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Distribution, biology, and stomach contents of paper nautilus (*Argonauta hians*) in the Andaman Sea

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ABSTRACT: Paper nautilus (*Argonauta hians*) were collected from fish markets and the bycatch of purse seiners operating in the Andaman Sea, Thailand. All specimens were mature females with egg cases with developing eggs inside. The distribution of paper nautilus was found between 7°30′24″–8°13′22″ N and 97°01′50″–98°55′48″ E around Phangnga, Phuket, and Krabi provinces, south of Thailand. All the specimens were female with average shell size of 20.6 ± 5.4 mm, average mantle length of 31.0 ± 6.5 mm, and average body weight of 6.4 ± 3.6 g. The relationship between mantle length (ML, mm) and fecundity is expressed as $\mathrm{Fe} = 268ML - 4428$ ($R^2 = 0.44$, $p < 0.05$, $n = 368$) and between weight (W, g) and fecundity is $\mathrm{Fe} = 538W + 573$ ($R^2 = 0.50$, $p < 0.05$, $n = 368$). The average fecundity of paper nautilus was 4160 ± 1770 eggs/batch, with high fecundities observed during the months of January, February, and December. Length at 50% maturity was estimated to be 20.1 mm (mantle length), whereas 27.5 mm would be the estimated length for a fully matured female. The stomach of *A. hians* contained crustaceans, cephalopods, and fish.

KEYWORDS: fecundity, Argonautidae

INTRODUCTION

Paper nautilus (*Argonauta hians* Lightfoot, 1786) is an epipelagic octopod which can be found in tropical and subtropical oceans[1]. In Thai waters, *A. hians* are recorded in both the Gulf of Thailand and the Andaman Sea[2,3]. Paper nautilus have an extreme sexual dimorphism in size. The male is much smaller than the female[4–6]. Whereas the stomach of other species of cephalopods usually contains crustaceans, cephalopods, and osteichthyes, paper nautilus appear to feed on heteropods, pteropods, and small fishes[7].

The paper nautilus has a slender body, narrow head, and unequal arm length. The longest mantle length can reach up to 50 mm in females and 20 mm in males[8]. Paper nautilus has eight arms, each arm has two rows of suckers, and the number of suckers on the arm depends on the species. Dorsal arms in females have laterally enlarged membranes. The male third left arm is hectocotylized, huge, and detachable. The hectocotylus of paper nautilus consists of a basal spermatophore reservoir, a central section bearing suckers and distally, a long lash-like 'penis'[1]. At copulation, the hectocotylus detaches, and forms an active, autonomous spermatophore carrier which remains in the female mantle cavity[9].

The unique characteristic of *Argonauta* is that the female secretes a shell with an enlarged web of dorsal arms, functioning as an elaborate egg case. The calcareous structured shell is thin and laterally compressed. The egg case is a single chamber with a flat keel fringed with two rows of tubercles[1]. The lateral sides of the shell have radial ribs. The shell centre is pressed in or bent outwards into a prominent horn[2]. The shell provides protection and is used as a flotation device by the female as well as a place to attach their eggs.

At present, knowledge on the biology and taxonomy of paper nautilus is still insufficient. Accordingly, this study is intended to provide information on the distribution, some biology, and the stomach contents of paper nautilus around Andaman Sea for the proper management and use of the species as part of biodiversity conservation efforts.

MATERIALS AND METHODS

In March 2006 and February 2007, 368 specimens of paper nautilus were collected from fish markets

and the bycatch of purse seiners operating in the Andaman Sea. The distribution of paper nautilus was determined through both field and fishermen surveys. All specimens were investigated in the laboratory to study their biology and stomach contents. Data were collected on the fecundity, length, morphological character, and weight. Fecundity was calculated using the same method as in Ref. 10. The fecundity, Fe, is given by $\mathrm{Fe} = nG/g$, where n is number of eggs, G is total weight of ovary, and g is the weight of the ovary sample. The length at 50% maturity was calculated using the same method as in Ref. 11.

Stomach content

Specimens of paper nautilus were fixed with 10% formalin and preserved in 70% alcohol. Mantle lengths were measured in millimetres. Then the contents of each stomach was sorted and identified. Stomach fullness was determined following Ref. 12, and classified as follows: 0 = empty stomach, 1 = traces of food, 2 = less than half filled, 3 = more than half filled, and 4 = full. The contribution of prey taxa to the diet was determined using the index of relative importance (IRI) which is given by $\mathrm{IRI} = F(N+V)$, where F is the percentage of non-empty stomachs containing a specific prey item, N is 100% times the total number of the specific prey item divided by the total of all prey items, and V is 100% times the volume of a specific prey item divided by the total volume of all prey[13]. Note that in the above formula for IRI, the values for F, N, V must be expressed as percentages with the result that the value of IRI can range from 0 to 10000.

RESULTS

All *Argonauta hians* collected from the Andaman Sea were mature females. Shell sizes ranged from 12.6 to 52.0 mm with an average length of 20.6 ± 5.3 mm (Fig. 1). Females laid eggs inside their shells and the average size of the egg capsules was 1.06 ± 0.11 mm.

Distribution

Argonauta hians samples were collected 20 nautical miles offshore during night time. *A. hians* can be found between 7°30′24″–8°13′22″ N and 97°01′50″–98°55′48″ E around Phangnga, Phuket, and Krabi provinces. (Fig. 2).

Fecundity

Eggs are kept in batches (Fig. 3) and each batch was laid at different times with an average fecundity of 4160 ± 1770 eggs/batch. The specimens found in January tended to have the highest fecundity (6900 ± 3400 eggs/batch) while the lowest was recorded in March (820 ± 500 eggs/batch).

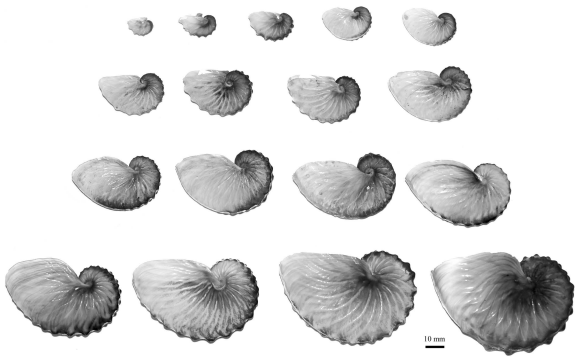

Fig. 1 Shell of *A. hians*.

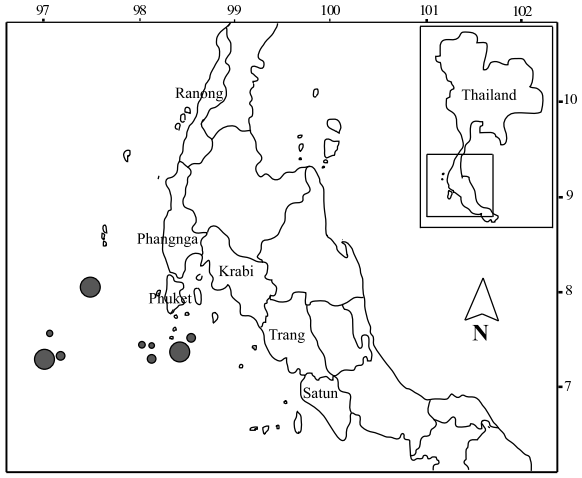

Fig. 2 Distribution of *A. hians* around Andaman Sea.

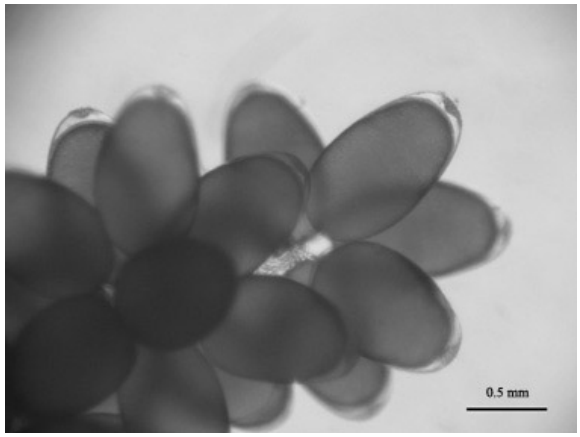

Fig. 3 Ovary of *A. hians*.

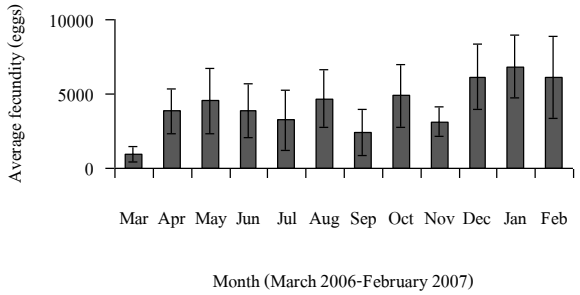

Fig. 4 Fecundity of *A. hians* according to month.

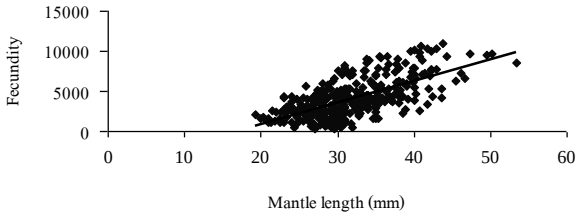

Fig. 5 Relationship between mantle length and fecundity of *A. hians*.

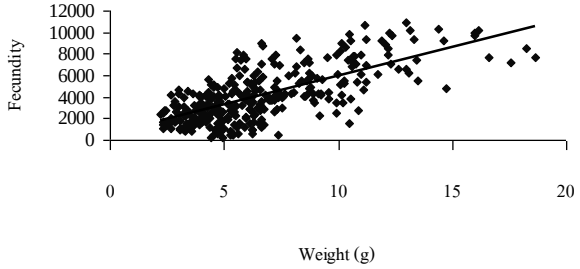

Fig. 6 Relationship between weight and fecundity of *A. hians*.

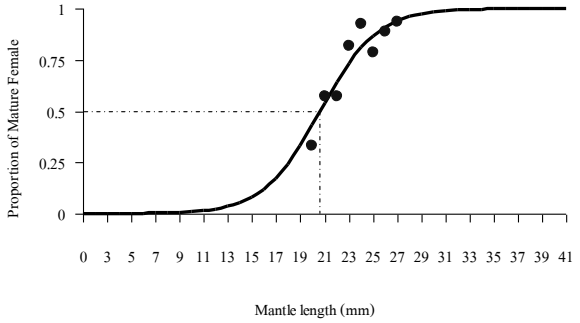

Fig. 7 Length at 50% maturity of *A. hians*.

This study collected female specimens with mature ovaries from March 2006 to February 2007, with approximately 30 specimens selected each month to measure the fecundity and average fecundity, which are shown in Fig. 4. It could be assumed that reproductive cycles peaked in December, January, and February but had the tendency to drop during the rainy season (May–October). This might be because of a high abundance of prey during the rainy season which provides enough food to support the growth of paper nautilus, so instead, the winter season (October–January) is used for their reproduction.

Relationships of fecundity with mantle length and body weight

Paper nautilus has a slender body with an average mantle length of 31.0 ± 6.5 mm and average body weight of 6.4 ± 3.6 g.

The relationship between fecundity and mantle length of the *A. hians* in this study was estimated to be $\mathrm{Fe} = 267.85ML - 4427.8$ ($R^2 = 0.4370$, $p < 0.05$, $n = 368$, Fig. 5), while the relationship between fecundity and body weight was estimated to be $\mathrm{Fe} = 538W + 573$ ($R^2 = 0.50$, $p < 0.05$, $n = 368$, Fig. 6).

Length at 50% maturity

Length at 50% maturity was calculated from 368 specimens, with 30 specimens classified as immature and the remaining 338 as mature. The immature specimens had mantle lengths between 14.5 and 26.5 mm. Length at 50% maturity was 20.14 mm. At 27.5 mm all females were mature.

The relationship between proportion of mature females and total number of females based on length, expressed by power regression, and analysed by least square analysis, was estimated to be $P_L = 1/[1 + \exp(8.7031 - 0.4321L)]$ (Fig. 7).

Stomach content

According to stomach fullness, more than half of the samples had some food in their digestive tracts and 23% had full stomachs. Three major groups of organisms dominating the diet composition in the stomach were crustaceans, cephalopods, and fish. Crustaceans were the most preferred food of paper nautilus (IRI = 1613), followed by cephalopods (IRI = 1281), and then fish, which was a rare group of prey in the stomachs of paper nautilus (IRI = 281). Appendages of all organisms found in the stomach could not be identified down to the lowest taxon because all of them were minute and finely fragmented. Crustaceans were recognized from the mandibles, eyes, legs, and various other fragments. Cephalopods were recognized from some parts of their suckers and beaks while the fish were recognized from scales and bones. Nevertheless

some appendages could not be identified because they were already digested and had no marker for identification.

DISCUSSION

Paper nautilus can be captured all year round and can be found from the surface to a depth of more than 80 m in the Andaman Sea. More than 75% of collected specimens were mature females with egg mass found inside their egg cases. Female argonauts reproduce very early and still continue growing. They can reproduce for a long period of time[1,7]. Eggs of *A. hians* develop into paralarvae and undergo up to 15 stages[14]. Eggs are telolecithal and oval in shape, with an average length of 1.06 ± 0.11 mm (ranging from 0.77 to 1.46 mm)[15]. The size is the same with that of *A. boettgeri* (about 0.85–1.1 mm)[7]. Ripened eggs are transparent and pale yellow in colour.

Female paper nautilus start to reproduce at an early adult stage, with mantle lengths of around 14–15 mm for *A. boettgeri* and 18–20 mm for *A. hians*[1]. Laptikchovsky and Salman[16] reported that the potential fecundity of *A. argo* was at least 86 000 eggs and batch fecundity was about 2000–4000 eggs, whereas in this study, the average fecundity of *A. hians* was 4160 ± 1770 eggs/batch. Fecundity of *A. argo* was higher than *A. hians* which might be due to size differences. *A. argo* is the biggest species (mantle length can reach up to 120 mm) while *A. hians* is the smallest species. The fecundities of cephalopod are different among species *Cistipus indicus* and *Octopus dollfusi*, which were 32–281 and 6895 oocytes, respectively[17]. Meanwhile, the common octopus (*Octopus vulgaris*) has a fecundity range between 70 000 and 600 000 oocytes and has a breeding season extending from February to October with spawning peaking in April–May and August[18].

Sampling of *A. hians* revealed that their stomachs appeared to be empty. It might be because *A. hians* feed primarily during the day[19], but the samples were collected at night, when the food in the stomach could already have been digested. The three main groups found in the stomachs of *A. hians* were crustaceans (IRI was 1612), cephalopods (IRI was 1281), and fish (IRI was 281). This finding is similar to what was reported by Robson[20] in that small fish and crustaceans are preferred by paper nautilus.

The stomach content in the other octopods such as *Cistopus indicus* in Thai waters was a little bit different as it was dominated by starfishes, clams, and crabs[21]. This finding is in contrast with Heeger et al[22], who reported that *A. argo* in the north of Bohol Island in the Philippines preferred jellyfish (*Phyllorhiza punctata*) for food.

The differences found in the diets reflect the combined effects of a broad distribution of the species and the diverse sampling locations, as well as some possible effects of seasons and the annual differences in prey abundance. However, cannibalism may be important as a supplement to their diet when other food sources are limited[12].

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