Systematics and Biogeography of Fiddler Crabs – A Special Issue in *Zoological Studies*

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Fiddler crabs are a fantastic group of intertidal brachyuran crabs and the research fields in biodiversity, phylogeography, phylogenomics, and larval biology of fiddler crabs are still in developing stages. In this special issue, seven articles are included focusing on the diversity, phylogeography, mitogenome phylogeny and larval morphology of fiddler crabs, covering the regions of Indo-West Pacific and Americas. Results from this special issue open up further opportunities to study new species identification based on integrative taxonomy approach, genomic-level phylogeny and larval morphology, especially the mitogenomes in the genera *Cranuca*, *Gelasimus*, *Paraleptuca*, and *Uca* for filling up the knowledge gap of fiddler crabs in the world.

Key words: Fiddler crabs, Systematics integrative taxonomy, Mitogenomes, Larval biology, Phylogeny.

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Fiddler crabs are a fantastic group of intertidal brachyuran crabs attracting a lot of naturalists focusing on their natural history, including taxonomy, phylogeny, evolution, behavior, ecology, etc. (Crane 1975; Shih et al. 2016; Pardo et al. 2020; Perez et al. 2020). Among the literature, Crane's (1975) "Fiddler Crabs of the World" (Crane 1975) is still an important monograph influencing the modern studies of fiddler crabs (von Hagen 1976). With respect to the systematics, Crane (1975) divided the fiddler crabs into nine subgenera in which seven of them were erected by her. However, Bott (1973) published a revision of fiddler crabs which divided fiddler crabs into 10 genera, with two additional subgenera. As a result, most of Crane's (1975) subgeneric names need to be replaced by the generic names in Bott (1973) according to the priority of nomenclature (von Hagen 1976). In Beinlich and von Hagen (2006), the systematics of fiddler crabs was revised into eight subgenera, including a new subgenus *Cranuca* Beinlich & von Hagen (2006); the subgenus *Gelasimus* Latreille, 1817 has priority over *Mesuca* Bott, 1973; the subgenus *Uca* Latreille, 1817 including *Afruca* Crane, 1975; and the subgenus *Paraleptuca* Bott, 1973 including *Austruca* Bott, 1973, which were followed by the checklist of extant brachyuran crabs of the world (Ng et al. 2008).

New modern taxonomy and systematics involve both morphological and molecular approach to study species lineages including fiddler crabs. Levinton et al. (1996) and Sturmbauer et al. (1996) studied the phylogeny of fiddler crabs by using mitochondrial 16S rDNA (*16S*) from 27 species and concluded that fiddler crabs comprise "Ancestral America Clade", "Derived American Clade" and "Indo-West Pacific Clade". Since then, however, few molecular studies of fiddler crabs until 2009, although the above two references have been cited and discussed in the revisions of Rosenberg (2001) and Beinlich and von Hagen (2006).

By using the mitochondrial *16S* and cytochrome oxidase subunit I (*COI*) and nuclear 28S rDNA (*28S*), Shih et al. (2016) revised the family Ocypodidae from 78 species of fiddler crabs and 13 ghost crabs (genus *Ocypode*). Molecular phylogeny of fiddler crabs showed the group is paraphyly, which was hardly accepted by most traditional naturalists, but the molecular phylogenetic results largely agreed with Levinton et al. (1996: fig. 2), *i.e.*, one clade of the

subfamily Gelasiminae, but another and *Ocypode* forming the subfamily Ocypodidae. Latest revision in fiddler crabs based on molecular evidences raise all the subgenera of fiddler crabs to 11 full genera, except *Australuca* Crane, 1975 has been synonymized with *Tubuca* Bott, 1973. The latest systematics, and the phylogenetic trees, established by Shih et al. (2016) has been applied for the evolution of synchronous waving behaviors (Backwell 2019; Perez et al. 2020) and above-ground sedimentary structures (Pardo et al. 2020).

There was alternative taxonomic grouping of fiddler crabs proposed by Rosenberg (2019) adopted the subfamily Ucinae Dana, 1851 and grouped species into tribes and subgenera. However, this system was not supported consistently by the current available genetic data (Shih et al. 2016) and were not followed by later taxonomic studies (*e.g.*, Shih and Poupin 2018; Sasaki 2019; Michie et al. 2021; Shih et al. 2021) and the World Register of Marine Species (WoRMS 2022).

Since 2009, a series of phylogenetic or taxonomic papers have been published by using mitochondrial and nuclear markers (*e.g.*, Shih et al. 2009 2013b), which supported two new subgenera (*Uca* (*Petruca*) Shih, Ng & Christy, 2015 and *Uca* (*Xeruca*) Shih, 2015) (Shih 2015; Shih et al. 2015a), six new species (*Austruca citrus* Shih & Poupin, 2020, *Austruca occidentalis* (Naderloo, Schubart & Shih, 2016), *Gelasimus jocelynae* (Shih, Naruse & Ng, 2010), *Minuca osa* (Landstorfer & Schubart, 2010), *Paraleptuca boninensis* (Shih, Komai & Liu, 2013), *Tubuca alcocki* Shih, Chan & Ng, 2018) (Landstorfer and Schubart 2010; Shih et al. 2010 2013a 2018; Naderloo et al. 2016; Shih and Poupin 2020), two resurrected species (*Paraleptuca splendida* (Stimpson, 1858) and *Austruca variegata* (Heller, 1862)) (Shih et al. 2012 2019) (Fig. 1). Many studies for the phylogeography of fiddler crabs were reported from the Indo-West Pacific (Silva et al. 2010; Aoki and Wada 2013; Shih et al. 2015b; Fratini et al. 2016; Nehemia and Kochzius 2017; Tokuyama et al. 2020; Hardianto et al. 2022) and Atlantic-East Pacific regions (Sanford et al. 2006; Wieman et al. 2013; Staton et al. 2014; Laurenzano et al. 2012 2013 2016, Thurman et al. 2018 2021). With regard to the mitogenomes, 10 species of fiddler crabs and three species of *Ocypode* are available (see Liu and Shih 2022). The study on the biodiversity, phylogeography, larval morphology and mitogenomes of fiddler crabs are still in developing stages.

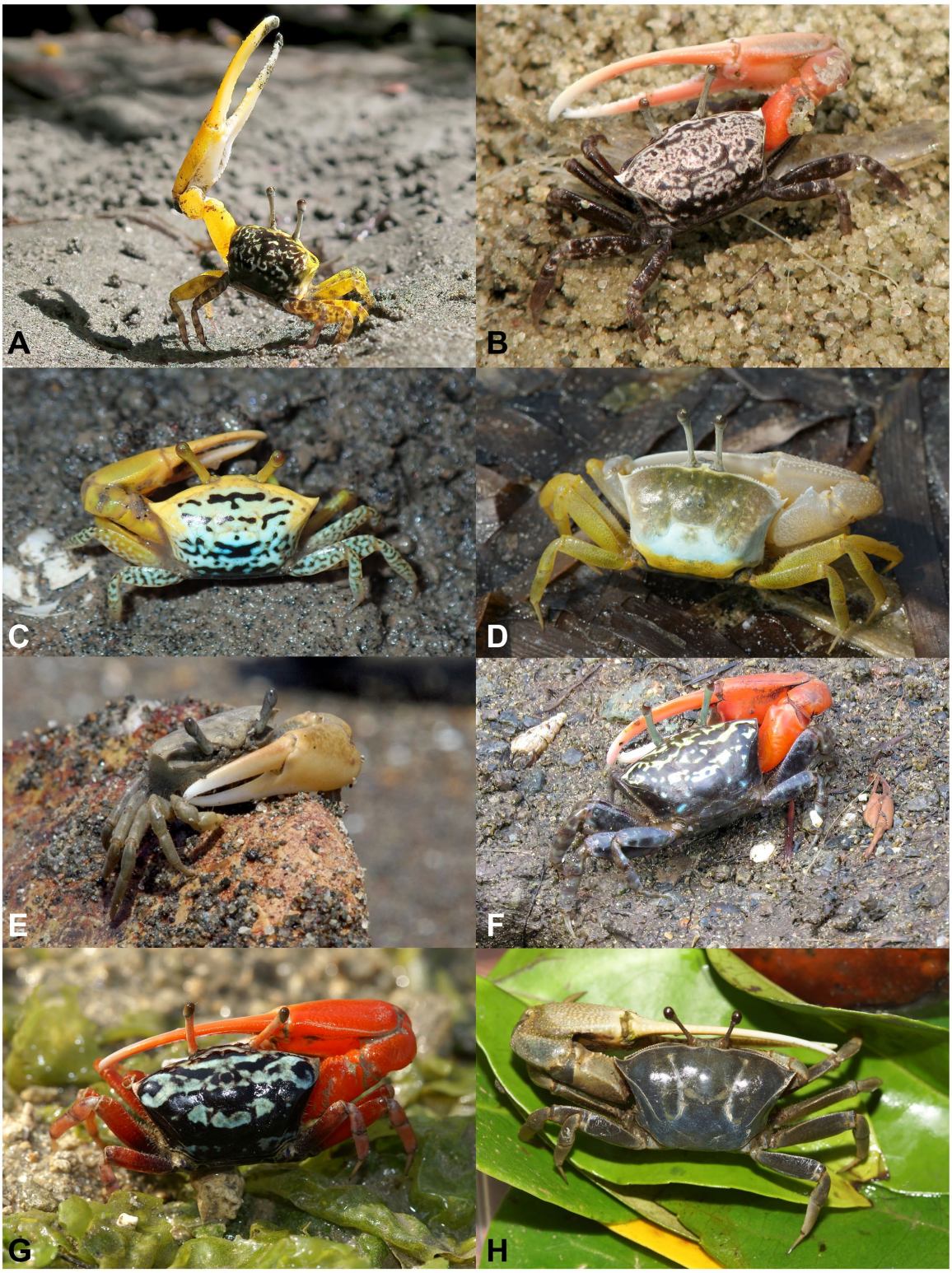

Fig. 1. Photographs of some taxa of fiddler crabs published as new or resurrected recently. A, *Austruca citrus* Shih & Poupin, 2020 (Fiji); B, *Austruca occidentalis* Naderloo, Schubart & Shih (Inhaca, Mozambique); C, *Austruca variegata* (Heller, 1862) (Vellar River estuary, Tamil Nadu, India); D, *Gelasimus jocelynae* (Shih, Naruse & Ng, 2010) (Dongsha Island, Taiwan); E, *Petruca panamensis* (Stimpson, 1859) (Panama); F, *Paraleptuca boninensis* (Shih, Komai & Liu, 2013) (Ogasawara Islands, Japan); G, *Tubuca alcocki* Shih, Chan & Ng, 2018 (Ranong, Thailand).

Photographs courtesy of T. Iwano (A), P. Backwell (B, E), M. Prema (C) and M.-H. Chuang (F).

In this special issue, seven articles are included focusing on the regional fauna, phylogeography, mitogenome phylogeny and larval morphology, covering the regions of Indo-West Pacific and Americas. Two articles about the diversity of fiddler crabs from around the Arabian Sea (Shih et al. 2022a) and Vietnam (Shih et al. 2022b), confirmed by the DNA barcoding analyses, which reveal the composition of faunas with biogeographical discussion. Two phylogeographic articles of *Letpuca thayeri* (Rathbun, 1900) and *Uca maracoani* (Latreille, 1803) along the tropical West Atlantic (Marochi et al. 2022), as well as *Tubuca arcuata* (De Haan, 1835) in East Asia and Vietnam (Shih et al. 2022c), which contribute the understanding of the potential mechanisms of population composition. A phylogeny based on the mitogenomes of the Taiwan endemic *Xeruca formosensis* (Rathbun, 1921) and other members of the Ocypodidae (Liu and Shih 2022) further agrees the systematics of this family established by Shih et al. (2022). A complete larval stages of *Austruca albimana* (Kossmann, 1877) from the Red Sea (Kumar and Al-Aidaroos 2022) and the first zoeal stage of 15 species from Taiwan (Zhang and Shih 2022) which show the importance of larval morphology to the taxonomy and systematics of fiddler crabs.

For the future studies of taxonomy and systematics of fiddler crabs, the following topics are suggested to be organized. First, more species, either new or resurrected species, supported by molecular evidence, will be published (personal communication and unpublished by HT Shih) to contribute to the diversity of fiddler crabs. Second, although a preliminary phylogenetic analysis based on multiple markers, viz. *16S*, *COI* and *28S*, as well as a nuclear histone 3, showed the same pattern with Shih et al. (2016) (unpublished data by HT Shih). Using more genetic markers, mitogenomes, or even whole genomes, of fiddler crabs, esp. species of the genera *Uca* and *Afruca*, as well as *Ucides* Rathbun, 1897, will strengthen the systematics of the Ocypodidae. Third, by analyzing the phylogeographic patterns of more species, it is expected to understand the underlying mechanisms of the species distribution within a region. Last, more studies of species with complete larval stages, esp. the species of the genera *Cranuca*, *Gelasimus*, *Paraleptuca*, and *Uca*, may reveal

more reliable larval characters to provide additional morphological evidence to taxonomy and systematics.

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