We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter 11

An Update on Reproduction in Ghost Shrimps (Decapoda: Axiidea) and Mud Lobsters (Decapoda: Gebiidea)

Patricio Hernáez

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.75067

Abstract

In this report, I review the taxonomic history, body adaptations, ecology, and reproduction of the infraorders Axiidea (ghost shrimps) and Gebiidea (mud lobsters). Known until recently as the "Thalassinidea," modern classification divided Axiidea into six families and Gebiidea into five. Ghost shrimps are characterized by having the first and second pereiopod chelate and a soft and delicate body, whereas mud lobsters possess the first pereiopod chelate or subchelate and second pereiopod subchelate or simple with a hard and heavily calcified body. Among the main body adaptations of these organisms are distinguished: (i) carapace laterally compressed, (ii) pleon longer than the cephalothorax in ghost shrimps but usually shorter in mud lobsters, and (iii) anterior feet thrown directly forward. Current accounting of axiideans and gebiideans reaches around 781 and 240 extant species, respectively, with major number of species in Callianassidae and Upogebiidae within of each clade. Male reproductive system involves paired testes linked to the vas deferens that open in gonopores on the ventral coxal segment of the fifth pereiopod. In females, the reproductive system is composed of paired and colored ovaries, one ovary shorter than another, and a pair of short and translucent oviducts linking each ovary to the gonopore, this latter located on the ventral coxal of the third pereiopod. When present in males, the first pleopod is sexually dimorphic. Most ghost shrimps show distinct sexual dimorphism in body size and the major cheliped which become them in a promising group for growth studies. Hypertrophied chelipeds in males are often used to defend galleries against invasion from other shrimps from the same or opposite sex or during the intense male-to-male competition for sexual partners. Knowledge about sexual systems of these species remains limited; however, available information suggests that hermaphroditism might be commonly present in axiideans and gebiideans. Regarding mating systems, all species of ghost shrimp and mud lobster with solitary habits and remarkable sexual dimorphism in the major cheliped are expected to be polygamous. Finally, considerable variability among Axiidea and Gebiidea species in fecundity and egg size may indicate important differences in the reproductive strategy and may also reflect a latitudinal trend as observed in other decapods.

IntechOpen

© 2018 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

Keywords: Thalassinidea, taxonomy, ecology, sexual systems, mating systems, sexual dimorphism

1. Taxonomic origin of Thalassinidea

The term "Thalassinoides" is introduced for the first time into subsection Macrura (reptant) by the zoologist Latreille [1], including in it the genera *Gebia* Leach, 1816; *Thalassina* Latreille, 1806; *Callianassa* Leach, 1814; and *Axius* Leach, 1815. Next, this term is Latinized as Thalassinidea Latreille, 1831, incorporating it to the suborder Pleocyemata Burkenroad, 1963. Dana [2] divided Thalassinidea into Eubranchiata (species with thoracic branchiae) and Anomobranchiata (species with abdominal branchial appendages), classifying the taxa Gebidae; Callianassidae Dana, 1852; and Thalassinidea Latreille, 1831, into Eubranchiata and *Callianidea* H. Milne Edwards, 1837, and *Isaea* H. Milne Edwards, 1830, into Anomobranchiata. The famous zoologist de Saint Laurent [3] elevated the genus *Upogebia* Leach, 1814 (e.g., Callianassidae) to family rank, and she reorganized the families Callianassidae; Callianideidae Kossmann, 1880; and Axiidae Huxley, 1879, into superfamily Axioidea [4]. In another work published in the same year, she divided Reptantia into 10 groups that in her opinion were caused by the process called "radiation Triassique" [5]. In her work, she stated that infraorder Thalassinidea was the only group of Reptantia impossible to define precisely and so introduced the term (French) "Thalassinacea." De Saint Laurent [5] argued that in "Thalassinacea," relationship between the epistome and the carapace varied notably from one family to another, also the number of chelate pereopods (sometimes one and sometimes two); an appendix interna was not always present. From these observations, she proposed the separation of "Thalassinacea" into infraorders Axiidea and Gebiidea, thus transferring the families Axiidae and Callianassidae for the former infraorder and Laomediidae; Upogebiidae Borradaile, 1903; and Thalassinidea for the latter infraorder [5].

The first cladistic analysis of Thalassinidea was conducted by Poore [6]. He found the group to be monophyletic and divided into three superfamilies (Callianassoidea, Axioidea, Thalassinidea). A subsequent phylogenetic study using molecular data divided Thalassinidea into two major clades [7]. The first clade composed of the families Strahlaxiidae Poore, 1994, and Callianassidae and the second clade of Laomediidae Borradaile, 1903, Upogebiidae, and Thalassinidea (see also [8] sperm data; [9] molecular data). Sakai [10] compared the gastric mill in species of the Thalassinidea and found the group "diphyletic." From his information, he proposed the division of Thalassinidea into superorder Callianassoidea composed of five families (Axiidae; Callianassidae; Callianideidae; Ctenochelidae Manning and Felder, 1991; Gourretiidae Sakai, 1999) and Thalassinidea composed of three families (Laomediidae, Upogebiidae, Thalassinidea). In the former group, all species are characterized by the presence of a propyloric ossicle simple, whereas in the latter group by having a propyloric ossicle triangularly protruded downward [6]. Lastly, Robles et al. [11] undertook a molecular phylogeny of the thalassinideans and discovered the same two groups proposed by de Saint Laurent [4, 5] and other researchers [12–14].

http://dx.doi.org/10.5772/intechopen.75067

Taxon
Class Malacostraca
Subclass Phyllocarida
Subclass Hoplocarida
Subclass Eumalacostraca
Superorder Syncarida Packard, 1885
Superorder Peracarida Calman, 1904
Superorder Eucarida Calman, 1904
Order Euphausiacea Dana, 1852
Order Decapoda Latreille, 1802
Suborder Dendrobranchiata Spence Bate, 1888
Suborder Pleocyemata Burkenroad, 1963
Infraorder Achelata Scholtz and Richter, 1995
Infraorder Anomura MacLeay, 1838
Infraorder Astacidea Latreille, 1802
Infraorder Axiidea de Saint Laurent, 1979
Family Axiidae Huxley, 1879
Family Callianassidae Dana, 1852
Family Callianideidae Kossmann, 1880
Family Gourretiidae Sakai, 1999
Family Micheleidae Sakai, 1992
Family Strahlaxiidae Poore, 1994
Infraorder Brachyura Latreille, 1802
Infraorder Caridea Dana, 1852
Infraorder Gebiidea de Saint Laurent, 1979
Family Axianassidae Schmitt, 1924
Family Kuwaitupogebiidae Sakai, Türkay and Al Aidaroos, 2015
Family Laomediidae Borradaile, 1903
Family Thalassinidea Latreille, 1831
Family Upogebiidae Borradaile, 1903
Infraorder Glypheidea Van Straelen, 1925
Infraorder Polychelida Scholtz and Richter, 1995
Infraorder Procaridida Felgenhauer and Abele, 1983
Infraorder Stenopodidea Spence Bate, 1888

Table 1. Families of Axiidea and Gebiidea within the classification of the arthropod superclass Multicrustacea based on Dworschak et al. [15], updated by worms [22].

Currently, it is reasonably assumed by researchers that Axiidea and Gebiidea represent two distinctly separate infraorders of decapods whose main evolutionary characteristic is the fossorial lifestyle [15]. Members of Axiidea (casually known as ghost shrimps) are characterized by having the first and second pereiopod chelate and a soft and delicate body, whereas all Gebiidea (casually known as mud lobsters) possess the first pereiopod chelate or subchelate and second pereiopod subchelate or simple with a hard and heavily calcified body [15, 16]. Recent discovery of new species has added a series of new families within Axiidea and Gebiidea [17, 18]. Considering this information, modern classification of both groups divided Axiidea into six families and Gebiidea into five (**Table 1**). Nevertheless, taxonomy of old name Thalassinidea follows being very controversial among carcinologists from the "American school" and opinions of Sakai, particularly in what concerns to the correct use of the names Axiidea and Gebiidea versus Callianassidea and Thalassinidea [19, 20].

2. A body adapted for a fossorial lifestyle

In order to understand and define what is meant by ghost shrimp and mud lobster, the general morphological components of the infraorders Axiidea and Gebiidea need to be examined.

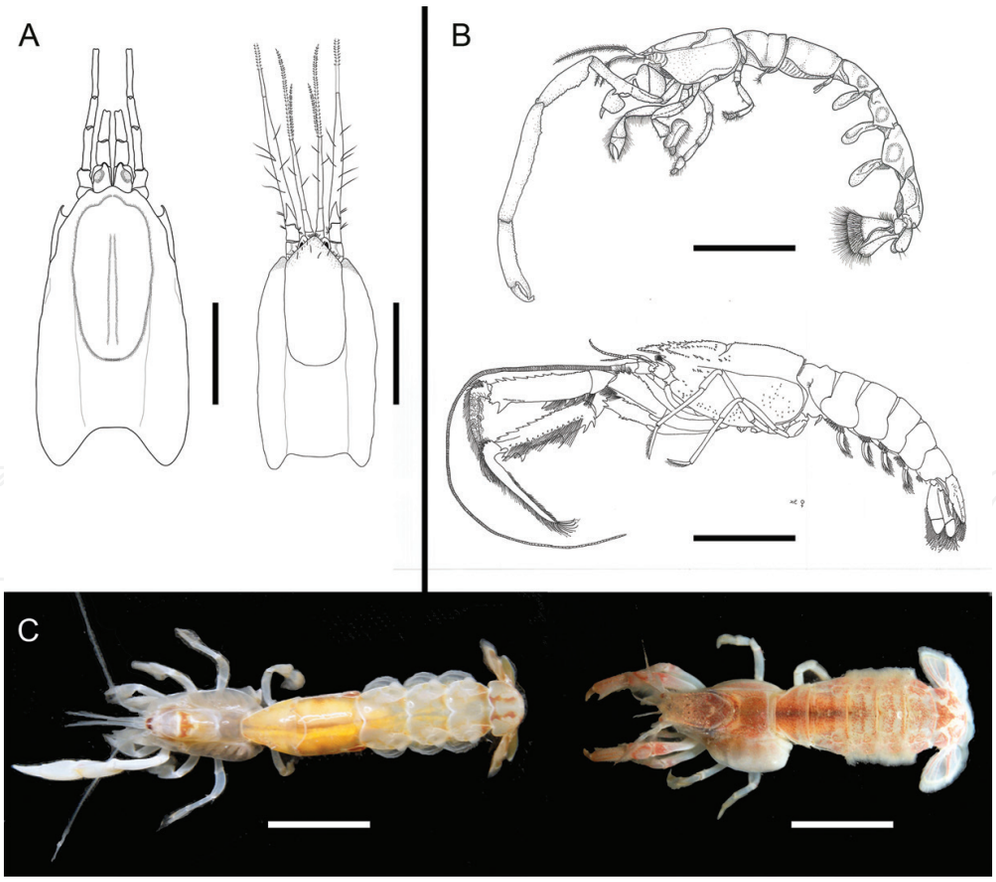


Figure 1. Main morphological adaptations in Axiidea and Gebiidea. (A) Carapace of *Neocallichirus grandimana* (left panel) and *Axianassa linda* (right panel), dorsal view; (B) male specimen of *Callichirus seilacheri* (top panel) and *Naushonia macginitiei* (Glassel, 1938) (down panel), lateral view; (C) male specimen of *Lepidophthalmus siriboia* (left panel) and *Upogebia omissa* (right panel), dorsal view. (a,B) left and right panel, scale bar = 1 cm, 0.5 cm, respectively; (B) top and down panels, scale bar = 1 cm, 0.5 cm, respectively.

http://dx.doi.org/10.5772/intechopen.75067

The carapace in most of these species (except in laomediids of the genus *Naushonia*) is laterally compressed and can be strongly ornamented (**Figure 1A**, left and right panel), with spines and tubercles as in Thalassinidea and Upogebiidae (Gebiidea) or unornamented as in Callianassidae and Callianideidae (Axiidea) [15, 16]. The pleon is longer than the cephalothorax in most ghost shrimps (**Figure 1B**, top panel) but usually shorter in mud lobsters (**Figure 1B**, down panel), and anterior feet are thrown directly forward in all members of these clades [15, 16] (**Figure 1C**, left and right panel).

3. Diversity and ecological importance

Inhabiting most oceans and seas of the world, ghost shrimps (Axiidea) and mud lobsters (Gebiidea) exhibit a greatest diversity with about 423 and 192 extant species, respectively [21]. According to information available in database World Register Marine Species, for Axiidea and Gebiidea, those values have increased in about 85% and 25%, respectively, during the last decade [22]. In terms of extant species, family Callianassidae exhibits the greatest diversity within infraorder Axiidea whereas Upogebiidae within Gebiidea (**Table 2**).

Both axiideans and gebiideans are known for constructing burrows of different shapes and depths [23–27] (**Figure 2A**) and for playing an important role in shaping the community structure in intertidal and shallow water of marine habitats [28–31]. Bioperturbation produced by these organisms, i.e., the activity of water and sediment expulsion from the galleries, contributes to the suspension of organic matter, nitrogen fixation, and the increases of food availability among the trophic levels [32–34] (**Figure 2B**). Members of Axiidea and Gebiidea can be found inhabiting as sponge symbionts, living between coarse coral rubble or even associated to hydrocarbon seeps

Taxon	Number of genera	Extant species
Infraorder Axiidea		
Family Axiidae	63	205
Family Callianassidae	67	495
Family Callianideidae	6	18
Family Gourretiidae	9	20
Family Micheleidae	4	33
Family Strahlaxiidae	3	10
Infraorder Gebiidea		
Family Axianassidae	2	15
Family Kuwaitupogebiidae	1	1
Family Laomediidae	4	21
Family Thalassinidea	1	11
Family Upogebiidae	13	192

Table 2. Number of genera and species for each family of Axiidea and Gebiidea based on database of worms [22].

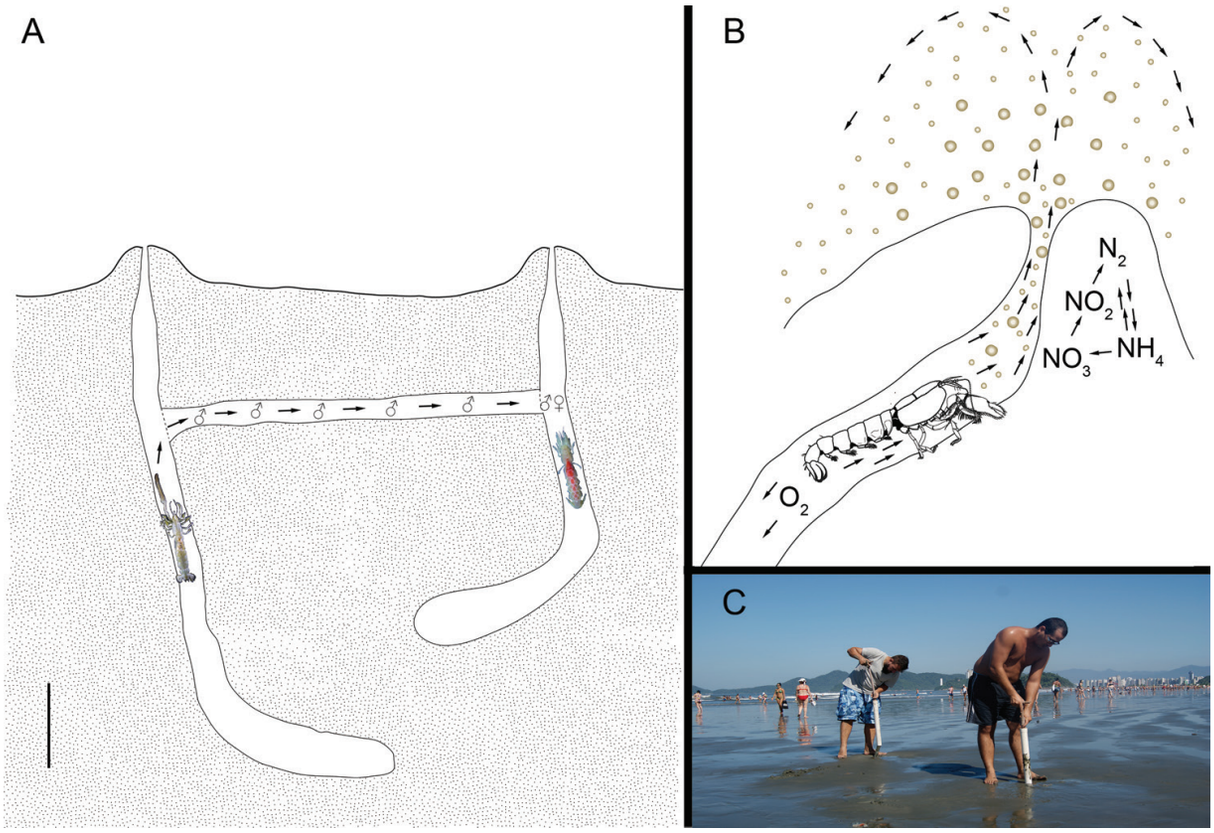


Figure 2. (A) Burrow morphology and copulatory behaviour in Callichirus seilacheri (Callianassidae), scale bar = 20 cm; (B) model of bioperturbation activity in Axianassa linda (Axianassidae); (C) fishermen harvesting Callichirus major (Callianassidae) at São Paulo State, Brazil.

and hydrothermal vents in deep water [35–38]. Some species of ghost shrimps are considered ecosystem engineers because of their capacity to modify, maintain, and/or create habitats for other marine invertebrates [39–40]. Also, several ghost shrimps and mud lobsters are used as a bait for recreational fishing and human consumption [41–45] (**Figure 2C**).

Dworschak et al. [15] stated that most ghost shrimps and mud lobster species are characterized by solitary habits; however, such assumption lacks empirical support from the available literature. With the exception of larval period [46–49], axiideans and gebiideans spend their lifetime within of gallery [15], which makes it difficult to capture and study them. As a result, the knowledge about population dynamics and reproduction of these species is restricted to about 6.00% of already described species, being most of these studies realized in species of the families Callianassidae and Upogebiidae [40, 50–56].

4. Reproductive biology

4.1. Gonopores and primary sexual characters

The location of the male and female sexual openings in Axiidea and Gebiidea is similar to described universally for the reptant decapods [57]. Males possess prominent gonopores on

the ventral coxal segment of the fifth pereiopod, whereas females have oval gonopores on the ventral coxal segment of the third pereiopod [40, 58, 59] (**Figure 3A**).

Information about internal anatomy of the reproductive system is virtually nonexistent in most species of ghost shrimps and mud lobsters. Scarce information published point out that male reproductive system involves paired testes dorsally to the hepatopancreas and the intestine and is located between first and second abdominal somites, whose connection with genital openings (gonopores) is produced through a pair of translucent or whitish vas deferens [60] (**Figure 3B**). Secreting epithelium of the vas deferens is responsible for forming the gelatinous spermatophoric mass [61], as observed in other decapods [62]. Female sexual system is composed of paired orange or dark red ovaries (depending upon developmental stage), one ovary shorter than another, both visible through pleonal region and a pair of short and translucent oviducts linking the ovary to gonopore [59, 60] (**Figure 3C**). Seminal receptacle or spermathecae have not been described for any Axiidea and Gebiidea, despite attempts to find them [63]. Laboratory observations show that females of callianassid shrimps are not able to store sperm [64], as reported in most brachyuran crabs [65].

4.2. Secondary sexual characters

Males of most ghost shrimps and mud lobsters can be identified by the absence/presence and morphology of the first pleopod. The first pleopod is absent in most males of Axianassidae, Laomediidae, Strahlaxiidae, and Upogebiidae and in numerous Callianassidae [15, 16, 66, 67]. When present, the male first pleopod is uniramous and can be unsegmented as in *Thalassina* [68], bisegmented as in *Callichirus* [58], or composed of four articles as in *Ctenocheles* [69]. Male first pleopod in some species as *Callianidea mariamartae* Hernáez and Vargas, 2013, and *Marcusiaxius lemoscastroi* Rodrigues and de Carvalho, 1972, is morphologically similar to gonopods of Brachyura [70, 71], showing a tiny size and function totally unknown [15]. First pleopod plays an important role during the mating behavior of caridean shrimps [72] and brachyuran crabs [65]; however, their function is not clearly defined in Axiidea and Gebiidea.

Female first pleopod is present in all females of Axiidea and Gebiidea [15]. It is uniramous and consists of one article in Axianassidae, two articles in most families, or three articles in Callianassidae, with the distal part sometimes appearing as a shovel (Callianassidae) or flagellum (Laomediidae, Callianideidae) [58, 59, 66, 73]. Depending upon species, sometimes the first two pairs or all female pleopods are used for carrying the eggs during the incubation of embryos [55, 74–76]. Females use pleopods 3–5 to generate strong water currents during the spawning and so help the larvae release from the burrow [76].

Ghost shrimps constitute a promising group for growth studies because many of them show marked differences between relative growth of chelipeds of males and females during post-puberty phase. In Callianideidae and Callianassidae, for instance, males show a positive allometric growth of the major cheliped in relation to body size, whereas this morphometric relationship is isometric in females of both families [40, 77]. According to Rodrigues and Höld [78], hypertrophied chelipeds in males of ghost shrimps are often used to defend galleries against invasion from other shrimps from the same or opposite sex. Also, Felder and Lovett [51] suggest that antagonistic interactions among males of callianassid shrimps might cause

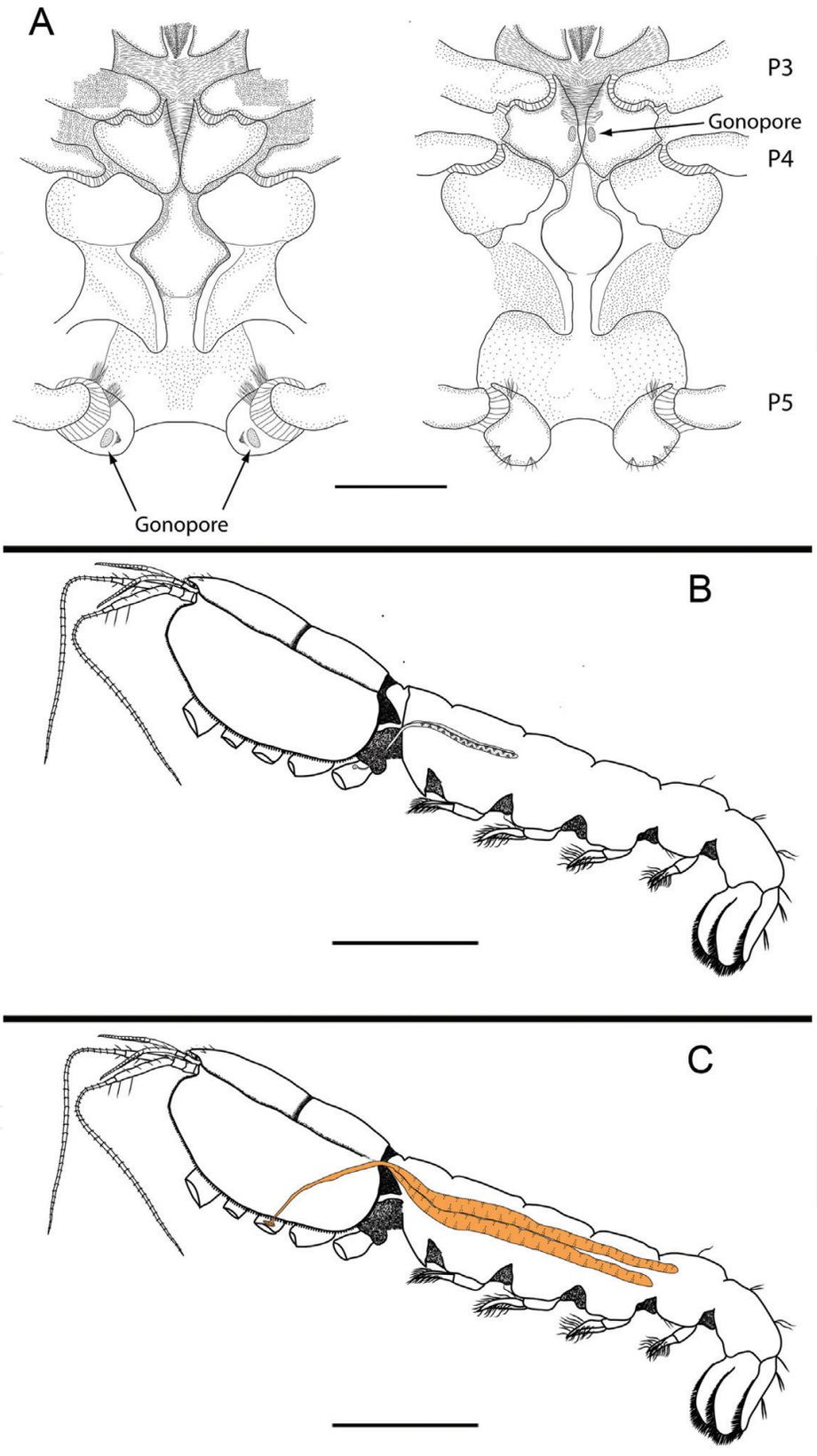


Figure 3. Schematic representation of the external genitalia and reproductive system in males (A, left panel, B) and females (A, right panel, C) of ghost shrimps and mud lobster. A–C scale bar = 5 mm.

http://dx.doi.org/10.5772/intechopen.75067

a high mortality of adult males, thus creating a bias toward females in these populations. Consequently, development of extremely larger chelipeds in callianassid species not only includes morphometric changes during sexual maturity but also can provide some advantages to males, a competition for sexual partners, as were widely documented in several species of Caridea Dana, 1852 [72].

4.3. Sexual systems

Sexual system varies considerably in Decapoda. Most caridean shrimps and brachyuran crabs are gonochoric, that is, all individuals in the population exhibit separate sexes throughout their lifetime [65, 72]. Other species are sequential hermaphrodites in which the individual changes sex at some point in the life history [79–84]. If the initial sex is male, the condition is known as protandry; the converse situation is protogyny [85]. Finally, several species have been reported as simultaneous hermaphrodites sensu Ghiselin [86], that is, an organism has both male and female sexual organs at the same time [72, 87, 88].

While the sexual system of most groups of Decapoda is well known such as Caridea [72], Astacidea [89], Anomura [90], and Brachyura [65] for most axiideans and gebiideans, the distribution of the sexes among individuals is not clear. This is because many researchers have omitted to report explicitly the sexual system of their focus species, wrongly accepting that most ghost shrimps and mud lobsters are gonochoric. Secondly, because in ghost shrimp and mud lobster studies, the sex ratio as a function of size is rarely reported, which is crucial to determine any sex changing through the ontogeny of one species [91].

Several studies conducted in Axiidea and Gebiidea species have reported morphological evidences that aim for a sexual system more complex than simply the existence of separate sexes during the lifetime of these species. For instance, in the intertidal mud lobster *Upogebia major* (De Haan, 1841) (Upogebiidae) and in the ghost shrimp *Callichirus major* (Say, 1818) (Callianassidae), male has the gonad divided in a posterior ovarian section and an anterior testicular section [92, 61] (**Table 3**). In both species, ovarian section produces functional oocytes. In other species of ghost shrimps and mud lobsters have been reported specimens with male and female gonopores which have been classified as intersexed (**Table 3**). To summarize, for 21 species of Axiidea and 12 of Gebiidea, explicit information—or strong indirect evidence—on their sexual system was available. Of these, 26 species are gonochoristic (i.e., all individuals in the population exhibit separate sexes throughout their lifetime); 2 males are hermaphrodites, and 10 species present intersexed specimens (**Table 3**). Considering this information and given that reproductive biology has been studied in only a small proportion of the 781 ghost shrimps and 240 mud lobsters, it can be concluded that hermaphroditism might not be unusual in these organisms.

4.4. Mating systems

Overall, monogamous decapods usually live in heterosexual pairs as a form to ensure the mating and optimize the survival [93]. In most monogamous species, disproportionate sexual dimorphism

Taxon	Sexual system	Intersex	Reference
Axiidea			
Callianassidae			
Biffarius filholi (A. Milne-Edwards, 1878)	Gc		[54]
Callianassa aqabaensis Dworschak, 2003		I (M,F)	[116]
Callianassa subterranea (Montagu, 1808)	Gc		[117]
Callichirus garthi (Retamal, 1975)	Gc	I (F)	[40]
Callichirus islagrande (Schmitt, 1935)	Gc		[63]
Callichirus major (Say, 1818)	H (M)	I (F)	[100]
Callichirus seilacheri (Bott, 1955)	Gc	I (F)	P. Hernáez unpublished data
Lepidophthalmus bocourti (A. Milne-Edwards, 1870)	Gc		P. Hernáez unpublished data
Lepidophthalmus louisianensis (Schmitt, 1935)	Gc		[51]
Lepidophthalmus sinuensis Lemaitre and Rodrigues, 1991	Gc		[118]
Lepidophthalmus siriboia Felder and Rodrigues, 1993	Gc		[56]
Neocallichirus maryae Karasawa, 2004	Gc		P. Hernáez unpublished data
Neocallichirus nickellae Manning, 1993	Gc		P. Hernáez unpublished data
Neotrypaea californiensis (Dana, 1854)	Gc		[119]
Neotrypaea tabogensis (Sakai, 2005)	Gc		P. Hernáez unpublished data
Nihonotrypaea harmandi (Bouvier, 1901)	Gc		[120]
Nihonotrypaea japonica (Ortmann, 1891)	Gc		[53]
Nihonotrypaea petalura (Stimpson, 1860)	Gc		[120]
Sergio mirim (Rodrigues, 1966)	Gc		[121]
Sergio trilobata (Biffar, 1970)	Gc		[122]
Callianideidae			
Callianidea mariamartae Hernáez and Vargas, 2013	Gc		[70]
Gebiidea			
Axianassidae			
Axianassa australis Rodrigues and Shimizu, 1992	Gc		P. Hernáez unpublished data
Upogebiidae			
Austinogebia edulis (Ngoc-Ho & Chan, 1992)		I (M)	[123]
Austinogebia spinifrons (Haswell, 1882)		I (F)	[124]
Paragebicula edentata (Lin, Ngoc-Ho & Chan, 2001)		I (M)	[125]
Upogebia dawsoni Williams, 1986	Gc		[126]
Upogebia deltaura (Leach, 1816)		I (M)	[50]

Taxon	Sexual system	Intersex	Reference
Upogebia major (De Haan, 1841)	H (M)		[92]
Upogebia omissa Gomes Corrêa, 1968	Gc		P. Hernáez unpublished data
Upogebia pusilla (Petagna, 1792)	Gc		[127]
Upogebia stellata (Montagu, 1808)	Gc	I ()	[128]
Upogebia thistlei Williams, 1986	Gc	I (M)	[129]
Upogebia vasquezi Ngoc-Ho, 1989	Gc		[130]

Table 3. Probable sexual system and the presence of specimens intersexed in 21 ghost shrimps and 12 mud lobsters. Empty spaces are left where no information is available; (Gc) = gonochoristic, (H) = hermaphroditic, (I) = intersex, (M) = male, and (F) = female.

of chelipeds is not observed because sexual selection is weak given that monogamy evolved from fidelity between heterosexual pairs [94]. On the contrary, in polygamous species there is no fidelity among individuals of the opposite sex, wherefore agonistic encounters are common between adult males during the search for receptive females [72, 95]. In these species, males invest heavily in structures, such as chelipeds, that are used as armament against other potential competitors [96, 97]. Considering this information, all species of ghost shrimp and mud lobster with solitary habits and remarkable sexual dimorphism in the major cheliped are expected to be polygamous.

In the intertidal ghost shrimp *Callichirus seilacheri* (Bott, 1955), the burrow is individually inhabited by one male or a female (**Figure 2A**), and adult male develops hypertrophied chelipeds which is a potential evidence of intense male-to-male competition for sexual partners and therefore an indirect evidence of polygamy [98]. In a study conducted in *Callichirus islagrande* (Schmitt, 1935), an intertidal species in that males possess highly developed chelipeds [59], the egg mass of females is fertilized by multiple males which denotes polyandry [63]. In both species, the authors assume that mating occurs when the male digs a straight and almost horizontal connection from its gallery to other nearby galleries in search of a receptive female (**Figure 2A**), such as one that is observed in *Upogebia noronhensis* Fausto-Filho, 1969 [98]. Unfortunately, information about mating system in Axiidea and Gebiidea is virtually nonexistent. Further studies including behavioral experiments between male and female specimens should be carried out to investigate a possible mating system in these species.

4.5. Sexual dimorphism in body size

In general, females of ghost shrimps attain, in average, a larger body size than males such as *Biffarius filholi* (A. Milne-Edwards, 1878) [99], *C. major* [100], and *Lepidophthalmus siriboia* Felder and Rodrigues, 1993 [56]. Females usually invest more energy into somatic growth than males when their reproductive success depends on reaching a larger body size [101]. In decapods, such evolutionary trend is explained by the fact that fecundity in females increases with body size [74, 102–105]. Supporting this assumption, fecundity in species of callianassids increase with the female size, resulting in greater production of eggs in larger females [54, 74, 75].

4.6. Egg number and egg size

The considerable variability among Axiidea and Gebiidea species in view of fecundity and egg size (**Table 4**) may indicate important differences in the reproductive strategy and may also reflect a latitudinal trend, as was observed in other decapods [106–110]. In *C. seilacheri*, for instance, females produce the highest number of eggs compared to those axiideans and gebiideans where data are available. However, this ghost shrimp and mud lobsters are the largest species among those listed in **Table 4**, and it is assumed that the area available for egg attachment increases with female size [102, 111]. When compared to a similar-sized species *Upogebia deltaura* (Leach, 1816) (18.9 mm CL, 5304 eggs) [50], fecundity in *C. seilacheri* is still substantially higher (18.6 mm CL, 9612 eggs). Moreover, this species produces considerably larger eggs (0.884 mm) than *U. deltaura* (0.558 mm). It is speculated that these differences in egg numbers in similar-sized species are related to the elasticity of the abdomen, which provides more space for egg attachment.

Egg size is one of the most variable parameters in decapods and offers valuable information on a species' reproductive strategy. It is a useful indicator of the duration of embryogenesis and larval size at hatching [112]. Moreover, several studies on ghost shrimps and mud lobsters showed a clear relation between egg size and type of larval development [113–115]. Such information, however, is restricted to just a few species of both clades.

Taxon	Carapace length (mm)	Number of eggs	Egg length (mm)	Reference
Infraorder Axiidea				
Family Callianassidae				
Biffarius filholi	5.5–14.9	1985	0.68	[54]
Callichirus garthi	18.6–23.2	17,450	0.88	[40]
Callichirus kraussi (Stebbing, 1900)	n.a.	122	1.52	[113]
Callichirus major (Brazil)	10.3–15.0	4564	0.79[a]	[75]
Callichirus seilacheri	12.2–17.2	2387	0.71	P. Hernáez unpublished data
Lepidophthalmus louisianensis	n.a.	598	n.a.	[47]
Lepidophthalmus sinuensis	7.0–16.8	251	1.22	[118]
Pestarella tyrrhena (Petagna, 1792)	5.2–10.4[b]	270	1.18	[131]
Infraorder Gebiidea				
Family Upogebiidae				
Upogebia affinis (Say, 1818)	n.a.	10,000	n.a.	[132]
Upogebia deltaura	16.6–18.9	4757	0.56	[50]
Upogebia pusilla	14.7–16.6	n.a.	n.a.	[127]

n.a., information not available. Letter in superscript indicates information obtained from further estimation

Table 4. Carapace length of ovigerous females and number and length of eggs in some ghost shrimp and mud lobster species.

http://dx.doi.org/10.5772/intechopen.75067

5. Conclusion

An updated classification of the infraorders Axiidea (ghost shrimps) and Gebiidea (mud lobsters) divide each of these clades into six families and five families, respectively. However, controversial taxonomic history of these infraorders is far from over due to recent discovery of new taxa. Diagnostic features of these organisms mainly include (i) carapace laterally compressed, (ii) pleon longer than the cephalothorax in Axiidea but usually shorter in Gebiidea, and (iii) anterior feet thrown directly forward. A recent count estimates the diversity of Axiidea and Gebiidea in about 781 and 240 extant species, respectively. In general, information about reproduction of these organisms is virtually nonexistent. Scarce reports about external and internal genital apparatus show that male possesses gonopores on the ventral coxal segment of the fifth pereiopod whereas females on the ventral coxal segment of the third pereiopod. Males of most ghost shrimps and mud lobsters can be identified by the absence/presence and morphology of the first pleopod and sexual dimorphism in the major cheliped during post-puberty phase. According to available information, gonochorism is the sexual system most common within Axiidea and Gebiidea. However, two cases of hermaphroditism and several cases of intersexuality have been also reported in ghost shrimps and mud lobsters that would be indicating the need of further studies about this topic in these organisms. Regarding mating system, all species of ghost shrimp and mud lobster with solitary habits and remarkable sexual dimorphism in the major cheliped are expected to be polygamous. Lastly, considerable variability among Axiidea and Gebiidea species in fecundity and egg size seems to indicate important differences in the reproductive strategy of these decapods.

Author details

Patricio Hernáez[1,2]*

*Address all correspondence to: phernaez@lycos.com

1 Universidad de Tarapacá – UTA, Facultad de Ciencias, Centro de Estudios Marinos y Limnológicos, Arica, Chile

2 Universidade Estadual Paulista – UNESP, Instituto de Biociências – IB, Grupo de Pesquisa em Biologia de Crustáceos – CRUSTA, Câmpus do Litoral Paulista, Praça Infante Dom Henrique, São Vicente, SP, Brasil

References

[1] Latreille PA. Cours d'entomologie ou de l'histoire naturelle des Crustacés, des Arachnides, des Myriopodes et des Insectes. Exposition méthodique des ordres, des familles et des genres des trois premières classes. A l'usage des élèves de l'école du Muséum d'Histoire Naturelle: i-xiii. 1831; 1-568, Atlas, 1-26, pls. 1-24. (Paris)

[2] Dana JD. Conspectus Crustaceorum, etc. conspectus of the Crustacea of the exploring expedition under Capt. Wilkes, U.S.N., including the Crustacea Cancroidea Corystoidea. Proceedings of the Academy of NaturalSciences. 1852;**6**:10-28

[3] De Saint Laurent M. Sur la systématique et la phylogénie des Thalassinidea: définition des familles des Callianassidae et des Upogebiidae et diagnose de cinq genres nouveaux (Crustacea Decapoda). Comptes Rendus Hebdomadaires de Séances de l'Académie des Sciences, Série D. 1973; **277**: 513-516.

[4] De Saint Laurent M. Vers une nouvelle classification des Crustaces Decapodes Reptantia. Bulletin de l'Office National des Peches Republique Tunisienne, Ministere de L'Agriculture. 1979a; **3**: 15-31.

[5] De Saint Laurent M. Sur la classification et la phylogenie des Thalassinides: definitions de la superfamille des Axioidea, de la sous-famille des Thomassiniinae et de deux genres nouveaux (Crustacea Decapoda). Comptes Rendus Hebdomadaires des Seances de L'Academie des Sciences. 1979b;**288**:1395-1397

[6] Poore GCB. A phylogeny of the families of Thalassinidea (Crustacea: Decapoda) with keys to families and genera. Memoirs of the Museum of Victoria. 1994; **54**: 79-120, Figs. 1-9.

[7] Tudge CC, Cunningham CW. Molecular phylogeny of the mud lobsters and mud shrimps (Crustacea: Decapoda: Thalassinidea) using nuclear 18s rDNA and mitochondrial 16s rDNA. Invertebrate Systematics. 2002;**16**:839-847

[8] Tudge CC. Phylogeny of the Anomura (Decapoda, Crustacea): Spermatozoa and spermatophore morphological evidence. Contributions to Zoology. 1997;**67**:125-141

[9] Morrison CL, Harvey AW, Lavery S, Tieu K, Huang Y, Cunningham CW. Mitochondrial gene rearrangements confirm the parallel evolution of the crab-like form. Proceedings Royal Society of London, B. 2002;**269**:345-350

[10] Sakai K. The diphyletic nature of the infraorder Thalassinidea (Decapoda, Pleocyemata) as derived from the morphology of the gastric mill. Crustaceana. 2005;**77**:1117-1129

[11] Robles R, Tudge CC, Dworschak PC, Poore GCB, Felder DL. Molecular phylogeny of the Thalassinidea based on nuclear and mitochondrial genes. In: Martin JW, Crandall KA, Felder DL, editors. Crustacean Issues 18: Decapod Crustacean Phylogenetics. Boca Raton, FL: Taylor and Francis/CRC Press; 2009. pp. 309-326

[12] Ahyong ST, O'Meally D. Phylogeny of the Decapoda Reptantia: Resolution using three molecular loci and morphology. The Raffles Bulletin of Zoology. 2004;**52**:673-693

[13] Tsang LM, Lin E-J, Chu KH, Chan T-H. Phylogeny of Thalassinidea (Crustacea, Decapoda) inferred from three rDNA sequences: Implications for morphological evolution and superfamily classification. Journal of Zoological Systematics and Evolutionary Research. 2008a;**46**:216-223

[14] Tsang LM, Ma KY, Ahyong ST, Chan T-Y, Chu KH. Phylogeny of Decapoda using two nuclear protein-coding genes: Origin and evolution of the Reptantia. Molecular Phylogenetics and Evolution. 2008b;**48**:359-368

[15] Dworschak PC, Felder DL, Tudge CC. Infraorders Axiidea de Saint Laurent, 1979 and Gebiidea de Saint Laurent, 1979 (formerly known collectively as Thalassinidea). In: Schram FR, von Vaupel Klein JC, Forest J, CharmantierDaures M, editors. Treatise on Zoology - Anatomy, Taxonomy, Biology. The Crustacea. Complementary to the Volumes Translated from the French of the Traité de Zoologie [Founded by P.-P. Grassé], Volume 9 Part B. Eucarida: Decapoda: Astacidea P.P. (Enoplometopoidea, Nephropoidea), Glypheidea, Axiidea, Gebiidea, and Anomura. Leiden: Brill; 2012. pp.109-219

[16] Sakai K. Axioidea of the world and a reconsideration of the Callianassoidea (Decapoda, Thalassinidea, Callianassida). In: Fransen CHJM, von Vaupel Klein JC, editors. Crustaceana Monographs 13. Leiden: Brill; 2011. pp. 1-520

[17] Sakai K, Türkay M, Aidaroos AA. One new species of a new genus, *Kuwaitupogebia* gen. Nov., in a new family, Kuwaitupogebiidae fam. Nov., from Kuwait, and two new species of the genus *Upogebia* from the red sea (Decapoda, Thalassinidea). Crustaceana. 2015;**88**:1221-1234

[18] Sakai K. One new species of a new genus, Tosacallianassa gen. Nov., in a new family, Tosacallianassidae fam. Nov., from Tosa-Saga, Kochi prefecture, Japan (Decapoda, Callianassidea1). Crustaceana. 2016;**89**:811-818

[19] Sakai K, Türkay MA. Collection of Thalassinidea Latreille, 1831 (Decapoda, Pleocyemata) from the Senckenberg Forschungsinstitut and Natural History Museum, Frankfurt am main. Crustaceana. 2016;**85**:723-765

[20] Poore GCB, Ahyong ST, Bracken-Grissom HD, Chan T-Y, Chu KH, et al. On stabilising the names of the infraorders of thalassinidean shrimps, Axiidea de Saint Laurent, 1979 and Gebiidea de Saint Laurent, 1979 (Decapoda). Crustaceana. 2014;**87**:1258-1272

[21] De Grave S, Pentcheff ND, Ahyong ST, Chan TY, et al. A classification of living and fossil genera of decapod crustaceans. Rafes Bulletin of Zoology. 2009;**21**:1-109

[22] World Register of Marine Species (Worms). Appeltans W, Bouchet P, Boxshall GA, de Broyer C, et al., editors. World Register of Marine Species. Available from: http://www.marinespecies.org (Accessed 26 January 2018)

[23] Suchanek T. Control of seagrass communities and sediment distribution by Callianassa (Crustacea: Thalassinidea) bioturbation. Journal of Marine Research. 1983;**41**:281-298

[24] Griffis R, Chávez F. Effects of sediment type on burrows of *Callianassa californiensis* Dana and *C. gigas* Dana. Journal of Experimental Marine Biology and Ecology. 1988;**117**:239-253

[25] Lemaitre R, Rodrigues S. *Lepidophthalmus sinuensis*: A new species of ghost shrimp (Decapoda: Thalassinidea: Callianassidae) of importance to the commercial culture of

penaeid shrimp on the Caribbean coast of Colombia, with observations on its ecology. Fishery Bulletin. 1991;**89**:623-630

[26] Atkinson RJA, Taylor C. Aspects of the biology and ecophysiology of thalassinidean shrimps in relation to their burrow environment. Proc. Symp. "Ecology of large bioturbators in tidal flats and shallow sublittoral sediments — from individual behavior to their role as ecosystem engineers"; 2004.pp.45-51, fig. 1, tabs. 1, 2. (Nagasaki Univ., Nagasaki)

[27] Heard RW, King RA, Knott DM, Thoma BP, Thornton-Devictor S. A guide to the Thalassinidea (Crustacea: Malacostraca: Decapoda) of the South Atlantic bight. NOAA professional paper. NMFS. 2007;**8**(i-iii):1-30

[28] Posey M. Changes in a benthic community associated with dense beds of a burrowing deposit feeder, *Callianassa californiensis*. Marine Ecology Progress Series. 1986;**31**:15-22

[29] Posey M, Dumbauld B, Armstrong D. Effects of a burrowing mud-shrimp, *Upogebia pugettensis* (Dana), on abundances of macroinfauna. Journal of Experimental Marine Biology and Ecology. 1991;**148**:283-294

[30] Nates S, Felder DL. Impacts of burrowing ghost shrimp, genus *Lepidophthalmus* (Crustacea: Decapoda: Thalassinidea), on penaeid shrimp culture. Journal of the World Aquaculture Society. 1998;**29**:188-210

[31] Felder DL. Diversity and ecological significance of deep-burrowing macrocrustaceans in coastal tropical waters of Americas (Decapoda: Thalassinidea). Interciencia. 2001;**26**:440-449

[32] Ziebis W, Forster S, Huettel M, Jørgensen B. Complex burrows of the mud shrimp *Callianassa truncata* and their geochemical impact in the sea bed. Nature. 1996;**382**:619-622

[33] Berkenbusch K, Rowden A. Factors influencing sediment turnover by the burrowing ghost shrimp *Callianassa filholi* (Decapoda:Thalassinidea). Journal of Experimental Marine Biology and Ecology. 1999;**238**:283-292

[34] Bertics VJ, Sohm JA, Treude T, Chow Ch- ET, et al. Burrowing deeper into benthic nitrogen cycling: The impact of bioturbation on nitrogen fixation coupled to sulfate reduction. Marine Ecology Progress Series. 2010;**409**:1-15

[35] Williams AB. *Upogebia synagelas*, new species. A comrnensal mud shrimp from sponges in the western Central Atlantic (Decapoda: Upogebiidae). Proceedings of the Biological Society of Washington. 1987;**100**:590-595

[36] Kensley B. A new species of the axiid shrimp genus *Acanthaxius* from the Caribbean (Crustacea: Decapoda: Thalassinidea). Proceedings of the Biological Society of Washington. 1996;**109**:70-74

[37] Türkay M, Sakai K. Decapod crustaceans from a volcanic hot spring in the Marianas. Senckenbergiana Maritima Series. 1995;**26**:25-35 figs. 1-9, Tab. 1

[38] Felder DL, Kensley B. A new species of axiid shrimp from chemosynthetic communities of the Louisiana continental slope, Gulf of Mexico (Crustacea: Decapoda: Thalassinidea). Proceedings of the Biological Society of Washington. 2002;**117**:68-75 Figs. 1, 2

[39] Berkenbusch K, Rowden AA. Ecosystem engineering- moving away from 'just-so' stories. Marine Ecology. 2003;**27**:67-73

[40] Hernáez P, Wehrtmann IS. 2007. Population biology of the burrowing shrimp *Callichirus seilacheri* (Dccapoda: Callianassidae) in northern Chile. Revista de Biología Tropical. 2007;**55**:141-152

[41] Liu JY. Economic shrimp and prawns of northern China. Marine Biology Institute "Academy of Science Beijing". 1955:1-73

[42] Tan LWH, Ng PKL. A Guide to Seashore Life. Singapore: Singapore Science Centre; 1988. pp. 1-160

[43] Rodrigues SA, Shimizu RM. Autoecologia de *Callichirus major* (say, 1818). Oecologia Brasiliensis. 1997;**3**:155-170

[44] Souza JRB, Borzone CA. A extração de corrupto, *Callichirus major* (Say) (Crustacea, Thalassinidea), para uso como isca em praias do litoral do Paraná: as populações exploradas. Revista Brasileira de Zoologia. 2003;**20**:625-630

[45] Hernáez P, Granda-Rodríguez H. The community of Mata de Limón, Central Pacific coast of Costa Rica and the extraction of colonchos *Callichirus seilacheri* (Bott, 1955) (Decapoda: Axiidea: Callianassidae). Latin American Journal of Aquatic Research. 2015;**43**:575-580

[46] Aste A, Retamal MA. Desarrollo larval de *Callianassa garthi* Retamal, 1975 bajo condiciones de laboratorio. Ciencia y Tecnología Marina. 1983;**7**:5-26

[47] Nates SF, Felder DL, Lemaitre R. Comparative larval development of two species of the burrowing ghost shrimp genus *Lepidophthalmus* (Decapoda: Callianassidae). Journal of Crustacean Biology. 1997;**17**:497-519

[48] Strasser KM, Felder DL. Larval development of two populations of the ghost shrimp *Callichirus major* (Decapoda: Thalassinidea) under laboratory conditions. Journal of Crustacean Biology. 1999;**19**:844-878

[49] Abrunhosa FA, Pires MAB, Lima de FJ, Coelho-Filho PA. Larval development of *Lepidophthalmus siriboia* Felder & Rodrigues, 1993 (Decapoda: Thalassinidea) from the Amazon region, reared in the laboratory. Acta Amazonica. 2005;**35**:77-84

[50] Tunberg B. Studies on the population ecology of *Upogebia deltaura* (leach) (Crustacea, Thalassinidea). Estuarine Coastal and Shelf Science. 1986;**22**:753-765

[51] Felder DL, Lovett D. Relative growth and sexual maturation in the estuarine ghost shrimp *Callianassa louisianensis* Schmitt, 1935. Journal of Crustacean Biology. 1989;**9**:540-553

[52] Dumbauld BR, Armstrong DA, Feldman KL. Life-history characteristics of two sympatric thalassinidean shrimps, *Neotrypaea californiensis* and *Upogebia pugettensis*, with implications for oyster culture. Journal of Crustacean Biology. 1996;**16**:689-708

[53] Tamaki A, Ingole B, Ikebe K, Muramatsu K, et al. Life history of the ghost shrimp, *Callianassa japonica* Ortmann (Decapoda: Thalassinidea), on an intertidal sandflat in western Kyushu, Japan. Journal of Experimental Marine Biology and Ecology. 1997;**210**:223-250

[54] Berkenbusch K, Rowden A. Latitudinal variation in the reproductive biology of the burrowing ghost shrimp *Callianassa filholi* (Decapoda: Thalassinidea). Marine Biology. 2000;**136**:497-504

[55] Hernáez P, Villegas-Jiménez E, Villalobos-Rojas F, Wehrtmann IS. Reproductive biology of the ghost shrimp *Lepidophthalmus bocourti* (a. Milne-Edwards, 1870) (Decapoda: Axiidea: Callianassidae): A tropical species with a seasonal reproduction. Marine Biology Research. 2012;**8**(**7**):635-643

[56] Rosa-Filho JS, Girard TC, Frédou FL. Population dynamics of the burrowing shrimp *Lepidophthalmus siriboia* Felder and Rodrigues, 1993 (Reptantia: Axiidea: Callianassidae) on the Amazonian coast. Journal of Crustacean Biology. 2013;**33**:503-511

[57] Felgenhauer BE. External anatomy and intergumentary structures. In: Harrison FW, Huvies AG, editors. Microscopic Anatomy of Invertebrates. Vol. 10. Decapod Crustacea. New York: Wiley-Liss; 1992. pp. 7-43

[58] Hernáez P, Gamboa-González A, De Grave S. *Callichirus garthi* is a valid species, distinct from *C. seilacheri* (Decapoda: Axiidea: Callianassidae). Marine Biology Research. 2015;**11**:990-997

[59] Hernáez P, Granda-Rodríguez H, Rio JPP, Pinheiro MAA. In press. Morphological remarks in the ghost shrimp *Callichirus seilacheri* (Bott, 1955) (Decapoda, Callianassidae). Boletim do Instituto de Pesca

[60] LeBlanc LA. Observations on Reproductive Behavior and Morphology in the Ghost Shrimp *Lepidophthalmus louisianensis* (Schmitt, 1935) (Decapoda: Thalassinidea: Callianassidae). Master's Thesis. The University of Louisiana at Lafayette; 2002 47 pp

[61] Souza TL, Braga AA, López-Greco LS, Nunes ET. Functional morphology of the male reproductive system in *Callichirus major* (Crustacea: Decapoda: Axiidea): Evidence of oocytes in the gonad. Acta Zoologica. 2017;**119**:1-10

[62] Simeó CG, Ribes E, Rotllant G. Internal anatomy and ultrastructure of the male reproductive system of the spider crab *Maja brachydactyla* (Decapoda: Brachyura). Tissue and Cell. 2009;**41**:345-361

[63] Bilodeau AL, Felder DL, Neigel JE. Multiple paternity in the thalassinidean ghost shrimp, *Callichirus islagrande* (Crustacea: Decapoda: Callianassidae). Marine Biology. 2005;**146**:381-385

[64] Tamaki A, Tanoue H, Itoh J, Fukuda Y. Brooding and larval developmental periods of the callianassid ghost shrimp, *Callianassa japonica* (Decapoda: Thalassinidea). Journal of the Marine Biological Association of the United Kingdom. 1996;**76**:675-689

[65] Guinot D, Tavares M, Castro P. Significance of the sexual openings and supplementary structures on the phylogeny of brachyuran crabs (Crustacea, Decapoda, Brachyura), with new nomina for higher-ranked podotreme taxa. Zootaxa (Monograph). 2013;**3665**:1-414

[66] Kensley B, Heard R. The genus *Axianassa* (Crustacea, Decapoda, Thalassinidea) in the Americas. Proceedings of the Biological Society of Washington. 1990, **103**:558-572

[67] Ngoc-Ho N. The genus *Laomedia* de Haan. 1841 with description of a new species from Vietnam (Decapoda, Thalassinidea, Laomediidae). Zoosystema. 1997;**19**:729-747

[68] Ngoc-Ho N, de Saint Laurent M. The genus *Thalassina* Latreille, 1806 (Crustacea: Thalassinidea: Thalassinidea). The Raffles Bulletin of Zoology. 2009;**20**:121-158

[69] Sakai K. Redescription of *Ctenocheles balssi* Kishinouye, 1926, with comments on its systematic position and establishment of a new subfamily Gourretiinae (Decapoda, Callianassidae). Crustaceana. 1999;**72**:85-97

[70] Hernáez P, Vargas R. A new species of *Callianidea* H. Milne Edwards, 1837 (Decapoda, Axiidea, Callianideidae) from the Pacific coast of central America, with key to the genus. Zootaxa. 2013;**3681**:147-154

[71] Carvalho HA, de Rodrigues SA. *Marcusiaxius lemoscastroi* g. n., sp. n., nova ocorrência da família Axiidae (Crustacea, Decapoda, Thalassinidea) no Brasil. Boletim de Zoologia e Biologia Marina. 1973;**30**:553-566

[72] Bauer RT. Remarkable Shrimps: Natural History and Adaptations of the Carideans. Norman: University of Okalahoma Press; 2004. p. 316

[73] Ngoc-Ho N. European and Medite1Tanean Thalassinidea (Crnstacea, Decapoda). Zoosystema. 2003;**25**:439-555

[74] Hernáez P, Palma S, Wehrtmann IS. Egg production of the burrowing shrimp *Callichirus seilacheri* (Bott, 1925) (Decapoda, Callianassidae) in northern Chile. Helgoland Marine Research. 2008;**62**:351-356

[75] Peiró DF, Wehrtmann IS, Mantelatto FL. Reproductive strategy of the ghost shrimp *Callichirus major* (Crustacea: Axiidea: Callianassidae) from the southwestern Atlantic: Sexual maturity of females, fecundity, egg features, and reproductive output. Invertebrate Reproduction & Development. 2014;**58**:294-305

[76] Somiya R, Tamaki A. Unraveling mating behavior for Axiidea (Crustacea: Decapoda): Burrow-dwelling callianassid shrimp in intertidal sandflat. Journal of Experimental Marine Biology and Ecology. 2017;**486**:305-313

[77] Rodrigues SA. Sobre o crescimento relativo de *Callichirus major* (Say, 1818) (Crustacea, Decapoda, Thalassinidea). Boletim de Zoologia Universidade de São Paulo. 1985;**9**:195-111

[78] Rodrigues SA, Höld W. Burrowing behaviour of *Callichirus major* and *C. mirim*. Wissenschaftlichen Film. 1990;**41**:48-58

[79] Butler TH. Growth, reproduction, and distribution of pandalid shrimps in British Columbia. Journal of the Fisheries Research Board of Canada. 1964;**21**:1403-1452

[80] Noël PL. évolution des caractères sexuels chez *Processa edulis* Risso (Décapode, Natantia). Vie Milieu. 1976;**26**:65-104

[81] Butler TH. Shrimps of the Pacific coast of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences. 1980;**202**:131-142

[82] Boddeke R, Bosschieter JR, Goudswaard PC. Sex change, Mating, and Sperm Transfer in *Crangon crangon* (L.) In: Bauer RT, Martin JW (eds). Crustacean Sexual Biology. New York: Columbia University Press; 1991. pp 164-182

[83] Bergström BI. The biology of Pandalus. Advances in Marine Biology. 2000;**38**:55-245

[84] Schatte J, Saborowski R. Change of external sexual characteristics during consecutive moults in *Crangon crangon* L. Helgoland Marine Research. 2006;**60**:70-73

[85] Wagner RR. The adaptive significance of sequential hermaphroditism in animals. The American Naturalist. 1975;**109**:61-82

[86] Ghiselin MT. The Economy of Nature and the Evolution of Sex. Berkeley: University of California Press; 1974 346 pp

[87] Bauer RT, Holt GJ. Simultaneous hermaphroditism in the marine shrimp *Lysmata wurdemanni* (Caridea: Hippolytidae): An undescribed sexual system in the decapod Crustacea. Marine Biology. 1998;**132**:223-235

[88] Baeza JA. Protandric simultaneous hermaphroditism in the shrimps *Lysmata bahia* and *L. intermedia*. Invertebrate Biology. 2008;**127**:181-188

[89] Rudolph E, Almeida A. On the sexuality of south American Parastacidae (Crustacea, Decapoda). Invertebrate Reproduction and Development. 2000;**37**:249-257

[90] Gusev O, Zabotin Y. Observation of intersexuality in land hermit crabs (Anomura: Coenobitidae). Journal of the Marine Biological Association of the United Kingdom. 2007;**87**:533-536

[91] Charnov EL. The Theory of Sex Allocation. Princeton: Princeton University Press; 1982 355 pp

[92] Kang BJ, Nanri T, Lee JM, Saito H, et al. Vitellogenesis in both sexes of gonochoristic mud shrimp, *Upogebia major* (Crustacea): Analyses of vitellogenin gene expression and vitellogenin processing. Comparative Biochemistry and Physiology Part B. 2008;**149**:589-598

[93] Thiel M, Baeza JA. Factors affecting the social behavior of crustaceans living symbiotically with other marine invertebrates: A modeling approach. Symbiosis. 2001;**30**:163-190

[94] Andersson M. Sexual Selection. Princeton: Princeton University Press; 1994 624 pp

[95] Correa C, Thiel M. Mating systems in caridean shrimp (Decapoda: Caridea) and their evolutionary consequences for sexual dimorphism and reproductive biology. Revista Chilena de Historia Natural. 2003;**76**:187-203

[96] Hartnoll RG. Variation in growth pattern between some secondary sexual characters in crabs (Decapoda, Brachyura). Crustaceana. 1974;**27**:131-136

[97] Baeza JA, Asorey C. Testing the role of male-male competition in the evolution of sexual dimorphism: A comparison between two species of porcelain crabs. Biological Journal of the Linnean Society. 2012;**105**:548-558

[98] Hernáez P. Estado taxonômico e história de vida de *Callichirus seilacheri* (Bott, 1955) (Decapoda, Axiidea, Callianassidae) na costa do Pacífico Leste: ecologia reprodutiva em ambientes tropicais e relação entre a abundância e a variabilidade latitudinal dos atributos populacionais na costa do Chile. PhD Thesis. Universidade de São Paulo, Department of Biology; 2014 156 pp

[99] Candisani LC, Sumida PYG, Pires-Vanin AMS. Burrow morphology and mating behaviour of the thalassinidean shrimp *Upogebia noronhensis*. Journal of the Marine Biological Association of the United Kingdom;**81**:799-803

[100] Devine CE. Ecology of *Callianassa filholi* Milne-Edwards, 1878 (Crustacea, Thalassinidea). Transactions of the Royal Society of New Zealand. 1966;**8**:93-110

[101] Botter-Carvalho ML, Santos PJP, Carvalho PVVC. Population dynamics of *Callichirus major* (say, 1818) (Crustacea, Thalassinidea) on a beach in northeastern Brazil. Estuarine, Coastal and Shelf Science. 2007;**71**:508-516

[102] Huber BA. Sexual selection research on spiders: Progress and biases. Biological Reviews. 2005;**80**:363-385

[103] Corey S, Reid DM. Comparative fecundity of decapod crustaceans. The fecundity of thirty three species of nine families of caridean shrimps. Crustaceana. 1991;**60**:270-294

[104] Reid DM, Corey S. Comparative fecundity of decapod crustaceans. II. The fecundity of fifteen species of anomuran and brachyuran crabs. Crustaceana. 1991;**61**:175-189

[105] Hines AH. Fecundity and reproductive output in nine species of *Cancer* crabs (Crustacea, Brachyura, Candridae). Canadian Journal of Fisheries and Aquatic Sciences. 1991;**48**:267-275

[106] Hernáez P, Palma S. Fecundidad, volumen del huevo y rendimiento reproductivo de cinco especies de porcelánidos intermareales del norte de Chile (Decapoda, Porcellanidae). Latin American Journal of Aquatic Research. 2003;**31**:35-46

[107] Thorson G. Reproductive and larval ecology of marine bottom invertebrates. Biological Reviews. 1950;**25**:1-45

[108] Sastry AN. Ecological aspects of reproduction. In: Vernberg FJ, Vernberg WB, editors. The Biology of Crustacea. Environmental Adaptations. New York: Academic Press; 1983. pp. 213-282

[109] Clarke A. Temperature, latitude and reproductive effort. Marine Ecology Progress Series. 1987;**38**:89-99

[110] Clarke A. Reproduction in the cold: Thorson revisited. Invertebrate Reproduction & Development. 1992;**22**:175-184

[111] Brante A, Cifuentes S, Pörtner HO, Arntz W. Ferna'ndez M. Latitudinal comparisons of reproductive traits in five brachyuran species along the Chilean coast. Revista Chilena de Historia Natural. 2004;**77**:15-27

[112] Hines AH. Allometric constraints and variables of reproductive effort in brachyuran crabs. Marine Biology. 1982;**69**:309-320

[113] Steele DH, Steele VJ. Egg size and duration of embryonic development in Crustacea. Internationale Revue der Gesamten Hydrobiologie. 1975;**60**:711-715

[114] Forbes AT. An unusual abbreviated larval life in the estuarine burrowing prawn *Callianassa kraussi* (Crustacea, Decapoda, Thalassinidea). Marine Biology. 1973;**22**:361-365

[115] Felder DL, Griffis RB. Dominant infaunal communities at risk in shoreline habitats: Burrowing thalassinid Crustacea. In: OCS Study MMS. Vol. 94-0007. Los Angeles: US Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Regional Office, New Orleans; 1994

[116] Thessalou M, Peppa A, Zacharaki M. Facultative lecithotrophy during larval development of the burrowing shrimp *Callianassa tyrrhena* (Decapoda, Callianassidae). Marine Biology. 1999;**133**:635-642

[117] Dworschak PC. A new species of ghost shrimp from the Gulf of Aqaba, Red Sea (Crustacea: Decapoda: Callianassidae). Annalen des Naturhistorischen Museums in Wien Part B. 2003;**104**:415-428

[118] Rowden AA, Jones MB. A contribution to the biology of the burrowing mud shrimp, *Callianassa subterranea* (Decapoda: Thalassinidea). Journal of the Marine Biological and Assessment of the United Kingdom. 1994;**7**:623-635

[119] Nates SF, Felder DL. Growth and maturation of the ghost shrimp *Lepidophthalmus sinuensis* Lemaitre and Rodrigues, 1991 (Crustacea, Decapoda, Callianassidae), a burrowing pest in penaeid shrimp culture ponds. Fishery Bulletin. 1999;**97**:526-541

[120] Labadie LV, Palmer AR. Pronounced heterochely in the ghost shrimp, *Neotrypaea californiensis* (Decapoda: Thalassinidea: Callianassidae): Allometry, inferred function and development Journal of Zoology. 1996;**240**:659-675

[121] Shimoda K, Wardiatno Y, Kubo K, Tamaki A. Intraspecific behaviors and major cheliped sexual dimorphism in three congeneric callianassid shrimp. Marine Biology. 2005;**146**:543-557

[122] Pezzuto PR. Population dynamics of *Sergio mirim* (Rodrigues, 1971) (Decapoda: Thalassinidea: Callianassidae) in CassinoBeach, southern Brazil. Marine Ecology. 1998;**19**:98-109

[123] Corsetti JL, Strasser KM. Population biology of the ghost shrimp *Sergio trilobata* (Biffar 1970) (Crustacea: Decapoda: Thalassinidea). Gulf and Caribbean Research. 2003;**15**:13-19

[124] Ngoc-Ho N, Chan TY. *Upogebia edulis*, new species, a mud-shrimp (Crustacea: Thalassinidea: Upogebiidae) from Taiwan and Vietnam, with a note on polymorphism in the male first pereiopod. The Raffles Bulletin of Zoology. 1992;**40**:33-43

[125] Sakai K. A new record of *Upogebia spinifrons* (HASWELL, 1882) (Decapoda, Thalassinidea) from Naruto, Japan, showing possible hermaphroditism. Crustaceana. 1984;**47**:209-214

[126] Lin F-J, Ngoc-Ho N, Chan T-Y. A new species of mud-shrimp of the genus *Upogebia* leach, 1814 from Taiwan (Decapoda: Thalassinidea: Upogebiidae). Zoological Studies. 2001;**40**:199-203

[127] Leija-Tristán A, Sánchez-Vargas DP. Biología y ecología del camarón de fango común Upogebia dawsoni (Crustacea: Thalassinoidea) del Manglar Requesón, Bahía Concepción y el Estero Rio de Mulege, Baja California Sur, México. Revista de Biología Tropical. 1988;**36**:107-114

[128] Kevrekidis T, Gouvis N, Koukouras A. Population dynamics, reproduction and growth of *Upogebia pusilla* (Decapoda, Thalassinidea) in the Evros delta (north Aegean Sea). Crustaceana. 1997;**70**:799-812

[129] Pinn EH, Atkinson RJA, Rogerson A. Sexual dimorphism and intersexuality in *Upogebia stellata* (Crustacea: Decapoda: Thalassinidea). Journal of the Marine Biological Association of the United Kingdom. 2001;**81**:1061-1062

[130] Williams AB. Mud shrimps, *Upogebia*, from the eastern Pacific (Thalassinoidea: Upogebiidae). Memoirs San Diego society. Natural History. 1986;**14**:1-60

[131] de Oliveira DB, Abrunhosa FA, Martinelli-Lemos JM. The Thalassinidean mud shrimp *Upogebia vasquezi*: Life cycle and reproductive traits on the Amazonian coast, Brazil, Theriogenology. In: Payan-Carreira R, editor. InTech, Chapter 8; 2017. p. 27

[132] Thessalou M. Contribution to the Study of Ecology and Biology of the Shrimp *Callianassa tyrrhena* (Petagna, 1792) (in Greek). (Crustacea, Decapoda, Thalassinidea). Ph.D. Thesis. Athens, Greece: University of Athens; 1987

[133] Pearse AS. Ecology of *Upogebia affinis* (say). Ecology. 1945;**26**:303-305

IntechOpen

IntechOpen