Zoological Studies **55:** 7 (2016)
doi:10.6620/ZS.2016.55-07

Zoological Studies

Anomuran and Brachyuran Symbiotic Crabs in Coastal Areas between the Southern Ryukyu arc and the Coral Triangle

Parinya Limviriyakul[1,2], Li-Chun Tseng[1], Jiang-Shiou Hwang[1,3], and Tung-Wei Shih[4,*]

[1]*Institute of Marine Biology, College of Life Sciences, National Taiwan Ocean University, Keelung 20224, Taiwan. E-mail: parinya_lim@hotmail.com; lichun@mail.bestredeye.org*

[2]*Department of Marine Science, Faculty of Fisheries, Kasetsart University, Bangkok 10900, Thailand*

[3]*Department of Biomedical Science and Environmental Biology, Kaohsiung Medical University, Kaohsiung 80708, Taiwan*

[4]*National Museum of Marine Science and Technology, Keelung 20248, Taiwan*

(Received April 13, 2015; Accepted October 13, 2015)

Parinya Limviriyakul, Li-Chun Tseng, Jiang-Shiou Hwang, and Tung-Wei Shih (2016) Symbiotic anomuran and brachyuran crabs were identified after extensive surveys of reef zones, especially from sponges, scleractinian corals, crinoids, and sea urchins, in the coastal areas of the southern East China Sea. Twenty-nine species belonging to 17 genera, 9 families, and 2 infraorders were identified (3 were identified to the generic level). More crabs belonged to the infraorder Brachyura (82.8%) than to Anomura (17.2%). Two anomuran symbionts (*Allogalathea elegans* and *Petrolisthes virgatus*) and 5 brachyuran symbionts (*Tetralia glaberrima*, *Tetralia rubridactyla*, *Trapezia cymodoce*, *Trapezia septata*, and *Cymo melanodactylus*) are common in this area. Two species of Anomura (*Lauriea simulata*, *Petrolisthes virgatus*) and 3 of Brachyura (*Gonatonotus nasutus*, *Tetralia aurantistellata* and *Tetralia nigrolineata*) were identified for the first time from waters adjacent to Taiwan. These records represent the northernmost recorded of *L. simulata* and *T. aurantistellata*. The occurrence of *P. virgatus* is the second in the western Pacific Ocean. This study revealed the geospatial distribution of symbiotic crabs, which connects the region from the southern Ryukyu arc to the Coral Triangle, and provides the supporting taxonomic account of symbiotic anomuran and brachyuran crab fauna inhabiting the reef zone in northern Taiwan.

Key words: Symbiosis, Anomura, Branchyura, Reef, Southern East China Sea.

BACKGROUND

Symbiotic associations are widespread across taxa and are generally found in all oceans around the world. The term *symbiosis* refers to members of different species living in close association (Castro and Huber 2003). Symbiotic crustaceans are common in most marine ecosystems, especially in tropical shallow waters (Bruce 1976; Castro 1988; Stella et al. 2011b). They associate with a variety of macro-invertebrate hosts such as sponges, cnidarians, polychaetes, mollusks, and echinoderms (Bruce 1972, 1976; Fautin et al. 1995; Guo et al. 1996; Marin et al. 2004; Thiel et al. 2003; Wei et al. 2005)

The prevalence of such associations make coral reef communities the most complex and biodiverse marine ecosystems in coastal areas (Paulay 1997; Veron 2000). Stella et al. (2011b) described at least 860 invertebrate species as coral associates, 310 of which are decapod crustaceans. Among these symbiotic decapods, crabs play a crucial role in increasing the survival rate of their hosts. They defend host corals against predators (Glynn 1980; Pratchett 2001; Pratchett et al. 2000) and help moving sediments away from their coral hosts (Stewart et al. 2006; Stier et al. 2012). Some coral species are reliant on these services and are

*Correspondence: E-mail: stw@mail.nmmst.gov.tw; jshwang@mail.ntou.edu.tw

unable to survive without their symbionts (Glynn 1983; Stella et al. 2011b; Stewart et al. 2006). *Cymo melanodactylus* Dana, 1852 has been reported to eat both the mucus and living polyps of its host, *Acropora* (Patton 1994)

Taiwan is located in the western North Pacific Ocean, with its northern part connected to the southern Ryukyu arc through the southern East China Sea, and the southern side connected to the Philippines, the South China Sea and the Coral Triangle through Luzon Strait. The biodiversity of anomuran and brachyuran crabs in Taiwan has been comprehensively studied since 1902, and more than 600 species from 64 families of brachyuran crabs have been recorded (Chan et al. 2009). Nearly one-tenth of all known crab species have been recorded in Taiwan. A substantial proportion of these records pertain to deep-water taxa (Ng et al. 2001). Studies on symbiotic crabs have been conducted in the reef and coastal waters of Taiwan (Chang et al. 1987; Galil 1983; Ho et al. 2000; Jeng 1994; Ng and Jeng 1999; Wei et al. 2013; Wei et al. 2005). Most of these studies collected specimens from southern Taiwan. The diversity and species composition of symbiotic crabs have not yet been explored in the southern East China Sea off the coast of northern Taiwan. The present study collected specimens in the reef zone of Fan-Zai-Aou Bay to evaluate the diversity of symbiotic anomuran and brachyuran crab fauna in order to provide baseline taxonomic information in the coastal areas of the southern East China Sea.

MATERIALS AND METHODS

Field sampling and sample treatment

Specimens were collected weekly between April and August 2014 from western Fan-Zai-Aou Bay, southern East China Sea, off the coast of Keelung City in northern Taiwan (Fig. 1). The seabed in the sampling area was characterized by rock, coral, and fine sediments. Anomuran and brachyuran crab specimens were collected by scuba diving in the zone above 24 m. Potential host animals (sponges, hydroids, sea anemones, scleractinian corals, soft corals, crinoids, and sea urchins) were investigated. Each host, along with its symbionts, was stored separately in a plastic zip-lock bag or box and taken to the Chaojing Ocean Center (National Museum of Marine Science and Technology) for identification.

The associated decapods were carefully removed from their hosts by using flexible plastic rods. Some hosts were immersed in seawater containing a 5-ppt clove oil-ethanol solution for 3 min and vigorously shaken to extract their symbionts. The decapod specimens were photographed, preserved in 70% ethyl alcohol, and deposited at the Chaojing Ocean Center collection. After identification, all host animals were returned to their place of origin.

Crab identification

In the laboratory, the associated crabs were identified under a dissecting microscope (Olympus SZX16). Anomuran crabs were identified using keys by Baba et al. (2009), Osawa et al. (2010), and Macpherson and Robainas-Barcia (2013), and brachyuran crabs were identified using keys by Serène (1984), Kropp (1990), Dai and Yang (1991), Chia et al. (1999), Chia and Ng (2000), Castro et al. (2004), and Trautwein (2007).

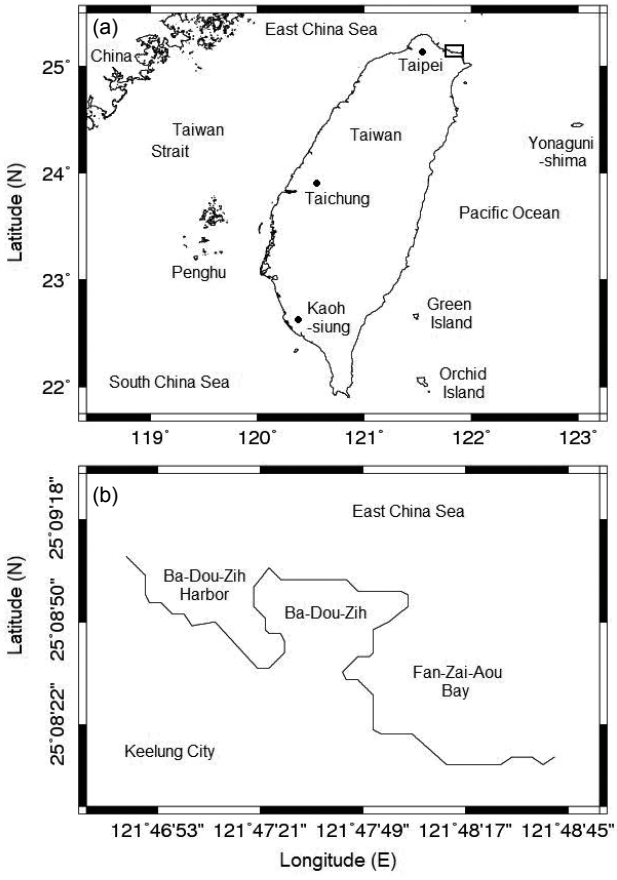

Fig. 1. Map of the sampling area (a) and locations (b) in northern Taiwan during the sampling period (April to August 2014).

RESULTS

Prevalence and host

The prevalence of symbiotic crabs varied among the host specimens; from a total of 29 species, 6.9% were found in sponges (N = 11), 79.3% in scleractinian corals (N = 106; *Acropora* 76, *Stylophora* 20, *Pocillopora* 10), 6.9% in crinoids (N = 50), and 10.3% in sea urchins (N = 63; *Diadema* 20, *Echinothrix* 10, *Echinometra* 30, *Prionocidaris* 3) (Table 1). A comparison of the host composition revealed that most symbiotic crabs were associated with branching corals (23 species, 79.3%) (Fig. 2).

Five species of Anomura (Fig. 3) and 24 species of Brachyura (Fig. 4) were identified. Twenty-nine species belonging to 17 genera, 9 families, and 2 infraorders were identified (3 were identified to generic level). More crabs belonged

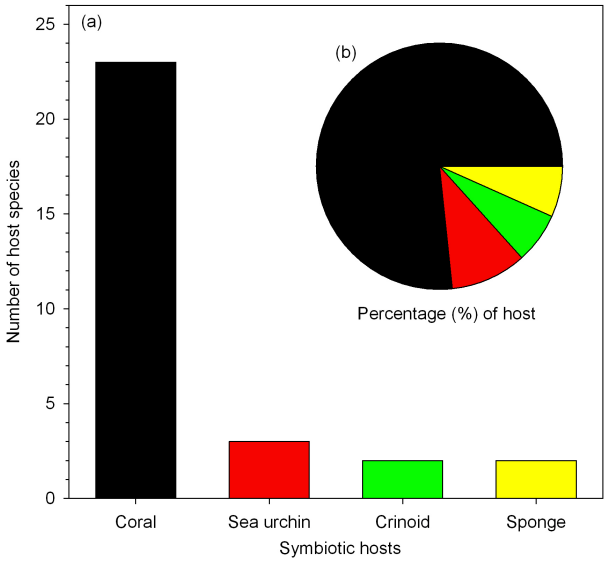

Fig. 2. Number (a) and proportion (b) of symbiont identified in the investigation area.

Table 1. Taxonomic list, occurrence rate (%), depth of collection (m), symbiotic host, and historical reports of anomuran and brachyuran crabs collected from northern Taiwan

Scientific name	Occurrence and depth	Symbiotic host	Historical records
Infraorder Anomura MacLeay, 1838			
Family Galatheidae Samouelle, 1819			
Allogalathea elegans (Adams and White, 1848)	++++, 4-24 m	Crinoid: Mariametroidea	East China Sea (Miyake and Keiji 1967), Japan (Baba 1969), Red Sea, east coast of Africa (Baba 1988), Philippine (Baba 1988), Australia and Tasman Sea (Ahyong 2007), Taiwan (Baba et al. 2009), Thailand (Thamrongnawasawat et al. 2009)
Galathea tanegashimae Baba, 1969	++, 2-6 m	Coral: *Acropora hyacinthus*, Sponge: unidentified	Japan (Baba 1969), Tasman Sea (Ahyong 2007), Taiwan (Baba et al. 2009), South-West Indian Ocean (Macpherson and Cleva 2010)
Lauriea simulata Macpherson and Robainas-Barcia, 2013*	+, 4 m	Coral: *Pocillopora damicornis*	Philippines, Vanuatu and New Caledonia (Macpherson and Robainas-Barcia 2013), South China Sea (Dong and Li 2013)
Family Porcellanidae Haworth, 1825			
Petrolisthes virgatus Paul'son, 1875*	+++, 0-3 m	Sea urchin: *Echinometra mathaei*	Red Sea (Ramadan 1936), Mozambique (Kalk 1958), Japan (Nakasone and Miyake 1972; Nomura et al. 1996), Somalia (Lewinsohn 1979), Oman (Hogarth 1988), Yemen (Simões et al. 2001)
Petrolisthes sp.	+, 4 m	Coral: *Pocillopora damicornis*	
Infraorder Brachyura Linnaeus, 1758			
Family Leucosiidae Samouelle, 1819			
Nucia sp.	+, 3 m	Coral: *Acropora hyacinthus*	
Family Pilumnidae Samouelle, 1819			
Echinoecus pentagonus (A. Milne-Edwards, 1879)	++, 6-20 m	Sea urchin: *Diadema setosum*, *Echinothrix* sp.	Japan (Miyake 1939), Hawaii (Castro 1969), China Seas (Dai and Yang 1991), Red Sea, East Africa, Indo-West Pacific and French Polynesia (Chia et al. 1999), Taiwan (Ng and Jeng 1999), Thailand (Thamrongnawasawat et al. 2009), Southern Korea (Lee et al. 2011)

Table 1. (continued)

Scientific name	Occurrence and depth	Symbiotic host	Historical records
Gonatonotus nasutus D. G. B. Chia and Ng, 2000*	+, 12 m	Sea urchin: *Prionocidaris* sp.	Western and eastern Australia, New Caledonia, Vanuatu, Philippines and Japan (Chia and Ng 2000)
Permanotus purpureus (Gordon, 1934)	++, 6-24 m	Crinoid: Mariametroidea	South-west Pacific, central Pacific, Japan (Chia and Ng 1998), Taiwan (Ng and Jeng 1999), Thailand (Thamrongnawasawat et al. 2009)
Pilumnus sp.	+, 17 m	Sponge: *Xestospongia* sp.	
Family Domeciidae Ortmann, 1893			
Domecia glabra Alcock, 1899	++, 2-7 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*, *Acropora* sp.	Japan (Nomura et al. 1996), China Seas (Dai and Yang 1991), Australia (Patton 1994), Taiwan (Ng et al. 2001)
Domecia hispida Eydoux and Souleyet, 1842	+, 3 m	Coral: *Pocillopora damicornis*	China Seas (Dai and Yang 1991), Japan (Nomura et al. 1996), French Polynesia (Peyrot-Clausade 1989; Poupin 1996), Taiwan (Ng et al. 2001)
Family Tetraliidae Castro, Ng and Ahyong, 2004			
Tetralia aurantistellata Trautwein, 2007*	+, 4 m	Coral: *Acropora hyacinthus*	New Caledonia and Fiji (Trautwein 2007), Philippines (Castro 2009)
Tetralia cinctipes Paul'son, 1875	++, 2-7 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*	East Africa, Red sea, Japan, Taiwan, Indonesia (Galil and Clark 1988), Australia (Patton 1994), French Polynesia (Poupin 1996), Indonesia (Castro 1999), Guam (Castro 2003), Philippines (Castro 2009)
Tetralia glaberrima (Herbst, 1790)	+++, 2-12 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*, *Acropora* spp.	Seychelles (Garth 1984), French Polynesia (Peyrot-Clausade 1989; Poupin 1996), China Seas (Dai and Yang 1991), Japan (Tsuchiya et al. 1993), Australia (Patton 1994), Indonesia (Castro 1999), Taiwan (Ng et al. 2001), Thailand (Castro 2002), Guam (Castro 2003), Philippines (Castro 2009), Andaman and Nicobar Is. (Kumaralingam et al. 2012), Galapagos (Tirado-Sanchez et al. 2014)
Tetralia nigrolineata Serène and Pham, 1957*	++, 2-10 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*	Thailand, Indonesia and Japan (Galil 1988), Singapore (Goh et al. 1990), Australia (Patton 1994), New Caledonia (Castro 1997b), Western Indian Ocean (Castro 1997b), Guam (Castro 2003), Philippines (Castro 2009)
Tetralia rubridactyla Garth, 1971	+++, 2-12 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*, *Acropora* spp.	East Africa (Galil and Clark 1988), Taiwan (Galil 1988), Japan (Tsuchiya et al. 1993), Australia (Patton 1994), Indian Ocean (Castro 1997a), French Polynesia (Castro 1997a), Indonesia (Castro 1999), Guam (Castro 2003), Philippines (Castro 2009)
Tetraloides heterodactylus (Heller, 1861)	+, 2-4 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*,	East Africa (Galil and Clark 1988), French Polynesia (Castro 1997a), Indonesia (Castro 1999), Guam (Castro 2003), Philippines (Castro 2009), Japan (Komatsu 2011), Taiwan (Fisheries Research Institute 2014)
Tetraloides nigrifrons (Dana, 1852)	++, 2-7 m	Coral: *Acropora hyacinthus*, *Acropora* sp.	East Africa (Galil and Clark 1988), Australia (Patton 1994), French Polynesia (Poupin 1996), Guam (Castro 2003), Philippines (Castro 2009), Taiwan (Fisheries Research Institute 2014)

Table 1. (continued)

Scientific name	Occurrence and depth	Symbiotic host	Historical records
Family Trapeziidae Miers, 1886			
Trapezia cymodoce (Herbst, 1801)	+++, 2-7 m	Coral: *Stylophora pistillata*	Seychelles (Garth 1984), Singapore (Goh et al. 1990), China Seas (Dai and Yang 1991), Oman (Hogarth 1994), Taiwan (Jeng 1994), French Polynesia (Poupin 1996), Japan (Nomura et al. 1996) , Indonesia (Castro 1999),Thailand (Castro 2002; Thamrongnawasawat et al. 2009), Guam (Castro 2003), Philippines (Castro 2009), Andaman and Nicobar Is. (Kumaralingam et al. 2012)
Trapezia digitalis Latreille, 1828	+, 2 m	Coral: *Pocillopora damicornis*	Red Sea (Ramadan 1936), Taiwan (Chang et al. 1987), Japan (Nomura et al. 1996), Hawaii, Eastern Pacific (Castro 1996, 1997b), Australia (Castro 1997b), French Polynesia (Castro 1997a), Indonesia (Castro 1999), Philippines (Castro 2009), Andaman and Nicobar Is. (Kumaralingam et al. 2012)
Trapezia lutea Castro, 1997	++, 2-7 m	Coral: *Stylophora pistillata*	French Polynesia (Castro 1997a), Indonesia (Castro 1999), Taiwan (Ng et al. 2001), Guam (Castro 2003), Thailand (Naiyanetr 2007), Philippines(Castro 2009)
Trapezia septata Dana, 1852	+++, 2-7 m	Coral: *Pocillopora damicornis*, *Stylophora pistillata*, *Acropora hyacinthus*	Japan, Taiwan, Sri Lanka, Australia, Hawaii, Samoa Is. (Jeng 1994), French Polynesia (Poupin 1996), New Caledonia (Castro 1997b), Indonesia (Castro 1999), Thailand (Castro 2002), Guam (Castro 2003), Philippines (Castro 2009), Andaman and Nicobar Is. (Kumaralingam et al. 2012)
Trapezia serenei Odinetz, 1984	++, 2-5 m	Coral: *Pocillopora damicornis*	French Polynesia (Poupin 1996), Indonesia (Castro 1999), Taiwan (Ng et al. 2001), Guam (Castro 2003)
Family Xanthidae MacLeay, 1838			
Chlorodiella laevissima (Dana, 1852)	++, 2-4 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*	Seychelles (Garth 1984), French Polynesia (Peyrot-Clausade 1989; Poupin 1996), China Seas (Dai and Yang 1991), Japan (Nomura et al. 1996), Taiwan (Ng et al. 2001)
Chlorodiella nigra (Forskål, 1775)	++, 2-7 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*, *Stylophora pistillata*	Seychelles (Garth 1984), China Seas (Dai and Yang 1991), French Polynesia (Poupin 1996), Japan (Nomura et al. 1996), Taiwan (Ng et al. 2001), Thailand (Thamrongnawasawat et al. 2009)
Cymo melanodactylus Dana, 1852	+++, 2-10 m	Coral: *Acropora hyacinthus*, *Acropora digitifera*, *Acropora* spp.	Seychelles (Garth 1984), Singapore (Goh et al. 1990), China Seas (Dai and Yang 1991), Australia (Patton 1994), Oman (Hogarth 1994), French Polynesia (Poupin 1996), Taiwan (Ho et al. 2000), Thailand (Thamrongnawasawat et al. 2009), Japan (Yamano et al. 2012), Red Sea (Broesing et al. 2014)
Family Cryptochiridae Paul'son, 1875			
Hapalocarcinus marsupialis Stimpson, 1859	++, 2-6 m	Coral: *Stylophora pistillata*	Pacific Ocean and Andaman sea (Kropp 1990), China Seas (Dai and Yang 1991), Japan (Nomura et al. 1996), Taiwan (Wei et al. 2005)
Utinomiella dimorpha (Henderson, 1906)	+, 3 m	Coral: *Pocillopora damicornis*	Pacific Ocean (Kropp 1990), Taiwan (Wei et al. 2005)

Occurrence: ++++ = 100%, +++ = >60%, ++ = 20% - 60%, + = <20%. * indicates first record of the species in waters adjacent to Taiwan.

to Brachyura (82.8%) than to Anomura (17.2%). Among the specimens of Tetraliidae (Brachyura), totaling 7 species were dominant. *Tetralia rubridactyla* Garth, 1971 was the most abundant followed by *Tetralia glaberrima* (Herbst, 1790) and *Tetralia nigrolineata* Serène and Pham, 1957. *Tetralia* crabs were found inhabiting all colonies of *Acropora* corals, each coral head contained at least one adult *Tetralia* crab.

Seven species shown high frequency of occurrence (more than 60%): *Allogalathea elegans* (Adams and White, 1848), *Petrolisthes virgatus* Paul'son, 1875, *T. glaberrima*, *T. rubridactyla*, *Trapezia cymodoce* (Herbst, 1801), *Trapezia septata* Dana, 1852 and *Cymo melanodactylus* Dana, 1852. Furthermore, 5 species, *Lauriea simulata* Macpherson and Robainas-Barcia, 2013, *P. virgatus*, *Gonatonotus nasutus* D. G. B. Chia and Ng, 2000, *Tetralia aurantistellata* Trautwein, 2007, and *T. nigrolineata* are recorded for the first time in waters adjacent to northern Taiwan.

Most coral symbiotic crabs can be found in several host coral species. Species of tetraliids were recorded from more than 2 species of *Acropora* corals.

DISCUSSION

Distribution of dominant species

Seven species of symbiotic crabs had a high occurrence in the investigated area. These species have varied distribution records worldwide. The galatheid crab *Allogalathea elegans* (Fig. 3a) occurred in all of the feather star specimens, each feather star containing at least 1 individual of *A. elegans*. A few feather star specimens contained both *A. elegans* and the brachyuran crab *Permanotus purpureus* (Gordon, 1934) (Fig. 4d). *Allogalathea elegans* usually lives on the aboral side, near the cirri of the feather star, whereas *P. purpureus* can be found on both the aboral and oral sides, near the crown. The occurrence of *A. elegans* has been recorded in the Red Sea and the east coast of Africa (Baba 1988), Thailand (Thamrongnawasawat et al. 2009), East China Sea (Miyake and Keiji 1967), Japan (Baba 1969), Taiwan (Baba et al. 2009), the Philippines (Baba 1988), and Australia and the Tasman Sea (Ahyong 2007). Its distribution ranges widely from the intertidal zone to 146 m (Baba 1988). It is usually found in several crinoid species: *Anneissia bennetti* (Müller, 1841), *Capillaster multiradiatus* (Linnaeus, 1758), *Comanthus parvicirrus* (Müller, 1841), *Comaster schlegelii* (Carpenter, 1881), *Heterometra savignii* (Müller, 1841), *Himerometra robustipinna* (Carpenter, 1881), *Lamprometra palmata* (Müller, 1841), *Stephanometra indica* (Smith, 1876) and *Tropiometra carinata* (Lamarck, 1816) (Baba et al. 2009).

The occurrence frequency of *P. virgatus* (Fig. 3d) was 80%-90%, and most sea urchin specimens contained only 1 crab individual. This anomuran crab, characterized as cryptic with echinoderms, was found beneath the rock-boring sea urchin

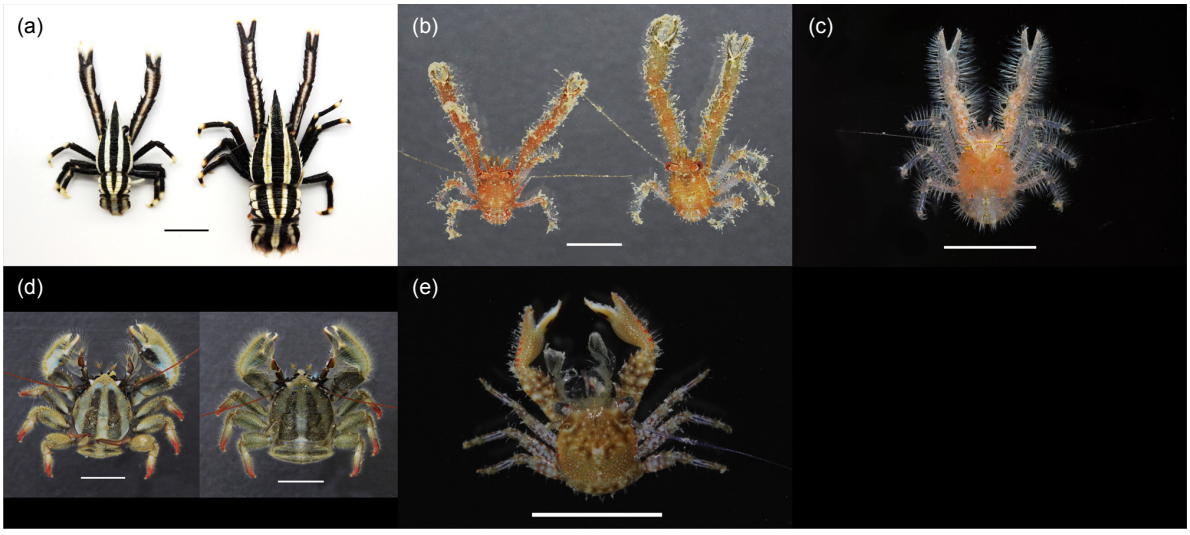

Fig. 3. Anomuran crabs recorded from the western Fan-Zai-Aou Bay in northern Taiwan. (a) *Allogalathea elegans* (♂, ♀), (b) *Galathea tanegashimae* (♂, ♀), (c) *Lauriea simulata* (♀), (d) *Petrolisthes virgatus* (♂, ♀), (e) *Petrolisthes* sp. (♀). Scale bar represents 5 mm.

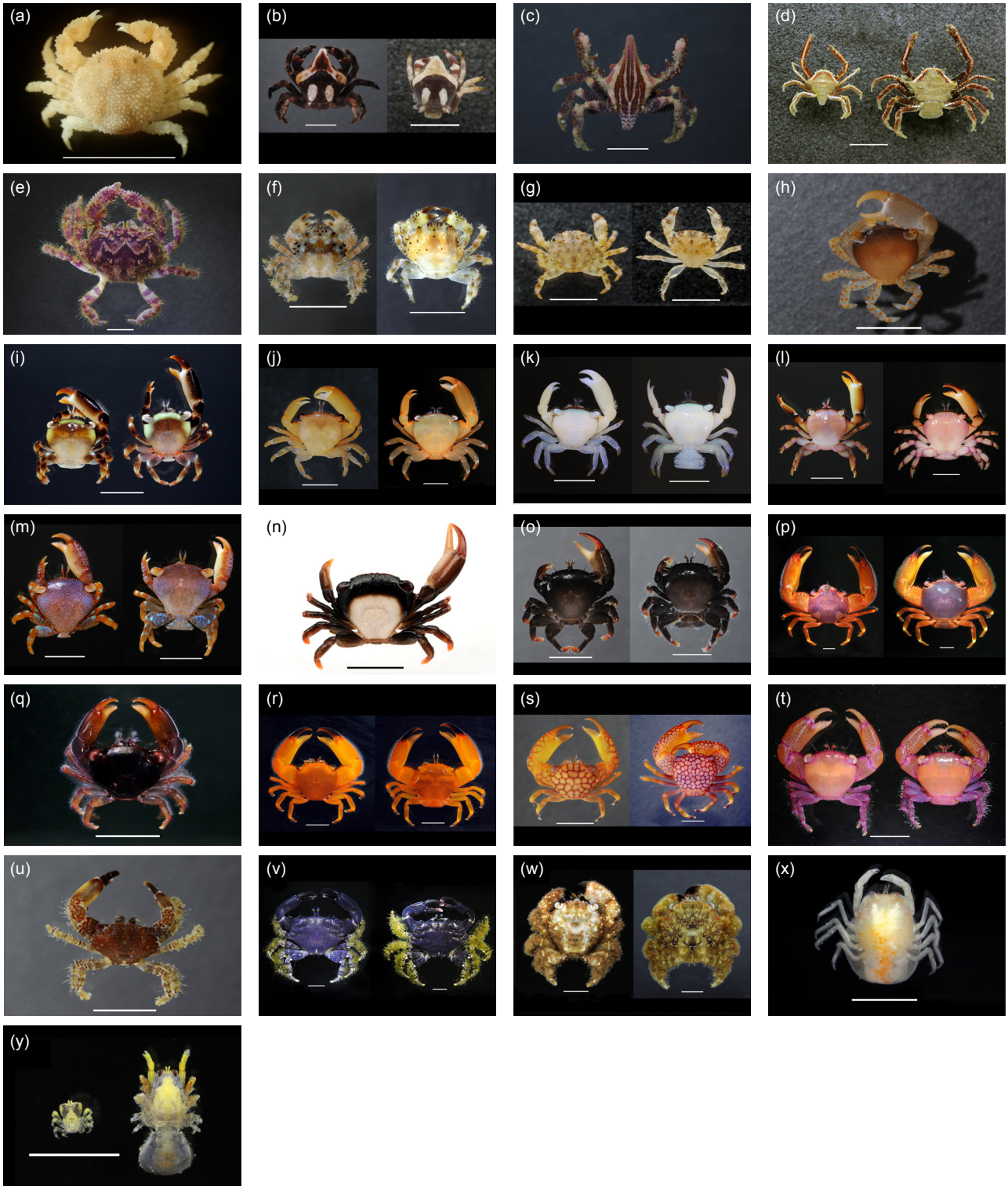

Fig. 4. Brachyuran crabs recorded from the western Fan-Zai-Aou Bay in northern Taiwan. (a) *Nucia* sp. (♂), (b) *Echinoecus pentagonus* (♂, ♀), (c) *Gonatonotus nasutus* (♂), (d) *Permanotus purpureus* (♂, ♀), (e) *Pilumnus* sp. (♀), (f) *Domecia glabra* (♂, ♀), (g) *Domecia hispida* (♂, ♀), (h) *Tetralia aurantistellata* (♂), (i) *Tetralia cinctipes* (♂, ♀), (j) *Tetralia glaberrima* (♂, ♀), (k) *Tetralia nigrolineata* (♂, ♀), (l) *Tetralia rubridactyla* (♂, ♀), (m) *Tetraloides heterodactylus* (♂, ♀), (n) *Tetraloides nigrifrons* (♂), (o) *Tetraloides nigrifrons* with darker color on carapace (♂, ♀), (p) *Trapezia cymodoce* (♂, ♀), (q) *Trapezia digitalis* (♂), (r) *Trapezia lutea* (♂, ♀), (s) *Trapezia septata* (♂, ♀), (t) *Trapezia serenei* (♂, ♀), (u) *Chlorodiella laevissima* (♂), (v) *Chlorodiella nigra* (♂, ♀), (w) *Cymo melanodactylus* (♂, ♀), (x) *Hapalocarcinus marsupialis* (♀), (y) *Utinomiella dimorpha* (♂, ♀). Scale bar represents 5 mm.

Echinometra mathaei (Blainville, 1825). Its habitat is the intertidal zone (Nakasone and Miyake 1972), which is consistent with our record of *P. virgatus* in the 0-3 m zone. In addition, *P. virgatus* is usually observed with the symbiotic snapping shrimp, *Arete indicus* Coutière, 1903 in tunnels and holes made by sea urchins.

Tetralia glaberrima (Fig. 4j) and *T. rubridactyla* (Fig. 4l) are small, brightly colored crabs with an obligatory symbiosis with various species of *Acropora* corals. Both species have been recorded across the Indo-West Pacific region (Castro 1997a, 2003; Galil 1988; Galil and Clark 1988). *Tetralia glaberrima* is found from the intertidal zone to 54 m (Castro 1997b), whereas *T. rubridactyla* has been found to a maximum depth of 27 m (Castro 1997a). *T. glaberrima* is easily distinguishable from *T. rubridactyla* by its color pattern, crestless cheliped merus, and the shape of the endopod of the first maxillipeds (Castro et al. 2004; Galil 1988). These two species have been found sympatrically with other species of tetraliids, *Cymo* crabs, *Coralliocaris* and *Jocaste* shrimps, and gobies (Gobiodon). *Tetralia glaberrima* has the highest occurrence frequency in the Great Barrier Reef and New Caledonia, followed by *T. nigrolineata* and *T. rubridactyla* (Castro 1997b; Patton 1994; Sin 1999). Species of *Tetralia* are dominant in the reef zone in our study area.

The brachyuran crabs *T. cymodoce* (Fig. 4p) and *T. septata* (Fig. 4s) are common throughout the Indo-West Pacific region (Castro 1997a, b); *T. cymodoce* is more prevalent (Castro 1997a) and is more widely distributed. Both *T. cymodoce* and *T. septata* have been recorded off the southern coast of Taiwan and off the Peng-hu Islands, Hsiao Liuchiu Island, Kenting National Park, and Orchid Island (Chang et al. 1987; Jeng 1994) associated with the branching corals *Seriatopora hystrix* Dana, 1846, *Stylophora pistillata* Esper, 1797, *Pocillopora damicornis* (Linnaeus, 1758), and *Pocillopora verrucosa* (Ellis & Solander, 1786) in southern Taiwan. We recorded *T. septata* in 2 species of corals *S. pistillata* and *P. damicornis*, and *T. cymodoce* in *S. pistillata*. *Trapezia cymodoce* and *T. septata* has been reported from depths of 1-55 m (Castro 1997b) and 0.5-45 m (Castro 2009), respectively.

Several studies have reported a positive correlation between the size and number of *Trapezia* crabs and the colony size of their host corals (Abele and Patton 1976; Austin et al. 1980; Castro 1978; Garth 1984; Tsuchiya et al. 1993). Despite the sampling a large number of small colonies of *P. damicornis* (diameter < 10 cm) in northeast Taiwan, we did not find *T. cymodoce* in any of them, suggesting that the corals were too small for the crabs. The mean carapace width of adult *T. cymodoce* individuals associated with *P. damicornis* is approximately 7.9 ± 2.0 to 9.7 ± 1.4 mm (mean ± SE) in southern Taiwan (Chang et al. 1987).

Trapezia species have been reported as an obligate symbiont of pocilloporid corals worldwide (Castro 2002, 2003; Chang et al. 1987; Knudsen 1967; Stella et al. 2011a). This coevolution of trapeziid crabs and corals appears to have been established in the Eocene (Schweitzer 2005). Symbiotic coral crabs living with atypical hosts is a rare phenomenon, in *T. cymodoce* (Patton 1994; Tsuchiya and Nojima 2002), *T. glaberrima* (Garth 1984; Knudsen 1967) and *T. rubridactyla* (Chang et al. 1987). We nevertheless found *T. septata* living with the atypical host *Acropora hyacinthus* (Fig. 5).

Cymo melanodactylus (Fig. 4w), a known obligatory symbiont, mainly inhabits acroporid corals (Garth 1984, Serène 1984). In this study, the occurrence frequency of *C. melanodactylus* was found to be higher than 60%, with low abundance (mostly 1 or 2 individuals per colony) and a small size (carapace width less than 6 mm). This species has been reported to be widespread in the Indo-West Pacific region (Goh et al. 1990; Dai and Yang 1991; Patton 1994; Poupin 1996; Ho et al. 2000; Thamrongnawasawat et al. 2009; Yamano et al. 2012) and in the western Indian Ocean (Garth 1984; Hogarth 1994; Broesing et al. 2014). These slow-moving crabs are known to feed on the tissues of their host, but do not appear to be harmful to their hosts when presented in a low number (less than 3 indivicuals per colony) (Patton

Fig. 5. Brachyuran crab *Trapezia septata* living with the host coral *Acropora hyacinthus*.

1994). However, recent studies have revealed that overabundance of *C. melanodactylus* (up to 47 individuals per colony) may cause mortality in *Acropora cytherea* (Dana, 1846) (Pratchett et al. 2010, 2013). The host corals were not healthy, with partial mortality of the colonies, indicating that *C. melanodactylus* may forage on the dead tissues of the corals.

New record of 5 species in Taiwan

The present study recorded 5 species for the first time in Taiwan waters: *L. simulata*, *P. virgatus*, *G. nasutus*, *T. aurantistellata*, and *T. nigrolineata*. The anomuran *L. simulata* (Fig. 3c) was identified in the scleractinian coral *P. damicornis*. This is only the third record of this species after specimens collected from gorgonians from the Philippines (Macpherson and Robainas-Barcia 2013) and living corals from Hainan, South China Sea (Dong and Li 2013). In addition, this is the northernmost record of *L. simulata*. The species has been recorded from the intertidal zone to 120 m (Macpherson and Robainas-Barcia 2013) and from 1-3 m to 21-54 m (Dong and Li 2013). The present study recorded *L. simulata* at 6 m. A new host coral of *L. simulata*, namely *P. damicornis*, was identified.

The anomuran crab *P. virgatus* (Fig. 3d) is abundant, with a high frequency rate (> 80%) in northeastern Taiwan. Its distribution record is unusual because the species has been found in Mozambique (Kalk 1958), Somalia (Lewinsohn 1979), Yemen (Simões et al. 2001), Oman (Hogarth 1988), the Red Sea (Ramadan 1936), and Japan (Nakasone and Miyake 1972; Nomura et al. 1996). Most reports are from the western Indian Ocean, and the only report from the western Pacific Ocean is from the Ogasawara and Ryukyu Islands, Japan. The identification of *P. virgatus* reported herein represents the second record of this species in the western Pacific Ocean, confirming its distribution in the Kuroshio-influenced regions. Our results suggest that the Kuroshio plays a crucial role in the distribution of the species, linking its habitats in the western Pacific Ocean.

In the present study, the brachyuran *G. nasutus* (Fig. 4c) was collected from the sea urchin *Prionocidaris* sp. at 12-m depth. Its distribution depth ranges widely from shallow water to 210 m (Chia and Ng 2000; Sakai 1976). This species has been recorded in western and eastern Australia, New Caledonia, Vanuatu, the Philippines, and Japan (Chia and Ng 2000). Studies have reported it living with the branching coral *S. pistillata* (Sakai 1976) and sea urchins *Phyllacanthus imperialis* (Lamarck, 1816) and *Phyllacanthus parvispinus* Tension Woods, 1878 (Chia and Ng 2000). Our study is the first record of *G. nasutus* living with *Prionocidaris* sea urchins.

Tetralia aurantistellata (Fig. 4h) and *T. nigrolineata* (Fig. 4k) are coral-dwelling crabs. The present study reports the northernmost distribution record of *T. aurantistellata*. The distribution depths of *T. aurantistellata* and *T. nigrolineata* are similar: 1-52 m (Castro 2009; Trautwein 2007) and shallow water to 52 m (Castro 1997b, 2009), respectively. Previous studies have revealed that *T. nigrolineata* associates solely with scleractinian corals of the genus *Acropora* (Castro 2003, 2009; Patton 1994). Surprisingly, a *T. nigrolineata* pre-adult individual was collected from a sea fan (Melithaeidae), suggesting that the megalopa of *T. nigrolineata* may be an opportunistic symbiont capable of living with diverse hosts (Castro 2009).

Diversity of coral-symbiotic crabs

The number of symbiotic crab species worldwide varies among studies according to collection frequency, sampling methods, location, and study period (Castro 2009). In southern Taiwan, Jeng (1994) and Chang et al. (1987) identified 8 and 20 species of symbiotic crabs in coral reefs, respectively. We identified 29 species from northeastern Taiwan because specimens were collected from diverse hosts such as sponges, corals, crinoids, and sea urchins. Shao (1998) estimated that the marine species around Taiwan represent 10% of those worldwide. The present study provides information on 5 species recorded for the first time in Taiwan, thus contributing to the baseline of symbiotic crustaceans in southern East China Sea.

Although several groups have studied anomuran and brachyuran crabs, most have focused on brachyuran crabs (Table 2). A few reports have elaborated on crab families (or taxon) and their hosts. However, most have not explored the relationship between symbiotic crabs and their hosts. Thus, assigning the crabs to symbiotic groups is difficult. Recent review reports have characterized certain crabs among specific families and genera as obligate symbionts. For example, crabs belonging to Tetraliidae, Trapeziidae, and Cryptochiridae families and those belonging to *Domecia* and *Cymo* genera are known obligate symbionts of scleractinian corals and most colonial anthozoan cnidarians (Castro et al. 2004; Patton

Table 2. Species richness of symbiotic crabs in different investigated areas

Study areas	Scientific grouping (Number of identified species)	Reference
Andaman and Nicobar Islands	Brachyura: Tetraliidae (1) and Trapeziidae (5)	Kumaralingam et al. (2012)
Australia	Brachyura: Domeciidae (1), Tetraliidae (6) and Xanthidae (2)	Patton (1994)
Australia	Brachyura: Pilumnidae (1)	Chia et al. (1995)
Australia (Tasman Sea)	Anomura: Galatheidae (1)	Ahyong (2007)
East Africa	Brachyura: Tetraliidae (5)	Galil and Clark (1988)
Eastern Pacific	Brachyura: Trapeziidae (4)	Castro (1996)
French Polynesia	Brachyura: Tetraliidae (6) and Trapeziidae (16)	Castro (1997a)
Galapagos	Brachyura: Trapeziidae (2)	Tirado-Sanchez et al. (2014)
Indonesia	Brachyura: Domeciidae (2), Tetraliidae (6) and Trapeziidae (17)	Castro (1999)
Japan	Brachyura: Pilumnidae (6)	Miyake (1939)
Japan	Brachyura: Tetraliidae (1), Trapeziidae (1) and Xanthidae (1)	Yamano et al. (2012)
Madagascar	Anomura: Galatheidae (1)	Baba (1990)
New Caledonia	Brachyura: Tetraliidae (5) and Trapeziidae (14)	Castro (1997b)
Oman	Brachyura: Tetraliidae (1), Trapeziidae (1) and Xanthidae (4)	Hogarth (1994)
Papua New Guinea	Brachyura: Trapeziidae (7)	Sin and Lee (2002)
Philippines	Anomura: Galatheidae (4)	Baba (1988)
Philippines	Brachyura: Tetraliidae (7) and Trapeziidae (14)	Castro (2009)
Red Sea	Anomura: Pocellanidae (1) Brachyura: Domeciidae (1), Tetraliidae (2), Trapeziidae (5), Xanthidae (2) and Pinnotheridae (1)	Ramadan (1936)
Red Sea	Brachyura: Xanthidae (4)	Broesing et al. (2014)
Somalia	Anomura: Porcellanidae (1)	Lewinsohn (1979)
South Korea	Brachyura: Pilumnidae (1)	Lee et al. (2011)
Taiwan (coast of southern)	Brachyura: Trapeziidae (2)	Galil (1983)
Taiwan (coast of southern)	Brachyura: Pilumnidae (3), Tetraliidae (1), Trapeziidae (9) and Xanthidae (7)	Chang et al. (1987)
Taiwan (coast of southern)	Brachyura: Majidae (1), Xanthidae (3) and Trapeziidae (4)	Jeng (1994)
Taiwan	Brachyura: Pilumnidae (4) and Portunidae (1)	Ng and Jeng (1999)
Taiwan	Brachyura: Xanthidae (7)	Ho et al. (2000)
Taiwan	Brachyura: Dromiidae (9), Majidae (3), Portunidae (4), Pilumnidae (4), Domeciidae (2), Tetraliidae (1), Trapeziidae (14), Xanthidae (8), Pinnotheridae (4) and Cryptochiridae (2)	Ng et al. (2001)
Taiwan (coast of southern)	Brachyuran: Cryptochiridae (9)	Wei et al. (2005)
Taiwan	Anomura: Pylochelidae (1), Diogenidae (13), Paguridae (3), Parapaguridae (7)	Mc Laughlin et al. (2007)
Taiwan	Anomura: Chirostylidae (10) and Galatheidae (9)	Baba et al. (2009)
Taiwan	Brachyuran: Dromiidae (10) and Dynomenidae (1)	Chan et al. (2009)
Taiwan	Anomura: Pocellanidae (13)	Osawa et al. (2010)
Taiwan (southern East China Sea, coast of northeastern)	Anomura: Galatheidae (3), Porcellanidae (2) Brachyura: Leucosiidae (1), Pilumnidae (4), Domeciidae (2), Tetraliidae (7), Trapeziidae (5), Xanthidae (3) and Cryptochiridae (2)	Present study
Thailand	Anomura: Diogenidae (3), Parapaguridae (1) and Porcellanidae (2) Brachyura: Dromiidae (5), Portunidae (3), Domeciidae (1), Tetraliidae (1), Trapeziidae (11), Xanthidae (6), Pinnotheridae (14) and Cryptochiridae (4)	Naiyanetr (2007)
Thailand	Anomura: Diogenidae (1), Galatheidae (2) and Porcellanidae (4) Brachyura: Majidae (5), Portunidae (2), Pilumnidae (5), Tetraliidae (1), Trapeziidae (4) and Xanthidae (6)	Thamrongnawasawat et al. (2009)
Yemen	Anomura: Porcellanidae (1) Brachyura: Majidae (3)	Simões et al. (2001)
Worldwide (revised)	Brachyura: Pilumnidae (3)	Chia et al. (1999)
Worldwide (revised)	Brachyura: Pilumnidae (8)	Chia and Ng (2000)
Worldwide (revised)	Brachyura: Domeciidae (4), Tetraliidae (8) and Trapeziidae (38)	Castro et al. (2004)

1994; Serène 1984). Almost all crabs of the subfamily Eumedioninae (Xanthidae) associate with echinoderms and cnidarians (Števčić et al. 1988) (Table 2).

The present study identified 5 symbiotic anomuran species, 3 from the Galatheidae family and 2 from Porcellanidae. The number of Galatheidae species is lesser than that in records from the Philippines (Baba 1988) and Taiwan (Baba et al. 2009); similarly, the number of Porcellanidae species is lesser than that in reports from Thailand (Thamrongnawasawat et al. 2009) and Taiwan (Osawa et al. 2010). However, we report on only symbiotic crabs, a small portion of these 2 families.

Decapod crustaceans Tetraliidae and Trapeziidae are diverse and distributed worldwide in the subtropical and tropical western Pacific Ocean (Table 3). Patton (1994) reported on decapod crustaceans in symbiosis with *Acropora* corals in the Great Barrier Reef of Australia. Patton recorded 8 corallicolous brachyuran Tetraliidae, 1 Domeciidae, and 2 Xanthidae species. The present study recorded similar species and numbers of species in northern Taiwan. Castro (1997a) investigated the diversity of coral symbiotic crabs in New Caledonia at the same latitude as Patton (1994) did and recorded 14 Trapeziid crabs, which is higher than that recorded in this study. Ng et al. (2001) reviewed historical records of brachyuran crabs in Taiwanese waters. The number of Trapeziidae is equal to that reported by Castro (1997a) from New Caledonia. The present study found 5 Trapeziid species, more than one-third of known species from Taiwan, which is higher than the number of those from coral reefs in southern Taiwan (Galil 1983; Jeng 1994), but lesser than the number reported by Chang et al. (1987). A comparison of the number of species identified in the present study and those worldwide (Castro et al. 2004; Trautwein 2007) revealed that 58.3% and 10.5% of all Tetraliidae and Trapeziidae species, respectively, are present in Taiwan.

The Coral Triangle, located in the Indo-Malayan region, is a marine biodiversity hot spot (Hoeksema 2007; Veron et al. 2009). To date, 7 and 14 species of Tetraliidae and Trapeziidae, respectively, including those from this study, have been identified in Taiwan. Compared with previous reports from the center of the Coral Triangle, the diversity of these symbiotic crabs in Taiwan is similar with that in Indonesia and the Philippines (Table 3). A similar diversity was reported in New Caledonia, which is east of the Coral Triangle. These results confirm the findings of Castro (2009), who stated that the subdivision of trapezoid crabs distributed from the Coral Triangle to margin areas exhibits no clear pattern; decreasing of species abundance with increasing distance from the center of the Coral Triangle.

CONCLUSIONS

The fauna composition indicates that the diversity may arise from the Kuroshio Current transporting tropical species to northern Taiwan. High species richness of crabs found in a bight environment during four-month period shows a great and promising opportunity for advanced studies on symbiotic crabs in Taiwan. It also indicates that corals are healthy in the area investigated, because some of these symbiotic crabs are considered to increase the persistence and resilience for their host, as they have the ability to mitigate environmental stresses to their host corals. Currently, coral reefs are facing the threat of various anthropogenic pressures. To effectively maintain and manage the reef ecosystem, it will be essential to increase the knowledge of biodiversity and fauna in reefs. Intensive studies on the diverse marine environments of Taiwan will be of immense interest in furthering the understanding of marine

Table 3. Species richness of Tetraliidae and Trapeziidae crustaceans in waters around the Coral Triangle

Location	*Tetraliidae*	*Trapeziidae*	Reference
Worldwide	12	38	Castro et al. (2004), Trautwein (2007)
Taiwan (Northern)	7	5	Present study
Taiwan	7	14	Ng et al. (2001) and present study
Philippines	7	14	Castro (2009)
Indonesia	5	17	Castro (1999)
Australia (Northeastern)	8	7	Castro (1997b), Patton (1994)
New Caledonia	7	14	Castro (1997b)

fauna, and this information could be applied to monitoring of possible changes in reef ecosystems in the future.

Acknowledgments: T.-W. Shih and J.-S. Hwang wrote the proposal and designed the study. Specimens collected at Fan-Zai-Aou Bay were using SCUBA by P. Limviriyakul and L.-C. Tseng. P. Limviriyakul completed the taxonomic work of crab species identification and took photographs of crabs in the laboratory. P. Limviriyakul and L.-C. Tseng analyzed the data, prepared figures and tables, and drafted the manuscript. P. Limviriyakul, J.-S. Hwang and T.-W. Shih finalized the manuscript. All authors read and approved the final manuscript.

Furthermore, we are grateful for financial support from the Ministry of Science and Technology (MOST) of Taiwan through the grant no. NSC-1021324062 and 103AS-14.3.2-FA-F1(5-1) to T.-W. Shih, and under grant no. MOST 103-2611-M-019-002 to J.-S. Hwang as well as the grant no. NSC 102-2811-M-019-006 and MOST 103-2811-M-019-005 to L.-C. Tseng. Special appreciate to the colleagues of T.-W. Shih's in National Museum of Marine Science and Technology for their assistance to the field sampling. Thanks are due to Professor Tin-Yam, Chan (Institute of Marine Biology, National Taiwan Ocean University), whose helps and advices on some taxonomy work.

REFERENCES

Abele LG, Patton WK. 1976. The size of coral heads and the community biology of associated decapod crustaceans. J Biogeogr **3:**35-47.

Ahyong ST. 2007. Decapod Crustacea collected by the NORFANZ expedition: Galatheidae and Polychelidae. Zootaxa **1593:**1-54.

Austin AD, Austin SA, Sale PF. 1980. Community structure of the fauna associated with the coral *Pocillopora damicornis* (L.) on the Great Barrier Reef. Aust J Mar Freshw Res **31:**163-174.

Baba K. 1969. Four new genera with their representatives and six new species of the Galatheidae in the collection of the Zoological Laboratory, Kyushu University, with redefinition of the genus *Galathea*. Ohmu **2:**1-32.

Baba K. 1988. Chirostylid and galatheid crustaceans (Decapoda: Anomura) of the "Albatross" Philippine Expedition, 1907-1910. Researches on Crustacea, Special Number **2:**1-203.

Baba K. 1990. Chirostylid and galatheid crustaceans of Madagascar (Decapoda, Anomura). Bulletin du Muséum National d'Histoire Naturelle, Paris, (4e série) Section A **11:**921-975.

Baba K, Macpherson E, Lin CW, Chan TY. 2009. Crustacean fauna of Taiwan: Squat lobsters (Chirostylidae and Galatheidae). National Taiwan Ocean University, Keelung, Taiwan.

Broesing A, Al-Aidaroos A, Türkay M. 2014. The Red Sea species of *Cymo* de Haan, 1833 (Decapoda, Brachyura, Xanthidae), associates of scleractinian corals. Zootaxa **3779:**195-214.

Bruce AJ. 1972. A review of information upon the coral hosts of commensal shrimps of the subfamily Pontoniinae, Kingsley, 1878 (Crustacea, Decapoda, Palaemonidae). *In*: Proceedings of the Symposium on Corals and Coral Reefs, 1969. The Marine Biological Association of India, pp. 399-418.

Bruce AJ. 1976. Shrimps and prawns of coral reefs, with special reference to commensalism. *In*: Jones OA, Endean R (eds) Biology and Geology of Coral Reefs, vol 3. Academic Press, New York, pp. 37-94.

Castro P. 1969. Symbiosis between *Echinoecus pentagonus* (Crustacea, Brachyura) and its host in Hawaii, *Echinothrix calamaris* (Echinoidea). Ph.D., University of Hawaii.

Castro P. 1978. Movements between coral colonies in *Trapezia ferruginea* (Crustacea: Brachyura), an obligate symbiont of scleractinian corals. Mar Biol **46:**237-245.

Castro P. 1988. Animal symbioses in coral reef communities: a review. Symbiosis **5:**161-184.

Castro P. 1996. Eastern Pacific species of *Trapezia* (Crustacea, Brachyura: Trapeziidae), sibling species ymbiotic with reef corals. Bull Mar Sci **58:**531-554.

Castro P. 1997a. Trapeziid crabs (Brachyura: Xanthoidea: Trapeziidae) of French Polynesia. *In*: Richer de Forges B (ed) Le benthos des fonds meubles des lagons de Nouvelle-Calédonie (Sédimentologie, Benthos). Études & Thèses, vol 3. ORSTOM, Paris, pp. 109-139.

Castro P. 1997b. Trapeziid crabs (Brachyura: Xanthoidea: Trapeziidae) of New Caledonia, eastern Australia, and the Coral Sea. *In*: Richer de Forges B (ed) Le benthos des fonds meubles des lagons de Nouvelle-Calédonie (Sédimentologie, Benthos). Études & Thèses, vol 3. ORSTOM, Paris, pp. 59-107.

Castro P. 1999. The Trapeziidae (Crustacea: Brachyura: Xanthoidea) of Indonesia, Results of the Rumphius Biohistorical Expedition to Ambon (1990), Part 7. Zool Meded **73:**27-61.

Castro P. 2002. New records of trapeziid crabs (Xanthoidea, Trapeziidae) from the Andaman Sea coast of Thailand, with notes on the taxonomic status of *Trapezia plana* Ward, 1941. Phuket Marine Biological Center Special Publication **23:**361-367.

Castro P. 2003. The trapeziid crabs (Brachyura) of Guam and Northern Mariana Islands, with the description of a new species of *Trapezia* Latreille, 1828. Micronesica **35:**440-455.

Castro P. 2009. Shallow-water Trapeziidae and Tetraliidae (Crustacea: Brachyura) of the Philippines (Panglao 2004 Expedition), New Guinea, and Vanuatu (Santo 2006 Expedition). Raff Bull Zool Supplement **20:**271-281.

Castro P, Huber ME. 2003. Marine Biology. 4th edn. McGraw-Hill, New York.

Castro P, Ng PKL, Ahyong ST. 2004. Phylogeny and systematics of the Trapeziidae Miers, 1886 (Crustacea: Brachyura), with the description of a new family. Zootaxa **643:**1-70.

Chan TY, Ng PKL, Ahyong ST, Tan SH. 2009. Crustacean fauna of Taiwan: Brachyuran crabs, volume I-Carcinology in Taiwan and Dromiacea, Raninoida, Cyclodorippoida.

National Taiwan Ocean University, Keelung, Taiwan.
Chang KH, Chen YS, Chen CP. 1987. Xanthid crabs in the corals, *Pocillopora damicornis* and *P. verrucosa* of southern Taiwan. Bull Mar Sci **41:**214-220.
Chia DGB, Castro P, Ng PKL. 1999. Revision of the genus *Echinoecus* (Decapoda: Brachyura: Eumedonidae), crabs symbiotic with sea urchins. J Crust Biol **19:**809-824.
Chia DGB, Ng PKL. 1998. A revision of *Ceratocarcinus* White, 1847, and *Harrovia* Adams & White, 1849 (Crustacea: Decapoda: Brachyura: Eumedonidae), two genera of crabs symbiotic with crinoids. Raff Bull Zool **46:**493-564.
Chia DGB, Ng PKL (2000) A revision of *Eumedonus* H. Milne Edwards, 1834 and *Gonatonotus* White, 1847 (Crustacea: Decapoda: Brachyura: Eumedonidae), two genera of crabs symbiotic with sea urchins. J Nat Hist **34:**15-56.
Chia DGB, Ng PKL, Castro P. 1995. On a new genus and species of eumedonid crab from the Gulf of Carpentaria, northern Australia (Crustacea: Decapoda: Brachyura: Eumedonidae). J Nat Hist **29:**1189-1195.
Dai A, Yang S. 1991. Crabs of the China Seas. China Ocean Press, Beijing.
Dong C, Li X. 2013. Galatheid squat lobster species from Chinese waters. Chin J Oceanol Limn **31:**1315-1321.
Fautin DG, Guo CC, Hwang JS. 1995. Costs and benefits of the symbiosis between the anemoneshrimp *Periclimenes brevicarpalis* and its host *Entacmaea quadricolor*. Mar Ecol Prog Ser **129:**77-84.
Fisheries Research Institute. 2014. Aquatic biological drawings. Fisheries Research Institute, Council of Agriculture. http://www.tfrin.gov.tw/lp.asp?CtNode=841&CtUnit=145&BaseDSD=77&mp=3&nowPage=20&pagesize=20&ispage=1. Accessed July 18 2014.
Galil BS. 1983. Two new species of *Trapezia* (Decapoda: Brachyura), coral-inhabiting crabs from Taiwan. Micronesica **19:**123-119.
Galil BS. 1988. Further notes on species of *Tetralia* (Decapoda, Trapeziidae). Crustaceana **54:**57-68
Galil BS, Clark PF. 1988. On a collection of *Acropora*-inhabiting trapeziids (Crustacea Brachyura Xanthoidea) from East Africa. Trop Zool **1:**137-151
Garth JS. 1984. Brachyuran decapod crustaceans of coral reef communities of the Seychelles and Amirante Islands. *In*: Stoddart DR (ed) Biogeography and ecology of the Seychelles Islands, vol 55. Dr. W. Junk Publishers, The Hague, pp. 103-122.
Glynn PW. 1980. Defense by symbiotic crustacea of host corals elicited by chemical cues from predator. Oecologia **47:**287-290.
Glynn PW. 1983. Increased survivorship in corals harboring crustacean symbionts. Mar Biol Lett **4:**105-111.
Goh BPL, Chou LM, Ng PKL. 1990. Anomuran and brachyuran crab symbionts of Singapore hard corals of the families Acroporidae, Agariciidae and Pocilloporidae. Indo-Mala Zool **6:**25-44.
Guo CC, Hwang JS, Fautin DG. 1996. Host selection by shrimps symbiotic with sea anemones: a field survey and experimental laboratory analysis. J Exp Mar Biol Ecol **202:**165-176.
Ho PH, Yu HP, Ng PKL. 2000. New records of Eriphiidae, Pilumnidae and Xanthidae (Crustacea: Decapoda: Brachyura) from Taiwan. Raff Bull of Zool **48:**111-122.
Hoeksema BW. 2007. Delineation of the Indo-Malayan centre of maximum marine biodiversity: The Coral Triangle. *In*: Renema W (ed) Biogeography, Time, and Place: Distributions, Barriers, and Islands, vol 29. Topics in Geobiology. Springer Netherlands, pp. 117-178.
Hogarth PJ. 1988. Anomuran Crustacea (Paguridea, Porcellanidae, and Hippidea) from Oman, principally from Dhofar province, southern Oman. J Nat Hist **22:**1095-1110.
Hogarth PJ. 1994. Brachyuran crabs (Xanthoidea: Xanthidae, Pilumnidae, Menippidae and Trapeziidae) of southern Oman. Trop Zool **7:**93-108.
Jeng MS. 1994. Newly recorded symbiotic crabs (Crustacea: Decapoda: Brachyura) from southern Taiwan coral reefs. Zool Stud **33:**314-318.
Kalk M. 1958. Ecological studies on the shores of Mozambique. I. The fauna of intertidal rocks at Inhaca Island, Delagoa Bay. Ann Natal Mus **14:**189-242.
Knudsen JW. 1967. *Trapezia* and *Tetralia* (Decapoda, Brachyura, Xanthidae) as obligate ectoparasites of pocilloporid and acroporid corals. Pac Sci **21:**51-57.
Komatsu H. 2011. Crabs dredged off the Ogasawara Islands (Crustacea, Decapoda, Brachyura). Mem Natl Mus Nat Sci **47:**219-277.
Kropp RK. 1990. Revision of the genera of gall crabs (Crustacea: Cryptochiridae) occurring in the Pacific Ocean. Pac Sci **44:**417-448.
Kumaralingam S, Sivaperuman C, Raghunathan C. 2012. Diversity and distribution of brachyuran crabs from Ritchie's Archipelago. Int J Oceanogr Marine Ecol Sys **1:**60-66.
Lee SH, Lee KH, Ko HS. 2011. First records of two pilumnid crabs (Crustacea: Decapoda) collected from Jejudo Island, Southern Korea. Kor J Syst Zool **27:**191-196.
Lewinsohn C. 1979. Research on the coast of Somalia. The shore and the dune of Sar Uanle: 23. Porcellanidae (Crustacea Decapod Anomura). Monitore Zool Ital Supplemento **12:**39-57.
Macpherson E, Cleva R. 2010. Shallow-water squat lobsters (Crustacea, Decapoda, Galatheidae) from Mayotte (Comoros Island), La Réunion and Madagascar, with the description of a new genus and two new species. Zootaxa **2612:**57-68.
Macpherson E, Robainas-Barcia A. 2013. A new genus and some new species of the genus *Lauriea* Baba, 1971 (Crustacea, Decapoda, Galatheidae) from the Pacific and Indian Oceans, using molecular and morphological characters. Zootaxa **3599:**136-160.
Marin IN, Britayev TA, Anker A. 2004. Pontoniine shrimps associated with cnidarians: new records and list of species from coastal waters of Viet Nam. Arthropoda Selecta **13:**199-218.
Mc Laughlin PA, Rahayu DL, Komai T, Chan TY. 2007. A catalog of the hermit crabs (Paguroidea) of Taiwan. National Taiwan Ocean University, Keelung, Taiwan.
Miyake S. 1939. Note on crabs of the genus *Echinoecus* Rathbun living commensally with echinoids (Parthenopidae, Eumedoninae). Annot Zool Japon **18:**83-94.
Miyake S, Keiji B. 1967. Galatheids of the East China Sea (Chirostylidae and Galatheidae, Decapoda, Crustacea). J Fac Agric Kyushu Univ **14:**225-246.
Naiyanetr P. 2007. Checklist of crustacean fauna in Thailand (Decapoda, Stomatopoda, Anostraca, Myodocopa and Isopoda). ONEP Biodiversity Series, vol 19. Office of Natural Resources and Environmental Policy and Planning, Bangkok.
Nakasone Y, Miyake S. 1972. Four unrecorded porcellanid crabs (Anomura: Porcellanidae) from Japan. Bull Sci Eng

Div, Univ Ryukyus, Math Nat Sci **15:**136-147.
Ng PKL, Jeng MS. 1999. The brachyuran crabs (Crustacea: Decapoda: Eumedonidae and Portunidae) symbiotic with echinoderms in Taiwan. Zool Stud **38:**268-274.
Ng PKL, Wang CH, Ho PH, Shih HT. 2001. An annotated checklist of brachyuran crabs from Taiwan (Crustacea: Decapoda). National Taiwan Museum Special Publication Series, vol 11. National Taiwan Museum, Taipei.
Nomura K, Nagai S, Asakura A, Komai T. 1996. A preliminary list of shallow water decapods Crustacea in the Kerama Group, the Ryukyu Archipelago. Bull Biogeogr Soc Jpn **51:**7-21.
Osawa M, Boyko CB, Chan TY, Ahyong ST, Macpherson E. 2010. Crustacean fauna of Taiwan: Crab-like anomurans (Hippoidea, Lithodoidea and Porcellanidae). National Taiwan Ocean University, Keelung, Taiwan.
Patton WK. 1994. Distribution and ecology of animals associated with branching corals (*Acropora* spp.) from the Great Barrier Reef, Australia. Bull Mar Sci **55:**193-211.
Paulay G. 1997. Diversity and distribution of reef organisms. In: Birkeland C (ed) Life and death of coral reefs. Chapman and Hall, New York, pp. 298-353.
Peyrot-Clausade M. 1989. Crab cryptofauna (Brachyura and Anomura) of Tikehau, Tuamotu Archipelago, French Polynesia. Coral Reefs **8:**109-117.
Poupin J. 1996. Crustacea Decapoda of French Polynesia (Astacidea, Palinuridea, Anomura, Brachyura). Atoll Res Bull **442:**1-114.
Pratchett MS. 2001. Influence of coral symbionts on feeding preferences of crown-of-thorns starfish *Acanthaster planci* in the western Pacific. Mar Ecol Prog Ser **214:**111-119.
Pratchett MS, Graham NAJ, Sheppard CRC, Mayes B. 2010. Are infestations of *Cymo melanodactylus* killing *Acropora cytherea* in the Chagos archipelago? Coral Reefs **29:**941-941.
Pratchett MS, Pisapia C, Sheppard CRC. 2013. Background mortality rates for recovering populations of *Acropora cytherea* in the Chagos Archipelago, central Indian Ocean. Mar Environ Res **86:**29-34
Pratchett MS, Vytopil E, Parks P. 2000. Coral crabs influence the feeding patterns of crown-of-thorns starfish. Coral Reefs **19:**36-36.
Ramadan MM. 1936. Report on a Collection of Stomatopoda and Decapoda from Ghardaga, Red Sea vol 6. Bulletin of the Faculty of Science. Egyptian University, Giza.
Sakai T. 1976. Crabs of Japan and the adjacent seas. Kodansha, Tokyo.
Schweitzer CE. 2005. The Trapeziidae and Domeciidae (Decapoda: Brachyura: Xanthoidea) in the fossil record and a new Eocene genus from Baja California Sur, Mexico. J Crust Biol **25:**625-636.
Serène R. 1984. Crustacés décapodes brachyoures de l'Océan Indien occidental et de la Mer Rouge, Xanthoidea: Xanthidae et Trapeziidae. Avec un addendum par Crosnier, A.: Carpiliidae et Menippidae. Faune Tropicale, vol 24. Institut Français de Recherche Scientifique pour le développement en coopération, Paris.
Shao KT. 1998. Marine Ecology. National Press Company, Ming Wen Book Co., Ltd., Taipei, Taiwan. (in Chinese)
Simões N, Apel M, Jones DA. 2001. Intertidal habitats and decapod faunal assemblages (Crustacea: Decapoda) of Socotra Island, Republic of Yemen. Hydrobiologia **449:**81-97.
Sin T. 1999. Distribution and host specialization in *Tetralia* crabs (Crustacea: Brachyura) symbiotic with corals in the Great Barrier Reef, Australia. Bull Mar Sci **65:**839-850.
Sin TM, Lee AC. 2002. Host specialisation in trapeziid crabs: consequences for rarity at local scales. *In*: Moosa MK, Soemodihardjo S, Soegiarto A, Romimohtarto K, Nontji A, Suharsono S (eds) Proceedings of the 9th International Coral Reef Symposium, Bali, 2000. pp. 533-536.
Stella JS, Munday PL, Jones GP. 2011a. Effects of coral bleaching on the obligate coral-dwelling crab *Trapezia cymodoce*. Coral Reefs **30:**719-727.
Stella JS, Pratchett MS, Hutchings PA, Jones GP. 2011b. Coral-associated invertebrates: density, ecological importance and vulnerability to disturbance. Oceanogr Mar Biol Ann Rev **49:**43-104.
Števčić Z, Castro P, Gore RH. 1988. Re-establishment of the family Eumedonidae Dana, 1853 (Crustacea: Brachyura). J Nat Hist **22:**1301-1324.
Stewart HL, Holbrook SJ, Schmitt RJ, Brooks AJ. 2006. Symbiotic crabs maintain coral health by clearing sediments. Coral Reefs **25:**609-615.
Stier AC, Gil MA, McKeon CS, Lemer S, Leray M, Mills SC, Osenberg CW. 2012. Housekeeping mutualisms: do more symbionts facilitate host performance? PloS One **7:**e32079.
Thamrongnawasawat T, Wisespongpand P, Limviriyakul P. 2009. Reef fauna of Thailand. The Agricultural Research Development Agency, Bangkok.
Thiel M, Zander A, Valdivia N, Baeza JA, Rueffler C. 2003. Host fidelity of a symbiotic porcellanid crab: the importance of host characteristics. J Zool **261:**353-362.
Tirado-Sanchez N, Chiriboga A, Ruiz D, Banks S. 2014. CDF Checklist of Galapagos Marine Crustaceans. Charles Darwin Foundation. http://www.darwinfoundation.org/datazone/checklists/marine-invertebrates/marine-crustaceans/. Accessed November 4 2014.
Trautwein SE. 2007. Four new species of coral crabs belonging to the genus *Tetralia* Dana, 1851 (Crustacea, Decapoda, Brachyura, Tetraliidae). Zootaxa **1450:**1-20
Tsuchiya M, Nojima S. 2002. Occurrence of *Trapezia* associated with *Acropora*: on the "wrong" host coral? Coral Reefs **21:**160-160.
Tsuchiya M, Yamauchi Y, Moretzsohn F, Tsukiji M. 1993. Species composition and some population traits of obligate symbiotic Xanthid crabs, *Trapezia* and *Tetralia*, associated with bleached corals. *In*: Richmond RH (ed) Proceedings of the 7th Coral Reef International Symposium, Guam, 1992. University of Guam Press, pp. 56-63.
Veron JEN. 2000. Corals of the world, vol. 3. Australian Institute of Marine Science, Townsville, Australia.
Veron JEN, Devantier LM, Turak E, Green AL, Kininmonth S, Stafford-Smith M, Peterson N. 2009. Delineating the coral triangle. Galaxea **11:**91-100.
Wei TP, Chen HC, Lee YC, Tsai ML, Hwang JS, Peng SH, Chiu YW. 2013. Gall polymorphism of coral-inhabiting crabs (Decapoda, Cryptochiridae): a new perspective. J Mar Sci Technol-Taiwan **21:**304-307.
Wei TP, Hwang JS, Tsai ML, Fang LS. 2005. New records of gall crabs (Decapoda, Cryptochiridae) from Orchid Island, Taiwan, northwestern Pacific. Crustaceana **78:**1063-1077.
Yamano H, Sugihara K, Goto K, Kazama T, Yokoyama K, Okuno J. 2012. Ranges of obligate coral-dwelling crabs extend northward as their hosts move north. Coral Reefs **31:**663-663.