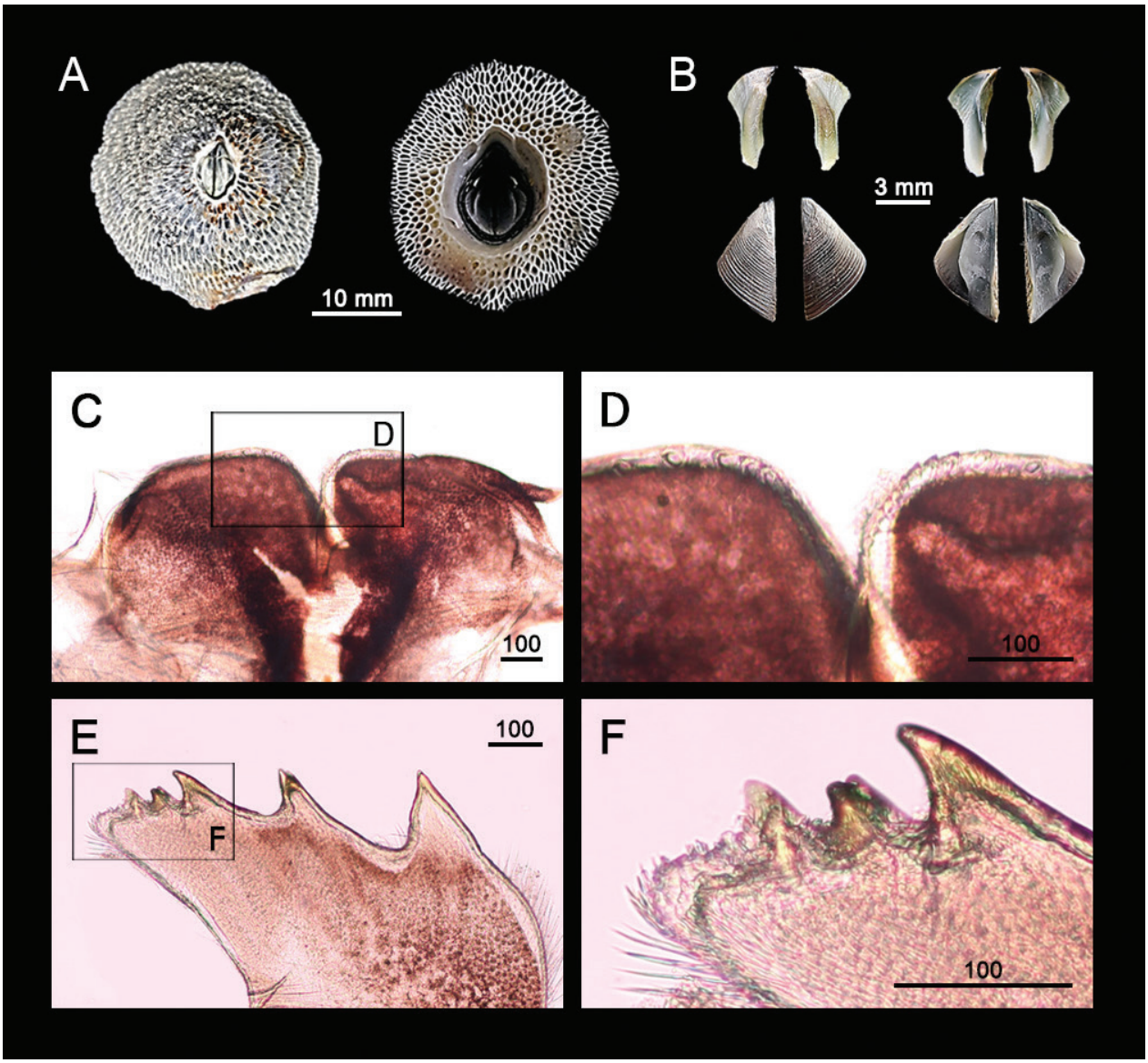

Figure 6. *Tetraclita kuroshioensis* collected from (BUU16.TC.TK01) from Na Tai beach, Phang-nga. **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C–F.** Light microscopy on mouthparts, **C.** Labrum, **D.** Close up on the teeth of the labrum, **E.** Mandible, **F.** Close up on the lower margin of mandible. **C–F.** Scale bars in μm.

Gulf of Thailand: 3 specimens, Prachuap Khiri Khan province, Bang Saphan district, Ban Krut beach, 06.IX.2015, A. Pochai (BUU16.TC.TK11-13). 3 specimens, Chon Buri province, Ko Si Chang district, Ko Kham Yai beach, 05.VII.2015, S. Khachonpisitsak (BUU16.TC.TK14-16).

Description. Peduncle absent; base membranous; shell greyish black to purplish-grey with 4 plates (1 carina, 2 latus, 1 rostrum), parietes conical, plates inseparable, 7–8 rows of parietal tubes (parietes multiple tubiferous), external surface with mosaic scales pattern radiating randomly from base to apex, internal surface of parietes smooth and white with dark grey striations around aperture. External surface of operculum mixed grey and yellowish-light brown, internal surface of operculum greyish-dusky green. Scutum bigger than tergum, scutum triangular, external surface of scutum with horizontal striations, occludent margin of scutum with obvious shallow and rough teeth, short articular ridge-basal margin, angle between basal margin and tergal margin is quite perpendicular. Tergum higher than wide, basi-scutal angle 158°, tergum with broad spur, spur angle 30°. Mandible with 4 big teeth, 1st tooth smaller; maxillule not notched with 11 setae; labrum with 5 small teeth on each side; cirri I possessing serrulate setae.

Distribution. *Tetraclita kuroshioensis* is reassigned the name from *Tetraclita squamosa* which were collected from Taiwan, and Okinawa and Honsu of Japan, and *Tetraclita pacifica*. The distribution of this species occurs

in broad area along north-west Pacific region (Chan et al. 2007a, b; Chan 2009). In this present study, the species distribution occurs along littoral intertidal zones in both the Andaman Sea (Ao Yon, Ao Khoei, Na Tai, and Kalim) and the Gulf of Thailand (Ban Krut and Ko Kham Yai).

Remark. *Tetraclita kuroshioensis* is quite similar to *Tetraclita singaporensis* in following characteristics: tergum without beak and with wide spur, scutum with short articular ridge-basal margin. However, angle between tergal margin and basal margin of *T. kuroshioensis* is more perpendicular (90°) or shaper while that of *T. singaporensis* is curved.

Tetraclita singaporensis Chan, Tsang & Chu, 2007

Figure 7; Suppl. material 2; Tables 2–3

Tetraclita singaporensis Chan, Tsang & Chu, 2007: 52–53, figs 1–3.

Non-type material examined. Andaman Sea: 2 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.TS.TSG01-02).

Description. Peduncle absent; base membranous; shell purplish-dusky green with 4 plates (1 carina, 2 latus, 1 rostrum), parietes conical, plates inseparable, 5–6 rows of parietal tubes (parietes multiple tubiferous), external surface with deep and irregular longitudinal striations from apex to base and small radiating lines, internal surface of parietes smooth and white with greyish-green horizontal striations around aperture. External surface of operculum yellowish brown mixed with dusky green, internal surface of operculum dusky green-purplish and white around spur of the tergum. Scutum bigger than tergum, scutum triangular, short articular ridge-basal margin, external surface of scutum with horizontal striations, occludent margin of scutum with rough teeth. Tergum higher than wide, tergum with broad spur and not beaked, spur angle 30–35°, basi-scutal margin 148–150°. Mandible with 4 big teeth, 2nd and 3rd teeth consisting double teeth, 1st tooth with small spines, lower margin pectinate with 8 small teeth and obvious double bigger teeth at the edge; maxillule notched, two large setae above notch, 13–17 setae below notch; labrum with 4–5 large teeth on each side; cirri I possessing bidenate serrulate setae.

Distribution. *Tetracliata singaporensis* has been reassigned the name from previously known as *Tetraclita squamosa*, which were collected from Singapore. Hence, the distribution of this species is firstly marked at Singapore, Indo-West Pacific region (Chan et al. 2007a). In this present work, the specimens were collected from Na Tai, Andaman Sea and it distributes in the mid shore.

Remarks. *Tetraclita singaporensis* differs from *Tetraclita squamosa* in that it has tergum without beak and broader spur, and scutum with short articular ridge-basal margin.

Tetraclita squamosa (Bruguiére, 1789)

Figure 8; Suppl. material 3; Tables 2–3

Balanus squamosa Bruguiére, 1789: 170.
Lepas porosa Gmelin, 1791: 3212.
Tetraclita porosa var. *viridis*: Darwin, 1854: 329; Borradaile, 1900: 799; Gruvel, 1905: 228; Krüger, 1911: 61, pl. 4, fig. 41b; Hoek, 1913: 254;
Tetraclita squamosa: Stebbing, 1910: 570; Barnard, 1924: 90; Oliveira, 1941: 6.
Tetraclita squamosa squamosa: Pilsbry, 1916: 251; Kolosváry, 1943: 96; Henry, 1957: 33; Stubbings, 1967: 294; Newman & Ross, 1976: 48; Ren & Liu, 1979: 339, pl. 1, figs. 1–11.
Tetraclita squamosa forma viridis: Broch, 1922: 337; 1931: 116.
Tetraclita porosa perfecta Nilsson-Cantell, 1921: 364.
Tetraclita squamosa: Yamaguchi, 1987: 344; Chan, 2001: 625, fig. 8; Chan et al., 2007b: 82, fig. 4.

Non-type material examined. Gulf of Thailand: 2 specimens, Nakhon Si Thammarat province, Sichon district, Hin Ngam beach, 04.VII.2015, A. Pochai (BUU16.TC.TSS01-02).

Description. Peduncle absent; base membranous; shell green mixed with brownish grey, shell with 4 plates (1 carina, 2 latus, 1 rostrum); parietes conical, plate fused, inseparable, 8 rows of parietal tubes (parietes multiple tubiferous), external surface with longitudinal lines from base to apex, internal surface of parietes smooth and white with purplish grey striations close to aperture, External surface of operculum brownish grey, internal surface of operculum purplish grey. Scutum larger than tergum, scutum triangular, long articular ridge-basal margin, external surface of scutum with horizontal striations, occludent margin of scutum with very shallow teeth; tergum higher than wide, basi-scutal margin 158–160°, tergum apex obviously beaked, tergum with spur long and sharp, spur angle 25°. Mandible with 4 big teeth, 1st tooth with three small spines, lower margin pectinate; maxillule notched, two large setae above notch, 11 big setae below notch and some smaller setae at the edge; labrum with 4 large teeth on each side; cirri I possessing bidenate serrulate setae.

Distribution. *Tetraclita squamosa* is widespread in tropical and subtropical waters from West Africa, the Indo-Pacific, the Indian Ocean, Australia, Indonesia and Singapore (Newman and Ross 1976; Ren and Liu 1979; Jones et al. 2000; Chan et al. 2007b). Its distributions in Thailand were previously recorded in two places: the Andaman Islands and the Gulf of Siam (recently called the Gulf of Thailand) (Jones 2000). In this present study, *T. squamosa* has restricted areas of distribution and it was found specifically at Hin Ngam beach, the Gulf of Thailand coast. Regarding vertical zonation, *T. squamosa* found in Thailand occurs on the mid shore.

Remark. As described in Chan et al. 2007a, b, *T. squamosa* (southern China) has unique tergum characteristics including tergum with beak and long spur, and scutum with long articular ridge-basal margin. Our specimens

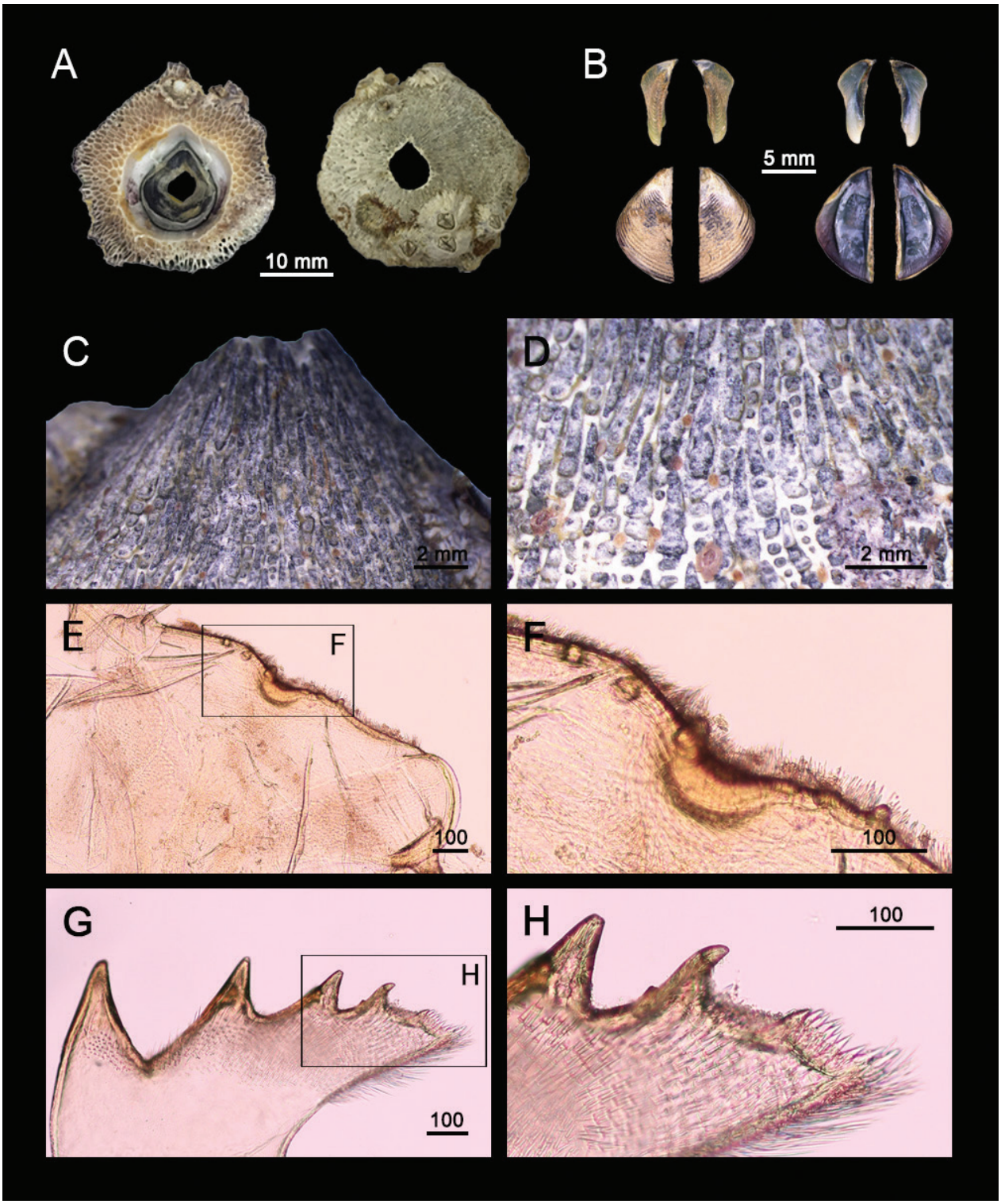

Figure 7. *Tetraclita singaporensis* collected from (BUU16.TC.TSG02) from Na Tai beach, Phang-nga. **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** Lateral side showing external surface of shell, **D.** Close up on the external surface of shell, **E–H.** Light microscopy on mouthparts, **E.** Labrum, **E.** Close up on the teeth of the labrum, **G.** Mandible, **G.** Close up on the pectinated lower margin of mandible. **E–H.** Scale bars in µm.

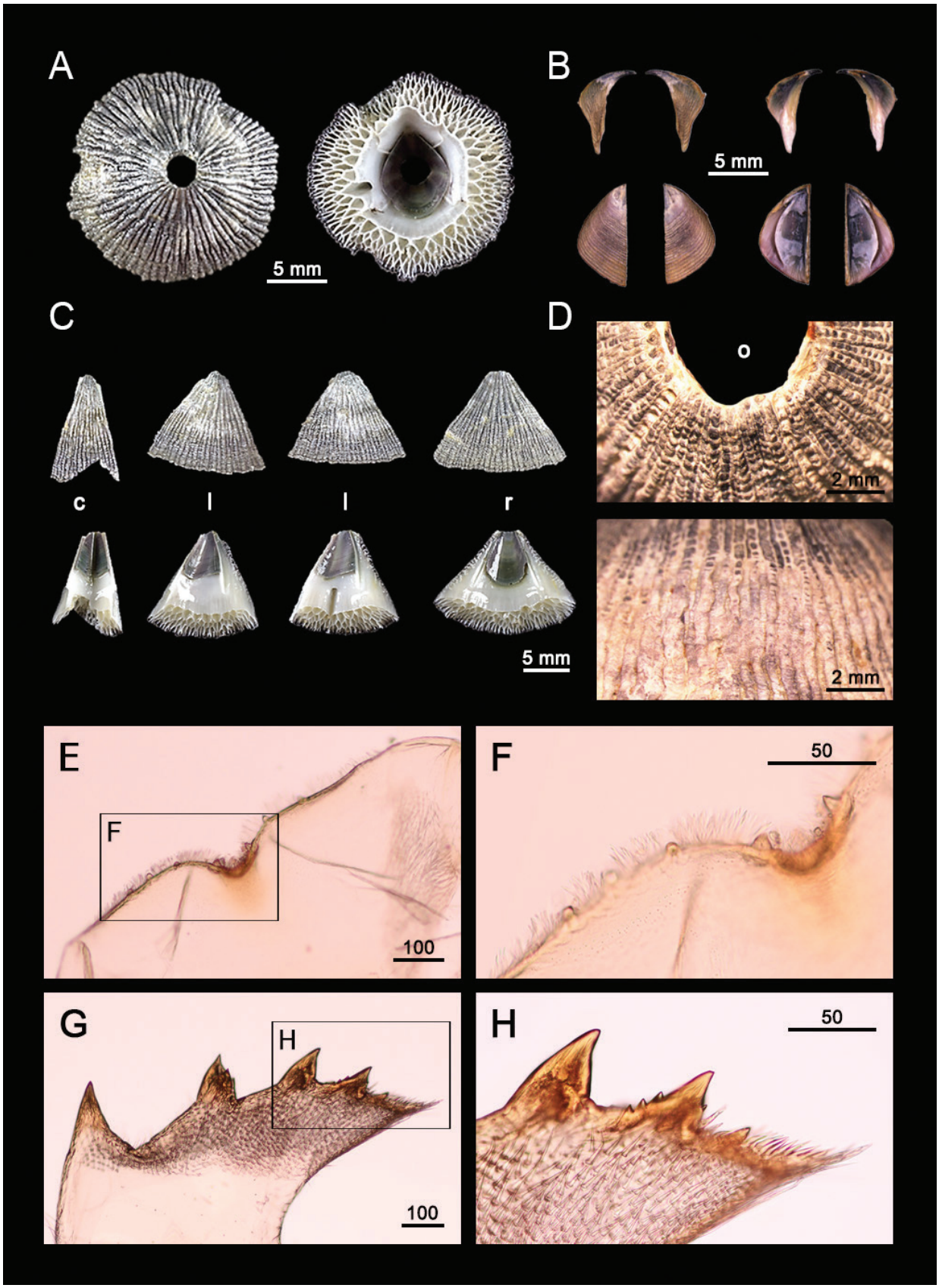

Figure 8. *Tetraclita squamosa* collected from Hin Ngam beach, Nakhon Si Thammarat (BUU16.TC.TS01). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates, **D.** Close up on external surface of shell, **E–H.** Light microscopy on mouthparts, **E.** Labrum, **E.** Close up on the teeth of the labrum, **G.** Mandible, **G.** Close up on the pectinated lower margin of mandible. **E–H.** Scale bars in µm. Abbreviations: c, carina; l, latus; r, rostrum.

from Hin Ngam beach have all of these characteristics; hence, it is more fitted into *T. squamosa* (Southern China) rather than *T. squamosa* (Singapore), which is reassigned as *T. singaporensis*.

Superfamily Balanoidea Leach, 1817
Family Balanidae Leach, 1817
Subfamily Amphibalaninae Pitombo, 2004

Genus *Amphibalanus* Pitombo, 2004

Type species. *Amphibalanus amphitrite* (Darwin, 1854)

1 genus, 2 species recorded: *Amphibalanus amphitrite* (Darwin, 1854) and *Amphibalanus reticulatus* (Utinomi, 1967).

Amphibalanus amphitrite (Darwin, 1854)

Figure 9; Tables 2–3

Balanus amphitrite var. *communis* Darwin, 1854: 240 (in part).
Balanus amphitrite Weltner, 1897: 264; Pilsbry, 1907: 190; 1928: 312.
Balanus amphitrite communis: Hiro, 1939: 263.
Balanus amphitrite hawaiiensis: Hiro, 1939: 260.
Amphibalanus amphitrite: Pitombo, 2004: 263.

Non-type material examined. Andaman Sea: 2 specimens, Phang-nga province, Khura Buri district, Ao Khoei beach, 30.VII.2015, A. Pochai (BUU16.BN.AA01-02). 4 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.BN.AA03-06). 4 specimens, Phuket province, Mueang Phuket district, Ao Yon beach, 15.VII.2015, A. Pochai (BUU16.BN.AA07-10). 3 specimens, Phuket province, Mueang Phuket district, Panwa beach, 16.VII.2015, S. Khachonpisitsak (BUU16.BN.AA11-13). 4 specimens, Phuket province, Katu district, Kalim beach, 15.VII.2015, A. Pochai (BUU16.BN.AA14-17).

Gulf of Thailand: 2 specimens, Nakhon Si Thammarat province, Sichon district, Hin Ngam beach, 09.VIII.2015, A. Pochai (BUU16.BN.AA18-19). 4 specimens, Prachuap Khiri Khan province, Bang Saphan district, Ban Krut beach, 06.IX.2015, A. Pochai (BUU16.BN.AA20-23). 2 specimens, Chon Buri province, Ko Si Chang district, Ko Kham Yai beach, 05.VII.2015, S. Khachonpisitsak (BUU16.BN.AA24-25). 4 specimens, Chon Buri province, Si Racha district, Si Racha beach, 04.VII.2015, A. Pochai (BUU16.BN.AA26-29). 3 specimens, Chon Buri province, Mueang Chon Buri district, Khao Sam Muk beach, 05.VII.2015, A. Pochai (BUU16.BN.AA30-32).

Description. Peduncle absent; base calcareous. Shell white-pale pink with 6 plates (1 carina, 2 carinal latus, 2 latus, 1 rostrum); single rows of parietal tubes (parietes single tubiferous) with transverse septa; radii solid. External surface with purple longitudinal striations from apex to base (3–4 lines per plate) without horizontal striation, transverse teeth on suture edges with denticles on lower regions, internal surface of parietes grey with black horizontal striations close to operculum. External surface of operculum brownish grey, internal surface of operculum grey-white. Scutum bigger than tergum, scutum triangular, external surface of scutum with curved striations; tergum spur board with growth lines.

Distribution. *Amphibalanus amphitrite* is a common fouling barnacle and cosmopolitan species distributed along intertidal zones of coastlines in both the Gulf of Thailand and the Andaman Sea. It was found in all stations examined. The settlement patterns are various (e.g. rocks, shells of oyster and green mussels, concrete walls of bridges and harbors, offshore vessels, dock pilling, and mooring robes). In previous records, this species distributes worldwide in both tropical and temperate regions including the Indo-West Pacific, and Western Australia (Jones 2004; Chen et al. 2014) and it has been suggested that this wide range of distribution was due to human-mediated activities during global trade expansion (Chen et al. 2014).

Remark. The morphology of *Amphibalanus amphitrite* is variable from diverse habitats worldwide. Shells exposed and eroded by heavy wave action showed no purple stripes on the external surface. The molecular analysis has confirmed its genetic differentiation which might be due to local adaptation and geographical isolation (Chen et al. 2014). Due to hypothesis on human-mediated activities as the main cause of *A. amphitrite*'s distribution across the globe, this species is considered as non-native or introduced species in these examined regions: Hawaii, California, North Carolina, and the Atlantic coast (Carlton et al. 2011), whereas it is considered as native in tropical waters (e.g. Hong Kong, Thailand, Malaysia) supported by molecular study (Chen et al. 2014). Despite the diverse morphology of *A. amphitrite*, another species in the same genus *Amphibalanus reticulatus* exhibits clear patterns of shell carrying both vertical and longitudinal striations on the external surface. The separation of settlement type is distinct between these two species; one is found mostly on rocky shores exposed to waves and the other one is found on some mollusk shells.

Amphibalanus reticulatus (Utinomi, 1967)

Figure 10; Tables 2–3

Balanus amphitrite var. *communis* Darwin, 1854: 240, pl. 5, figs. 2e, h, l [type locality: Tachitgatani, Tanabe Bay, Japan].
Balanus amphitrite communis: Hiro, 1938: 301, figs. 1a, b; Utinomi, 1956: 52, pl. 26, fig. 11.; 1960: 44, figs. 1c, d, 2c, d.
Balanus reticulatus: Utinomi, 1967: 216, figs. 9a, b, 10a, b, 11a-e, pl. 6, figs. 7–8; Henry & McLaughlin, 1975: 88, text figs. 11, 18, pl. 7, fig. d, pl. 8, pl. 9, figs. a, d, e.

Non-type material examined. Andaman Sea: 2 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.BN.AR01-02).

Gulf of Thailand: 3 specimens, Chon Buri province, Si Racha district, Si Racha beach, 04.VII.2015, A. Pochai (BUU16.BN.AR03-05). 3 specimens, Chon Buri

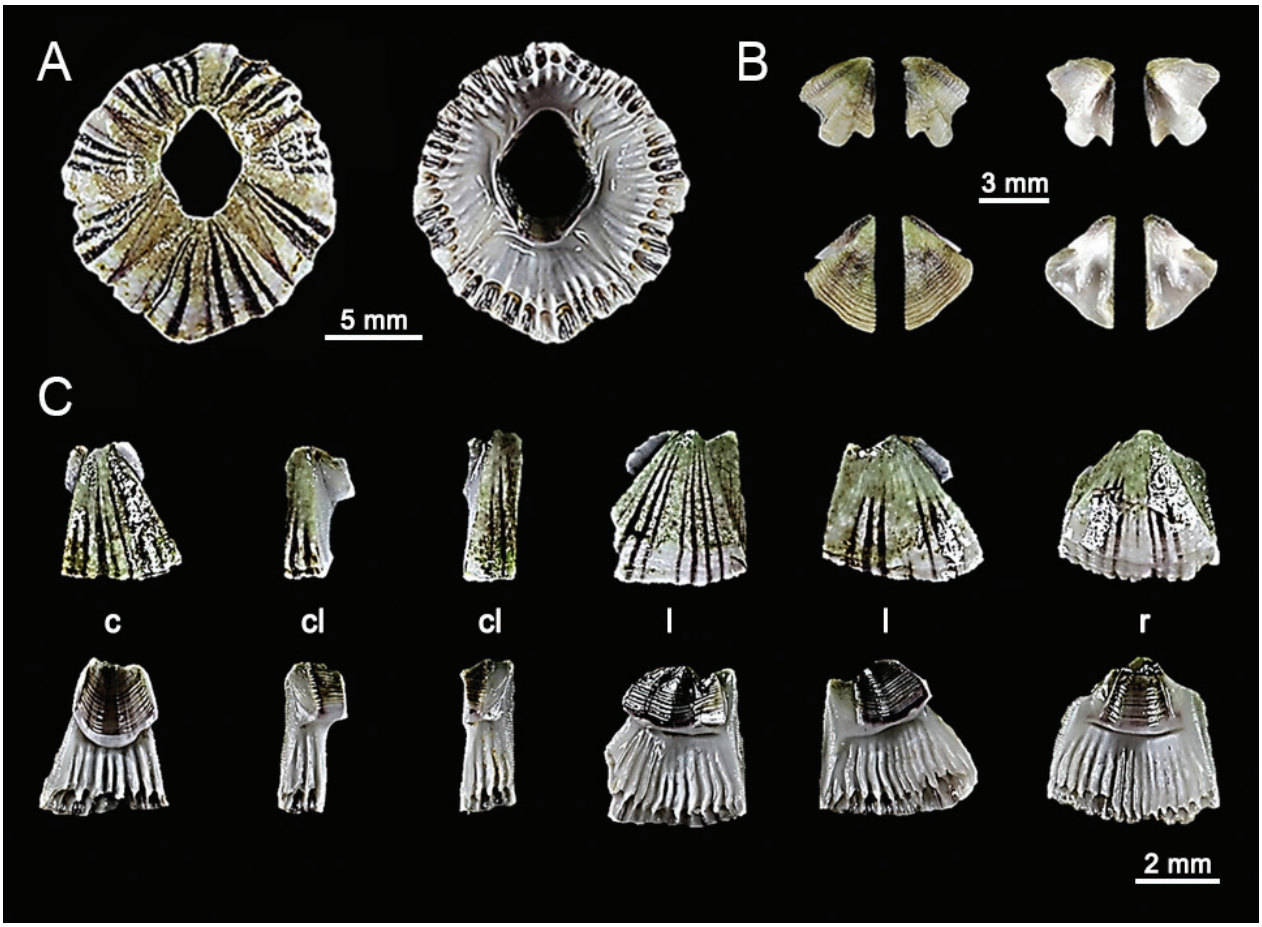

Figure 9. *Amphibalanus amphitrite* collected from Khao Sam Muk beach, Chon Buri (BUU16.BA.AA30). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

province, Mueang Chon Buri district, Khao Sam Muk beach, 05.VII.2015, A. Pochai (BUU16.BN.AR06-08). 3 specimens, Chon Buri province, Ko Si Chang district, Ko Kham Yai beach, 05.VII.2015, S. Khachonpisitsak (BUU16.BN.AR09-11).

Description. Peduncle absent; base calcareous. Shell white-pale pink and orange with 6 plates (1 carina, 2 carinal latus, 2 latus, 1 rostrum); single rows of parietal tubes (parietes single tubiferous) with transverse septa; radii solid. External surface with longitudinal and horizontal striations, transverse teeth on suture edges with denticles on lower regions, internal surface of parietes white. External surface of operculum white-pale pink and orange with striations in both tergum and scutum, internal surface of operculum white. Scutum bigger than tergum, scutum triangular; tergum spur sharp with growth lines.

Distribution. *Amphibalanus reticulatus* is widely distributed from Japan, the Indo-West Pacific to Australia, of which the latter is considered as an introduced species carried by ship transport (Jones 2004). In this study, *A. reticulatus* occurred in the intertidal zone along the Andaman Sea and the Gulf of Thailand. These specimens were found at Si Racha, Khao Sam Muk, Ko Kham Yai (Chon Buri) and Na Tai (Phang-nga).

Remark. *Amphibalanus reticulatus* exhibits clear vertical and horizontal striations while *Amphibalanus amphitrite* shows only vertical purple striation in all shell plates. In addition, the shapes of shell of *A. reticulatus* is more columnar than that of *A. amphitrite*, which might be due to elongation of parietes in response to crowding when growing as colonies. On all examined stations, distinct distribution and settlement between *A. amphitrite* and *A. reticulatus* can be noticed, in that *A. amphitrite* were found in almost all kinds of substrates but *A. reticulatus* preferred its attachment on shells which obviously did not live along the rocky shores and it might probably inhabit the deeper areas of the sea and were occasionally carried away into the shores by wave action.

Subfamily Megabalaninae Newman, 1979

Genus *Megabalanus* Hoek, 1913

Type species. *Megabalanus tintinnabulum* (Linnaeus, 1758)

1 genus, 1 species recorded: *Megabalanus tintinnabulum* Linnaeus, 1758.

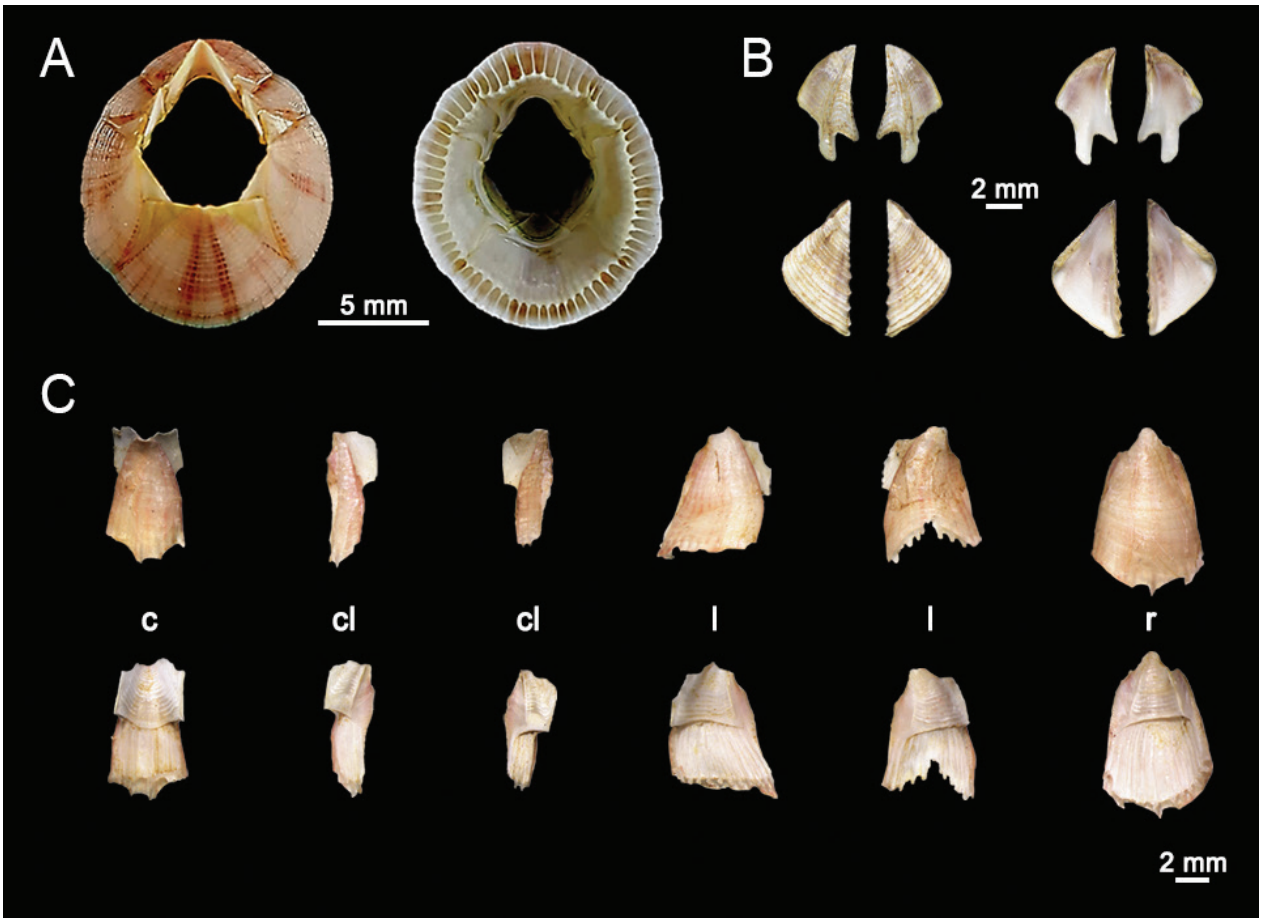

Figure 10. *Amphibalanus reticulatus* collected from Si Racha beach, Chon Buri (BUU16.BN.AR01, **A**; BUU16.BN.AR 03, **B & C**). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

Megabalanus tintinnabulum (Linnaeus, 1758)

Figure 11; Tables 2–3

Lepas tintinnabulum Linnaeus, 1758: 668.
Balanus tintinnabulum: Bruguiére, 1789: 165 (in part); Holthuis & Heerebout, 1972: 24, pl.1.
Lepas tintinnabulum Wood, 1815: 38, pl. 6, figs. 1, 2.
Balanus tintinnabulum tintinnabulum: Pilsbry, 1916: 55, pl. 10, fig.1–1e; Hiro, 1939: 258, figs. 7a-b; Daniel, 1956: 17, pl. 4, figs. 1–6; Davadie, 1963: 26, pl.2, fig. 4, pl. 6, figs. 1a, 2b; Zevina & Tarasov, 1963: 87, fig. 8; Stubbings, 1964: 335.
Balanus tintinnabulum var. *tintinnabulum*: Oliveira, 1941: 11, text-fig. 1, pl. 2, figs. 1, 2, pl. 4, fig. 1, pl. 5 fig. 3, pl. 8, fig. 6.
Megabalanus tintinnabulum: Newman & Ross, 1976: 68; Lacombe & Rangel, 1978: 3, fig. 4.

Non-type material examined. Andaman Sea: 3 specimens, Phang-nga province, Takua Thung district, Na Tai beach, 16.V.2015, A. Pochai (BUU16.BN.MT01-03).

Description. Peduncle absent; base calcareous. Shell cylindric or conic with 6 plates (1 carina, 2 carinal latus, 2 latus, 1 rostrum); parietes reddish to brownish red usually with longitudinal striations on external surface, parietes not prominently ribbed and rather smooth, irregular shape of parietal tubes (parietes tubiferous), sutural edges of radii with regular denticles, radii wide with horizontally striated, radii tubiferous; internal surface of parietes pale-purple with horizontal greyish violet striations around aperture. Orifice subcircular to rhombus. External surface of operculum white-pale pink and orange with prominent growth ridges in both tergums and scutums, internal surface of operculum white. Scutum bigger than tergum, scutum triangular, adductor ridge of scutum prominent; tergum with spur, spur furrow of tergum closed, scutal margin denticulate.

Distribution. *Megabalanus tintinnabulum* is widely distributed across almost all continents and is a well-known cosmopolitan fouling species. It was previously found in French Guiana, the United States, Australia, Mexico, Ecuador, Kuwait, Saudi Arabia, Sweden, France, Netherlands, Singapore, Indonesia and India (Henry and Mclaughlin 1986; Thiyagarajan et al. 1997; Jones et al. 2000; Jones 2004). Similar to *Amphibalanus*, it is considered as an introduced species in several regions and its distribution has been facilitated via shipping (Jones 2004). In Thailand, *M. tintinnabulum* specifically occurs in the low

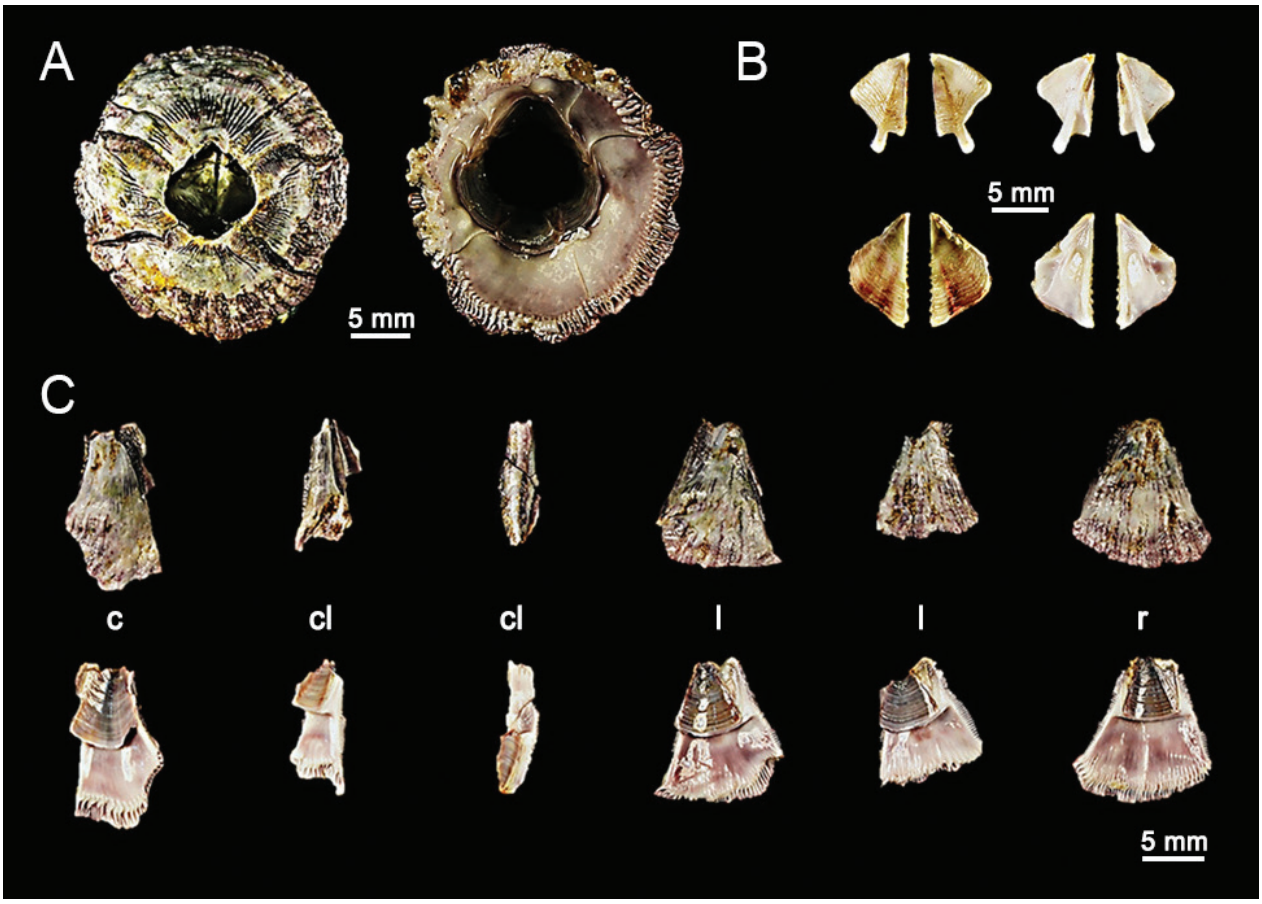

Figure 11. *Megabalanus tintinnabulum* collected from Na Tai beach, Phang-nga (BUU16.BN.MT01). **A.** Dorsal and ventral view of external shell, **B.** External (left panel) and internal (right panel) view of tergum (upper panel) and scutum (lower panel), **C.** External (upper panel) and internal (lower panel) view of shell plates. Abbreviations: c, carina; cl, carinal latus; l, latus; r, rostrum.

shores at Na Tai beach, Phang-nga province (the Andaman Sea). However, it does not appear to be a common fouling species as seen in some regions. *M. tintinnabulum* might have been introduced to Phang-nga beaches via ship transport, and the competition for habitat niche is compromised, compared to previously occupying cosmopolitan *A. amphitrite*.

Remarks. *Megabalanus tintinnabulum* has relatively larger shell plates than those of *Amphibalanus*. All three examined species (*M. tintinnabulum*, *A. amphitrite* and *A. reticulatus*) in family Balanidae have opercular valves with prominent growth ridges horizontally, and tergum with a clear spur. The coloration among these three species is easily distinguishable, in that purplish longitudinal striations presenting *A. amphitrite*, vertical and longitudinal red-orange striations with orange-pale pink background presenting *A. reticulatus* and brownish red surface with some irregular and unclear longitudinal stripes presenting *M. tintinnabulum*.

Identification key

1a Shell conical to low conical with 4 plates with distinct parietes or shell with 4 plates with indistinct parietes or fused parietes, parietes multi-tubiferous 2
1b Shell with 6 plates with distinct parietes 5
2a Shell low conical, parietes discrete, summit of radii oblique, orifice pentagonal and wide, external surface of shell with deep longitudinal striations ..... *Newmanella spinosus* Chan & Cheang, 2016
2b Shell conical, parietes not discrete, summit of radii horizontal, orifice circular or oval and small 3
3a Shell green, external surface of shell with longitudinal striation, shell plates separable, tergum with obvious beak and tergum with sharp and narrow spur ..... *Tetraclita squamosa* (Bruguiere, 1789)
3b Shell greyish black, external surface of shell with mosaic scale-like, plates inseparable, tergum without beak and with broad spur 4

4a Angle between basal margin and tergal margin of scutum is almost perpendicular ..... *Tetraclita kuroshioensis* Chan, Tsang & Chu, 2007

4b Angle between basal margin and tergal margin of scutum is curved.... *Tetraclita singaporensis* Chan, Tsang & Chu, 2007

5a Parietes solid 6

5b Parietes tubiferous 8

6a Body length 10–30 mm, gigantic appearance ..... *Euraphia hembeli* Conrad, 1837

6b Body length 3–10 mm, tergum with 3–4 lateral depressor crests 7

7a Mandible with four teeth, cirri I with conical spines, cirri II with multi-cuspidate setae and basal guard, articulation of opercular valves deep (shape of articulation similar to jigsaw-shaped), ... *Chthamalus malayensis* Pilsbry, 1916

7b Mandible with three teeth and 11 smaller setae at the lower margin, articulation of opercular valves shallow (shape of articulation from outside view similar to bird beak ..... *Euraphia depressa* (Poli, 1795)

8a Parietal tubes single row and irregular shaped, shell with irregular and deep longitudinal striations, shell purplish white... ..... *Megabalanus tintinnabulum* (Linnaeus, 1758)

8b Parietal tubes single row and uniform 9

9a External surface with purple longitudinal striations from apex to base against white surface..... ..... *Amphibalanus amphitrite* (Darwin, 1854)

9b External surface with shall longitudinal and horizontal striations, shell white-pale pink and orange..... ..... *Amphibalanus reticulatus* (Utinomi, 1967)

Discussion

In the present study, we examine geographical distribution of sessile acorn barnacles along Thai Peninsular coastal areas including the Gulf of Thailand and the Andaman Sea. So far, there has been a lack of information regarding the diversity of sessilian Thoracican barnacles in Thailand. Hence, we attempt to generate a checklist to understand the species diversification and how they distribute on intertidal rocky shores and sandy shores along the coast of Thailand. At least ten different forms of acorn barnacles were diagnosed so far that are classified into 6 genera and 3 families (Chthamalidae, Tetraclitidae and Balanidae), which can be distinguished based on their external shell morphology, including pattern of parietes, opercular plates, and arthropodal characters as described in previous literatures (Ross and Perreault 1999; Chan 2001; Chan et al. 2007a, b; Chan et al. 2009; Lozano-Cortés and Londoño-Cruz 2013; Chen et al. 2014; Hayashi and Chan 2015; Chan and Cheang 2016).

Our study also shows that the numbers of species found in the Andaman Sea (8 species) are more than those found in the Gulf of Thailand (6 species). At Na Tai station located in the Andaman Sea, up to 8 species (6 genera and 3 families) were recorded. Four of these 8 species were found only at this station including *Newmanella spinosus*, *Euraphia hembeli*, *Megabalanus tintinnabulum* and *Tetraclita singaporensis*. In other examined stations, only 2–3 species could be found, and most of them were of the genus *Amphibalanus*, *Tetraclita*, and *Chthamalus*. The differences in species abundance between two coastlines might probably due to the past history of the barnacle colonization. It has been shown in Voris (2000) that sea level was fluctuated during the Pleistocene, caused by glaciation. The spread of acorn barnacle seen in present day is possibly due to successful colonization when there were the connections between the eastern part of Indian Ocean and the Gulf of Thailand. The nature of local habitats such as the incoming oceanic current and freshwater discharge might also be another factor promoting or limiting the boundary of barnacle distribution. In addition, the spread of the barnacles found in the Gulf of Thailand was probably facilitated by the influence of the South China Sea Warm Current (SCSWC) as shown in the case of *Chthamalus malayensis* (Tsang et al. 2012). However, at this present work, we cannot clearly conclude that all of these species found in this work successfully distributed before the glaciation or influenced by nature of specific local habitats as further extensive works need to be done to include more stations along both coastlines with proper oceanographic data.

In addition, we found five new records identified as *Newmanella spinosus*, *Euraphia depressa* and *Euraphia hembeli*, *Tetraclita singaporensis*, and *Tetraclita kuroshioensis* on which the presence of these species in Thailand has not been mentioned in any literatures. *N. spinosus*, *E. hembeli* and *T. singaporensis* can only be seen at Na Tai station, Phang-nga province while *E. depressa* is specific to Khao Sam Muk, Chon Buri province. However, we cannot rule out the possibility of their presences in other places and more intensive field surveys covering all provinces along Thailand's coasts are required.

Recently, there are 26 species in the genus *Chthamalus* (Chan et al. 2009). In this study, one of them is clearly diagnosed as *Chthalamus malayensis* based on distinct shell, operculum morphology and arthropodal characters. However, we also found another Chthamalid which has shallow articulation of tergum and scutum; suggesting the possibility of a different species. Surprisingly, this Chthamalids is similar to *Chthamalus depressus* (reassigned as *Euraphia depressa*), described in Southward (1964). The presence in Thailand was not mentioned as they were thought to be found around the Mediterranean. In addition, the Chthamalids we found exhibit great variation and this has previously been reported that

Chthamalids have high intraspecific variation in external morphology (Helmuth et al. 2006; Hawkins et al. 2008) and thus using shell morphology is not ideal for taxonomic identification; thus several studies have used other measures for species diagnosis, including opercular plate geometry (Tsang et al. 2012), light microscopy and SEM of arthropodal characters (e.g. the number of conical spines and the number of setules of the basal guard setae on cirri and pattern of oral cones) (Miller and Blower 1989; Southward and Newman 2003; Yan and Chan 2004; Tsang et al. 2012) and molecular approaches (Tsang et al. 2012). In any future studies, we will use all of these measures, particularly the examination of mitochondrial COI, 12s rDNA, 16s rDNA sequences or performing DNA barcoding in order to get accurate identifications of chthamalid barnacles.

According to a field survey on water quality and metal contamination of both coastal regions of Thailand, the Andaman Sea is still in a good condition compared to the Gulf of Thailand. On the other hand, habitat degradation along the Gulf of Thailand is much more severe and the number of species of these sessile arthropods has been declining dramatically over the last 20 years due to high amount of water pollution. For example, along Chon Buri's coast around 20 years ago, at least five species were commonly seen along rocky shores of the now developing centrum area. Recently, however, only *Amphibalanus amphitrite* have been able to tolerate severe human activities and even in some sites there are no more barnacles on rocky shores. This might be because the local communities have been releasing non-treated waste water directly into the sea (personal communication and unpublished report (1996): Department of Biology, Faculty of Science, Burapha University). Hence, the richness of barnacle species can also be used to indirectly monitor the conditions of sea water.

Taken together, we demonstrate a clearer view of diversity for acorn barnacles from various localities in Thailand. This study shows at least 10 species of barnacles, in total, exist along Thai coast regions. Future works with more sampling sites and further in-depth investigations using SEM and molecular approaches with the help of phylogenetic analysis will provide a much better view especially of the history of barnacles and intraspecific variation between sessile crustaceans and that may reveal new barnacle species inhabiting Thailand.

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Supplementary material 1

Arthropodal characters of *Tetraclita kuroshioensis*

Authors: Ashitapol Pochai, Sutin Kingtong, Woranop Sukparangsi, Salinee Khachonpisitsak

Data type: species data

Explanation note: *Tetraclita kuroshioensis* collected from (BUU16.TC.TK01) from Na Tai beach, Phang-nga. A.-I. Light microscopy on arthropodal characters. A. Cirri I, B.-C. Close up on cirri I showing serrulate setae, D. Cirri II, E.-F. Close up on cirri II showing serrulate setae, G. Maxillule, H. Mandible, I. Labrum.

Supplementary material 2

Arthropodal characters of *Tetraclita singaporensis*

Authors: Ashitapol Pochai, Sutin Kingtong, Woranop Sukparangsi, Salinee Khachonpisitsak

Data type: species data

Explanation note: *Tetraclita singaporensis* collected from (BUU16.TC.TSG02) from Na Tai beach, Phang-nga. A.-I. Light microscopy on arthropodal characters. A. Cirri I, B.-C. Close up on cirri I showing serrulate setae, D. Cirri II, E.-F. Close up on cirri II showing serrulate setae, G. Maxillule, H. Mandible, I. Labrum.

Supplementary material 3

Arthropodal characters of *Tetraclita squamosa*

Authors: Ashitapol Pochai, Sutin Kingtong, Woranop Sukparangsi, Salinee Khachonpisitsak

Data type: species data

Explanation note: *Tetraclita squamosa* collected from Hin Ngam beach, Nakhon Si Thammarat (BUU16.TC.TS01). A.-I. Light microscopy on arthropodal characters. A. Cirri I, B.-C. Close up on cirri I showing serrulate setae, D. Cirri II, E.-F. Close up on cirri II showing serrulate setae, G. Maxillule, H. Mandible, I. Labrum.