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Ovary Development of the Deep-water Shrimp *Aristaeomorpha foliacea* (Risso, 1826) (Crustacea: Decapoda: Aristeidae) from Taiwan

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Hui-Chen Kao, Tin-Yam Chan and Hsiang-Ping Yu (1999) Ovary development of the deep-water shrimp *Aristaeomorpha foliacea* (Risso, 1826) (Crustacea: Decapoda: Aristeidae) from Taiwan. *Zoological Studies* **38**(4): 373-378. *Aristaeomorpha foliacea* (Risso, 1826) is a commercially harvested deep-water shrimp in Taiwan. Considerable changes in the color and shape of the ovary occur during the maturation of this species. According to the relationships among the general appearance of the ovary, histology of ovarian tissues and gonadosomatic index, 4 distinct stages of ovarian development can be defined. The final stage, a ripe ovary is pale black and clearly visible through the carapace, and it can be a reliable guide for judging of stage of maturation. There is evidence that development of the ovary is induced by copulation. The arrangement of developing oocytes in a rouleau formation is unique for this species among shrimp.

Key words: Ovary development, Histology, Deep-water shrimp, *Aristaeomorpha foliacea*, Taiwan.

The aristeid shrimp *Aristaeomorpha foliacea* (Risso, 1826) is a cosmopolitan species. Although it inhabits deep waters, its large size often attracts commercial fishery interests, and regular fisheries of this species have been developed in the Mediterranean (Holthuis 1980, Bianchini and Ragonese 1994). In Taiwan, *A. foliacea* is caught by coastal commercial deep-water trawlers mainly off the northeastern and southwestern coasts, at 300-600 m deep, and is of moderate economic importance (Yu and Chan 1986, Chan 1996). Although there are many studies on this species in the Mediterranean (see Bianchini and Ragonese 1994), very little is known on the biology of the West Pacific population (e.g., Liu et al. 1988, Hayashi 1992). Therefore, it is rather difficult to make fishery management decision for this species in local waters. Reproductive biology is one of the main concerns in formulating proper management practices for a fishery species. Since the eggs of *A. foliacea* are directly shed during spawning, and are not carried beneath the abdomen, knowledge about the maturation of the ovary becomes particularly important for recognizing fully ripe females. The present work attempts to identify the different developmental stages of the ovary in this commercial shrimp by means of relationships among such features as the general appearance of the ovary, histology of ovarian tissues, and gonadosomatic index.

MATERIALS AND METHODS

Specimens were obtained from a deep-sea fishing port, Tashi, in northeastern Taiwan between July 1997 and September 1998. Shrimp was caught by commercial trawlers operating on a daily basis on a fishing ground close to the fishing port. Altogether 353 non-melanotic females of 24.7-60.0 mm carapace length (cl., excluding rostrum) were carefully dissected, with the shape and color of the ovary recorded. Presence or absence of spermatophores on females were also noted. Body and ovary weights were measured to the nearest 0.01 g and 0.001 g, respectively. Female gonadosomatic index (GSI) was calculated as (ovary weight/body weight × 100).

At least 18 individuals of each ovary type were prepared for histological examination. Fresh ovarian tissue was fixed in 20 volumes of 10% neutral formalin for 12-24 h. Afterwards the tissue was dehydrated in alcohol and cleared in xylene and embedded in

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paraffin. It was sectioned at 6-8 µm. Sections were stained with hematoxylin-eosin and then mounted permanently for microscopic analysis. Oocytes were measured with an ocular micrometer (100X) to the nearest 0.01 mm and their volumes calculated.

RESULTS

Of the specimens examined, considerable differences in the color and shape of the ovaries were observed in *Aristaeomorpha foliacea*. The condition of the ovaries varied from transparent, small, duct-like, and restricted at the posterodorsal part of the stomach, to black, greatly swollen, subdivided into distinct lobes, and covering most of the stomach and hepatopancreas. Nevertheless, 4 distinct ovarian stages could be readily recognized by the marked differences in the color and size of the ovaries (Table 1). Below are the characteristics of these 4 ovarian stages in terms of their general appearance, cell histology, and GSI.

External appearance of ovaries

Type I ovary (Fig. 1a): Ovary transparent and colorless, tubular but thin and simple, situated at the posterodorsal part of stomach, divided posteriorly into 2 parallel branches and extending dorsally along the alimentary canal to the 2nd abdominal somite.

Type II ovary (Fig. 1b): Ovary increasing in size and becoming semi-transparent, somewhat light gray or light orange-red; anterior part branched into 2 parts and covering posterolateral part of stomach; median part subdivided into 8-10 distinct lateral lobes and covering small part of dorsal hepatopancreas; caudal lobes slightly swollen and extending to 3rd abdominal somite.

Type III ovary (Fig. 1c): Ovary expanded and becoming bluish gray; frontal lobes covering about half of lateral stomach; lateral lobes expanded and covering half of dorsal hepatopancreas; caudal lobes, closely parallel and swollen, extending to 4th abdominal somite.

Type IV ovary (Fig. 1d): Ovary very ripe and occupying more than half of dorsal space inside carapace, pale black and with frontal lobes completely covering sides of stomach; lateral lobes, 8-10 in number, greatly swollen and covering almost entire dorsal hepatopancreas; caudal lobes as 2 parallel inflated tubes and extending to 4th abdominal somite.

Histology of ovarian tissues at different stages

Type I ovary (Fig. 2a): Only 1 type of oocyte (i.e., resting oocyte) presents in ovarian tissue, consisting of tiny and morphologically similar cells scattered around connective stroma and with many empty spaces in between. Size of oocytes mainly with diameters of about 0.001 m, a few larger ones attaining 0.003 mm in diameter.

Type II ovary (Fig. 2b): Ovarian tissue having 2 types of oocytes, with about 30% resting and 70% developing cells. Developing oocytes organized themselves into tubule-like structural units (i.e., ovarian parenchyma). Each tubule, with wall composed of a thin layer of developing follicular cells, and packed with 8 to more than 50 developing oocytes in a row. These developing oocytes becoming semi-spherical, with diameter 0.10-0.14 mm, height 0.08-0.10 mm, volume 0.001-0.002 mm^3 and, nucleus/cytoplasm ratio 0.8-0.9; nucleus bearing 2-9 nucleoli

Table 1. Different types of ovary conditions in the deep-water shrimp, *Aristaeomorpha foliacea* (Risso, 1826)

Ovary	General appearance	Color	Oocyte development[a]
Type I	Tubular, posteriorly divided into 2 parallel branches and extending to 2nd abdominal somite	Translucent and colorless	Resting oocytes = 100%
Type II	Slightly swollen, frontal part branched into 2, median part subdivided into 8-10 lateral lobes, caudal lobes extending to 3rd abdominal somite	Light orange-red or light gray, semi-translucent	Resting oocytes ~ 30% Developing oocytes ~ 70%
Type III	Expanded, frontal lobes covering about half of lateral stomach, lateral lobes covering half of dorsal hepatopancreas, caudal lobes extending to 4th abdominal somite	Bluish gray	Resting oocytes ~ 10% Developing oocytes ~ 35% Expanding oocytes ~ 45% Mature oocytes ~ 10%
Type IV	Greatly swollen, frontal lobes completely covering lateral stomach, lateral lobes covering almost entire dorsal hepatopancreas, caudal lobes as a pair of inflated tubes and extending to 4th abdominal somite	Pale black	Resting oocytes ~ 5% Developing oocytes ~ 15% Expanding oocytes ~ 30% Mature oocytes ~ 50%

[a]See text for definitions of the 4 types of oocytes.

and cytoplasm composed of basophilic mass (i.e., color bluish under H-E stain). These developing oocytes progressively filling up available space within connective stroma of ovarian tissue.

Type III ovary (Fig. 2c): Four types of oocytes present in ovarian tissue, with about 10% resting oocytes, 35% developing oocytes, 45% expanding oocytes, and 10% mature oocytes. Resting and developing oocytes resembling those described in previous stages. Expanding oocytes being somewhat quadrangular, with longest diameter 0.25-0.40 mm, height 0.12-0.16 mm, and volume 0.008-0.021 mm^3, nucleus/cytoplasm ratio 0.3-0.5; nucleus spherical and medial, bearing 5-16 nucleoli, cytoplasm filled with acidophilic mass (i.e., color light red under H-E stain). Tubules with greatly expanded oocytes having follicular layer somewhat compressed, and each tubule containing 3-20 closely packed oocytes in a row. Mature oocytes similar to expanding oocytes but much bigger in size, with diameter 0.42-0.44 mm, height 0.21-0.28 mm, volume 0.038-0.043 mm^3, nucleus/cytoplasm ratio 0.1-0.2, and bearing 2-7

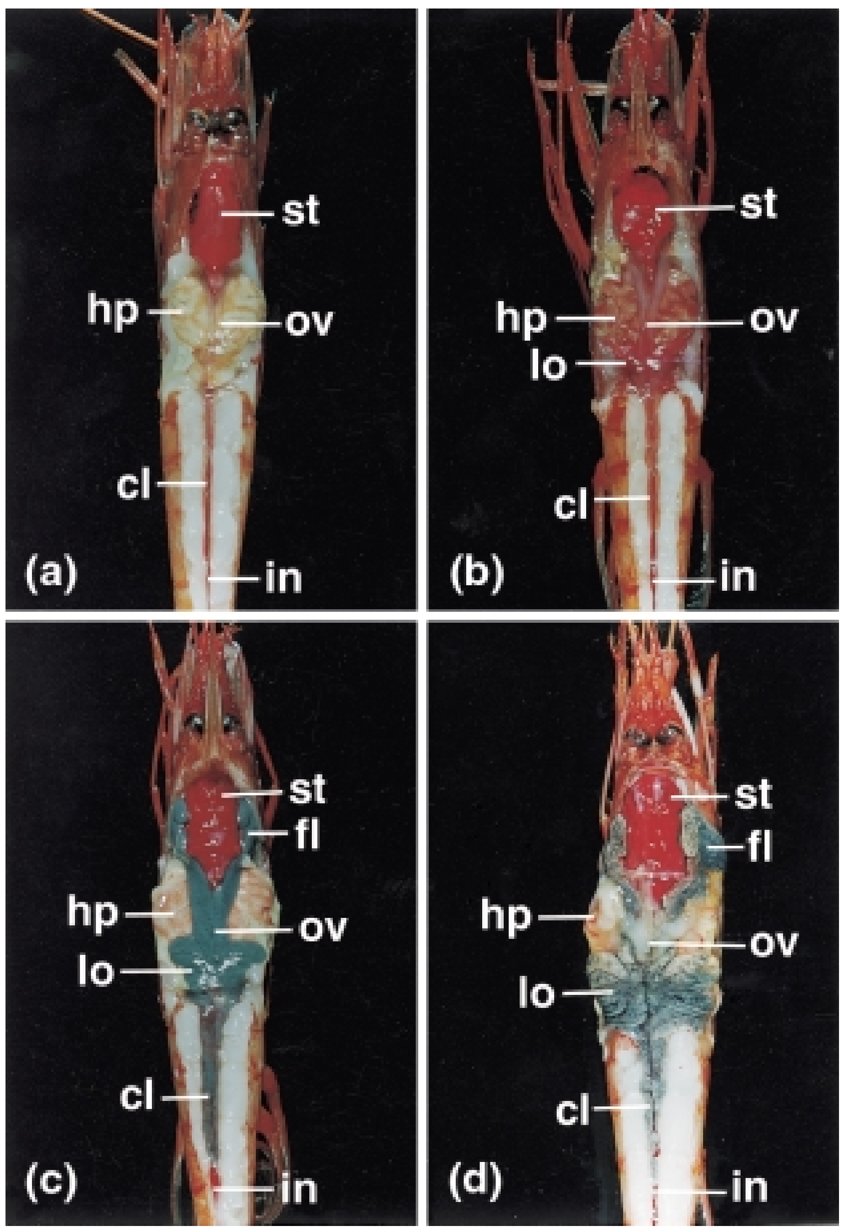

Fig. 1. Changes in size and color of the ovary during maturation in *Aristaeomorpha foliacea* (Risso, 1826), dorsal view, st = stomach, hp = hapatopancreas, ov = ovary, fl = frontal lobel of ovary, lo = lateral lobe of ovary, cl = caudal lobe of ovary, in = alimentary canal: **(a)** Type I ovary, **(b)** Type II ovary, **(c)** Type III ovary, **(d)** Type IV or ripe ovary.

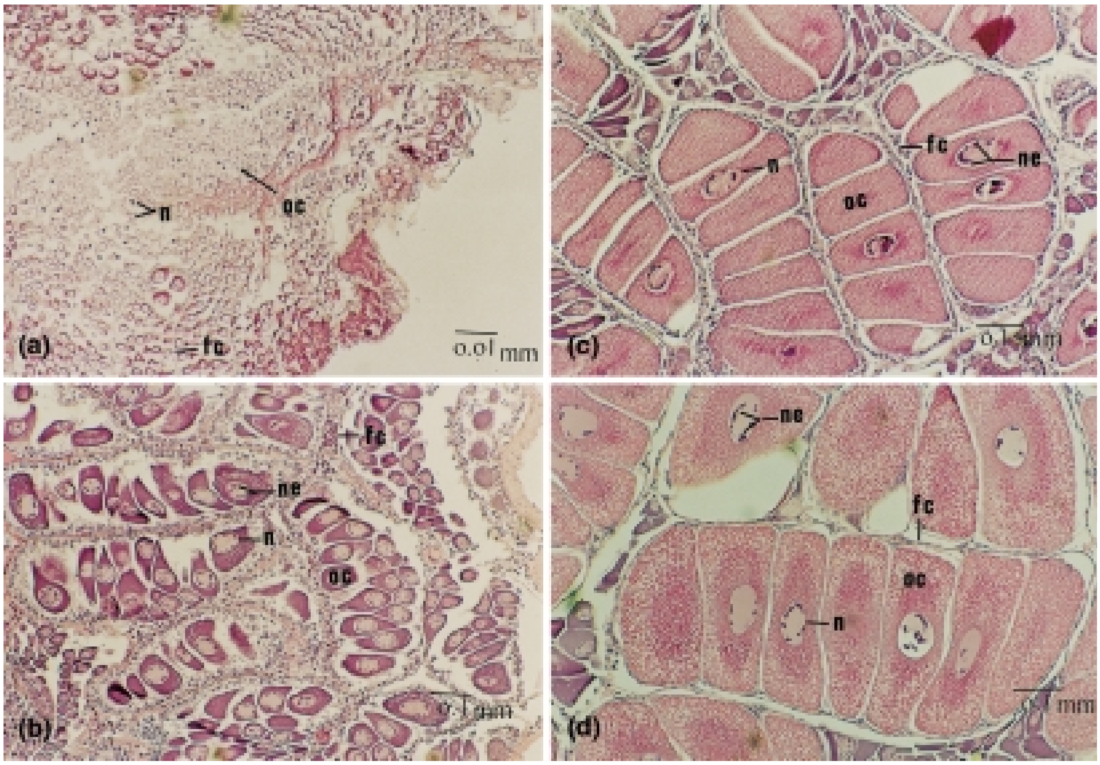

Fig. 2. Histology of the ovarian tissue of *Aristaeomorpha foliacea* (Risso, 1826); smear stained with H-E stain, 100X, oc = oocyte, n = nucleus, ne = nucleoli, fc = follicular cells: **(a)** Type I ovary, **(b)** Type II ovary, **(c)** Type III ovary, **(d)** Type IV or ripe ovary (ovary types equivalent to those of Fig. 1).

nucleoli; somewhat rectangular in section and tightly packed, squeezing against each other and against follicular layer which appeared to be strongly compressed. These fully mature oocytes, 3-18 (very rarely 1) in number in a single row, piled up like cones and arranged in a rouleau formation inside each tubule.

Type IV ovary (Fig. 2d): With fully mature oocytes occupying about half of ovarian tissue. Other ovarian tissue composed of about 30% expanding, 15% developing, and 5% still undeveloped oocytes.

Gonadosomatic index (GSI)

The lowest and highest GSI values of the material examined in the present study are 0.36 and 12.42. Table 2 shows the size of the females and the GSI values of the 4 different ovary types described above. There are marked differences (e.g., about double of the values) among the mean GSI values of the 4 ovary types, and there is no overlap between their standard deviations (even no overlap in ranges for some stages). The sizes of females also progressively increased from type I to type IV ovary. Furthermore, only 6.4% of females with type I ovary carried spermatophores. Females with the other ovary types all had spermatophores attached to their thelyca.

Table 2. Gonadosomatic index (GSI), size (carapace length, cl.), and spermatopore attachment in different ovary types of *Aristaeomorpha foliacea* (Risso, 1826)

Ovary type	GSI Mean ± SD (range)	cl. (mm) Avg. (range)	Spermatopore attached	*n*
Type I	1.38 ± 0.44 (0.36-2.07)	38.8 (24.7-54.6)	6.4%	188
Type II	2.91 ± 0.44 (2.08-4.20)	49.8 (36.5-57.3)	100%	65
Type III	6.87 ± 1.21 (4.30-8.76)	50.2 (42.5-58.0)	100%	45
Type IV	10.11 ± 1.12 (8.22-12.42)	53.9 (45.5-60.0)	100%	55

DISCUSSION

The results from the histology of ovarian tissues and GSI analysis show that changes in color and shape of the ovaries match very well with the development of oocytes and the weight of the ovary. The average GSI value increased from 1.38 in females with type I ovary to 10.11 in females with type IV ovary. Oocytes and follicular cells are very small and with no sign of development in type I ovary. The high number of nucleoli inside the nucleus of developing oocytes in type II ovary indicates that these oocytes have become very active. The enlargement of the expanding oocytes in type III ovary mainly results from expansion of the cytoplasm, which has become acidophilic, probably indicating the presence of yolk droplets, vitellogenic, and/or glycoprotein substances. Finally, about half of the oocytes in a pale black or type IV ovary are fully ripe. Therefore, it can be concluded that changes in color and morphology depicted in the ovary truly reflect the different developing stages of the ovarian tissue in *Aristaemorpha foliacea*. Table 2 also shows that the development of the ovary increases with the size of females: the average size of females having type I ovary being 38.8 mm cl. and increasing to 53.9 mm cl. when reaching type IV or mature stage. Moreover, females with type II to IV ovaries all bear spermatophores while females without spermatophores all had type I or resting ovary. This indicates that ovary development in this species may be related to mating. On the other hand, the low percentage (i.e., 6.4%) of type I females bearing spermatophores suggests that copulation can probably quickly induce the development of ovarian tissue (also see Ragonese and Bianchini 1995).

Color change in the ovary during maturation is well known for decapod crustaceans, particularly for penaeoid shrimp (see Dall et al. 1990). For deep-sea aristeid shrimp, there are very few reports on the relationships between change in color and histology of ovarian tissue, with most work focusing on *Aristaeus antennatus* (Risso, 1816) (e.g., Relini Orsi and Relini 1979, Relini Orsi and Semeria 1982 1983). Nevertheless, all other shrimp species for which the histology of the mature ovary is known to have the ripe oocyte forming a single unit by itself (e.g., *Penaeus* spp.: Liao 1973, Yano 1988, Tan-Fermin and Paudadera 1989, Dall et al. 1990, Chen and Chen 1994, Sandoval Quintero and Gracia 1998; *Parapenaeus longirostris*: Tom et al. 1987; *Aristeus antennatus*: Relini Orsi and Relini 1979, Relini Orsi and Semeria 1982 1983; *Macrobrachium rosenbergii*: Chang and Shih 1995). Developing oocytes pile up like cones (i.e., in a rouleau formation) inside a fusiform structural unit with the wall made up of a thin layer of follicular cells which is so far only known in *Aristaeomorpha foliacea*. It will be interesting to know whether *A. woodmasoni* Calman, 1925, the only other species known in the genus *Aristaeomorpha*, also has a similar rouleau arrangement of oocytes during ovarian development.

Ovarian development of *A. foliacea* from the Mediterranean has been reported by Relini Orsi and Semeria (1983) and Levi and Vacchi (1988), and our results are very similar to theirs. In older taxonomic literature, the name *A. foliacea* only referred to specimens from the Atlantic and the Mediterranean. A different name, *A. rostridenata* (Bate, 1888), was often used for the Indo-West Pacific material (see Holthuis 1980). *A. foliacea* and *A. rostridenata* are now generally treated as synonym, with the species considered to be cosmopolitan. In several closely related deep-sea shrimp species, it is found that the color of their mature ovaries are remarkably different (Chan and Yu 1987). The similar morphology and color of the developing ovary between the Taiwan and Mediterranean populations further support the view that they belong to the same species. Similar to the observation by Levi and Vacchi (1988), the final stage of a blackish ovary is clearly visible through the carapace (but unclear in other earlier stages) in the Taiwanese materials. Therefore, maturity can be easily determined by direct observation of the color visible inside the carapace for this shrimp. This can be very useful and practical during population studies and fishery management of this species.

Ovarian development in shrimp is sometimes considered to have 5 stages including the “spent stage” (see Dall et al. 1990). However, none of the 353 specimens examined in the present study showed any sign of a spent ovary. In Levi and Vacchi (1988), only 3 out of the 506 females examined from the Mediterranean showed a probable spent ovary. This may indicate that spawning is very rapid and females quickly die after spawning in this species, or that spent females of this deep-water shrimp will move to even deeper waters so that they have not been collected by local trawlers which so far have maximum operational depths to about 600 m only.

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臺灣產葉狀擬鬚蝦卵巢發育之研究

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葉狀擬鬚蝦在臺灣是深海拖網的常見漁獲物，並具有頗高的經濟價值。但目前對其基本生物學特性之了解卻十分闕如，無法進一步的經營管理這一深海資源。本研究深入探討葉狀擬鬚蝦的卵巢發育狀況，從而有效判別不同卵巢發育期之母蝦，以作為日後對其資源管理及研究等之參考。根據卵巢之外部形態、顏色和細胞組織之變化，以及生殖腺成熟指數(GSI)之相互關聯，葉狀擬鬚蝦之卵巢發育可大致分為四個階段，而成熟的卵巢是呈黑色，並可清楚透過頭胸甲加以確認。另外精莢之附著（即交配）似乎是啓動卵巢發育的關鍵，而葉狀擬鬚蝦成熟卵細胞會相互擠壓並排列成緡錢狀，此現象為蝦類中僅見。

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