Morphological Characteristics and Relationships between Beak Dimensions and Length of Marbled Octopus *Amphioctopus aegina* (Gray, 1849)

Sonthaya Phuynoi*, Charuay Sukhsangchan and Pawida Prasopsook

ABSTRACT

Morphological characteristics and the relationship between beak dimensions and body size of marbled octopus, *Amphioctopus aegina* (Gray, 1849) were determined using specimens collected from the Gulf of Thailand. A total of 408 individuals, 207 males and 201 females, were measured and weighed. Their body weights ranged from 7.30 to 120.00 g (39.78±19.05), mantle length (ML) from 32 to 80 mm (54.39±8.97) and total length (TL) from 114 to 305 mm (210.04±32.19). The rostral tips of the upper and lower beaks were brown to black in color, slightly curved, short, and with a small hood. The upper beak of this species has a short wing with large lateral wall. The ratios among upper beak dimensions were 1:2.95 for upper hood length (UHL):upper crest length (UCL), 1:3.64 for upper rostral width (URW):UCL, and 1:3.05 for upper rostral length (URL):UHL. The lower beak has a long wing and narrow lateral wall. The ratios of lower beak dimensions were 1:3.44 for lower hood length (LHL): lower crest length (LCL), and 1:1.25 for lower rostral width (LRW):LCL. Regressions of body size on beak dimensions were statistically significant ($p<0.05$). The best equations for determining mantle length (ML) and total length (TL) were ML = 0.531+2.108UHL ($R^2 = 0.704$, $MS_{res} = 0.238$) and TL = 3.574+2.539UCL ($R^2 = 0.731$, $MS_{res} = 2.791$), respectively.

Keywords: *Amphioctopus aegina*, Beak, Cephalopods, Octopus, Thailand

INTRODUCTION

Thailand is located in Southeast Asia, with coastlines along the Pacific and Indian oceans, and is host to abundant aquatic organisms, including economically-important cephalopods such as octopuses, squids and cuttlefishes. In Thailand, the catch of cephalopods in 2019 was 98,093 tonnes, with a value of 390,904,766 USD (DOF, 2019). There are 116 species of cephalopods in the Gulf of Thailand, of which 19 are octopuses, with the most common species being the marbled octopus (*Amphioctopus aegina*) and king octopus (*A. rex*) (Nateewathana and Norman, 1999; Aungtonya *et al*., 2007; Jereb *et al*., 2014; DOF, 2019; Nabhitabhata *et al*., 2019). Usually, fishers capture them using octopus traps, and the primary fishing grounds are in the Gulf of Thailand and the Andaman Sea. Octopuses are typically found from coastal areas to deep areas of the ocean (Norman, 2000). Differentiation among some octopus species is quite complicated because the external morphological characteristics differ only slightly. Nonetheless, there have been numerous studies about the biology and ecology of octopuses in Thailand, especially *A. aegina* (Nateewathana, 1997; Promboon *et al*., 2011; Jereb *et al*., 2014; Tuanapaya *et al*., 2018); these publications can aid in distinguishing among octopus species.

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Several morphological features of the octopus beak can be used to identify octopuses, including size, color, shape of wings, and curvature of the rostrum (Clarke, 1986; Smale *et al*., 1993; Lu and Ickeringill, 2002; Staudinger *et al*., 2008). The upper and lower beaks can also be used to identify species within some genera of cephalopods, especially for the genus *Amphioctopus*. In addition, these hard structures can be used to determine an individual's growth rate, body size, and body weight, and to estimate the biomass of cephalopods consumed by predators (Clarke, 1986; Raya and Hernández-González, 1998; Staudinger *et al*., 2008; Chen *et al*., 2012; Rodrigues *et al*., 2013; Fang *et al*., 2015). The beak of a cephalopod is a stiff structure composed of chitin fibers and protein, located within the buccal mass (Clarke, 1986; Miserez *et al*., 2007). Due to their durable composition, beaks can resist digestion in predators' stomachs, and as a result, cephalopod beaks are usually found or collected from stomachs of top marine predators such as whales, seals, fishes, and seabirds (Clarke, 1986; Lalas, 2009; Xavier *et al*., 2011).

Currently, there insufficient morphological and growth information about the marbled octopus in Thailand, especially as it relates to the beak. This study therefore aims to 1) describe the morphological characteristics of the beak of the marbled octopus (*A. aegina*), and 2) study the relationship between beak dimensions and body size in this species. Results of the study can be beneficial to fisheries management, as well as to other studies on the population dynamics, biology, and ecology of these cephalopods.

MATERIALS AND METHODS

Sample collection

A total of 408 specimens of marbled octopus were collected from fishers who used octopus traps ("Kung-King") in Phetchaburi Province, Thailand (13°03.291' N and 100°08.318' E). Specimens were kept in ice and then transferred to the laboratory of the Department of Marine Science, Faculty of Fisheries, Kasetsart University, Bangkok. The octopus specimens were identified by sex, weighed to the nearest milligram using an electronic balance (Xue *et al*., 2013), and were measured for mantle length (ML) and total length (TL) to the nearest millimeter. The mantle length (ML) was measured from the posterior end of the mantle to the middle of the eye, while the total length (TL) was measured from the posterior end of the mantle to the tip of the longest arm (Lalas, 2009) (Figure 1).

Beak measurements

The upper beak and lower beak were removed from the buccal mass and cleaned with seawater, and then fixed in 70% ethyl alcohol

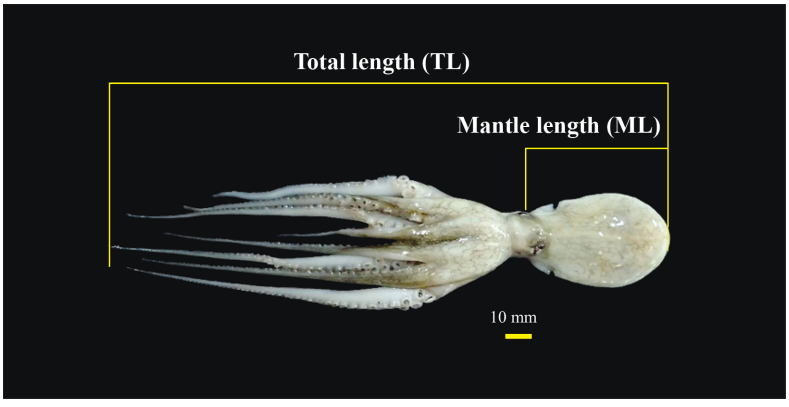

Figure 1. Adult specimen of marbled octopus, *Amphioctopus aegina* (Gray, 1849).

(Clarke, 1986). Using digital Vernier calipers (Wolff, 1981), dimensions of the upper and lower beaks were measured: upper rostral length (URL), upper rostral width (URW), upper hood length (UHL), upper wing length (UWL), upper lateral wall length (ULWL), upper crest length (UCL), lower hood length (LHL), lower crest length (LCL), lower rostral width (LRW), lower rostral length (LRL), lower wing length (LWL). Upper (Ujw) and lower jaw angle widths (Ljw) were also measured (Figure 2).

Data analysis

Regression analysis was used to describe relationships between beak dimensions and octopus size (mantle length and total length). For each pair of variables, analysis of covariance (ANCOVA) was applied to test the homogeneity of regression coefficients using slope and elevation comparison between males and females. Moreover, adjusted R-squared (R) and mean squared residual (MS_{res}) were used as criteria to select the best regression equation for further prediction.

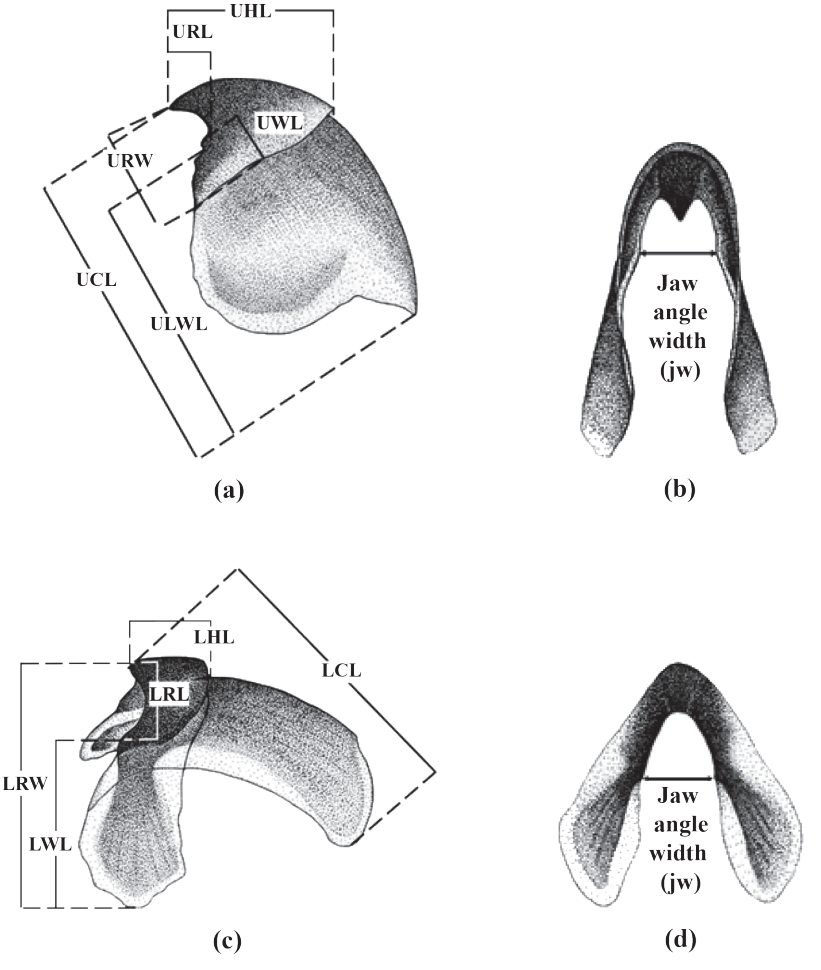

Figure 2. Beak dimensions: (a) upper beak: upper rostral length (URL), upper rostral width (URW), upper hood length (UHL), upper wing length (UWL), upper lateral wall length (ULWL), upper crest length (UCL); (b) upper jaw angle width (jw); (c) lower beak: lower hood length (LHL), lower crest length (LCL), lower rostral width (LRW), lower rostral length (LRL), lower wing length (LWL); and (d) lower jaw angle width (jw).

RESULTS

Based on the 408 specimens of marbled octopus collected, the range of mantle lengths (ML) observed was 32-80 mm (mean = 54.30±8.90 mm), range of total lengths (TL) was 114-305 mm (209.90±32.10 mm), and range of body weights (BW) was 7.30-120.00 g (39.78±19.05 g). The sample contained 207 males, with mean ML of 53.70±8.20 mm (range 34-75 mm), mean TL of 206.1±30.6 mm (114-280 mm), and mean body weight of 37.92±17.94 g (8.30-113.35 g). The 201 females collected had a mean ML of 55.1±9.50 mm (32-80 mm), mean TL of 214.20±33.30 mm (120-305 mm), and mean body weight of 41.80±20.13 g (7.30-120.00 g).

Morphological characteristics of beaks of marbled octopus

On the upper beak of specimens examined, the rostrum was short and curved with a small hood. The rostral tip was slightly curved, obtuse, black in color, and covering about 1/16 of the length of UHL. The upper crest was short, and the lateral wall had a large plate and was slightly curved. Jaw angle was curved from the tip to the front of the lateral wall. The base of the lateral wall was light to dark brown in color and the rostral tip wasblack. Ratios of upper beak measurements were 1:2.95 for UHL:UCL, 1:3.64 for URW:UCL, and 1:3.05 for URL:UHL.

For the lower beak, the rostral tip was less curved and blunt. Crest length was short, the inner jaw angle was obviously large and curved, wings were long, and the lateral wall was slightly curved and narrow. Ratios of lower beak measurements were 1:3.44 for LHL:LCL and 1:1.25 for LRW:LCL (Figure 3).

Ratios of beak dimensions in male and female octopuses

The ratios of upper beak dimensions of the male octopuses were 1:2.94 for UHL:UCL, 1:3.68 for URW:UCL, 1:2.97 for URL:UHL, while for the lower beak, ratios were 1:2.84 for LHL:LCL and 1:1.25 for LRW:LCL.

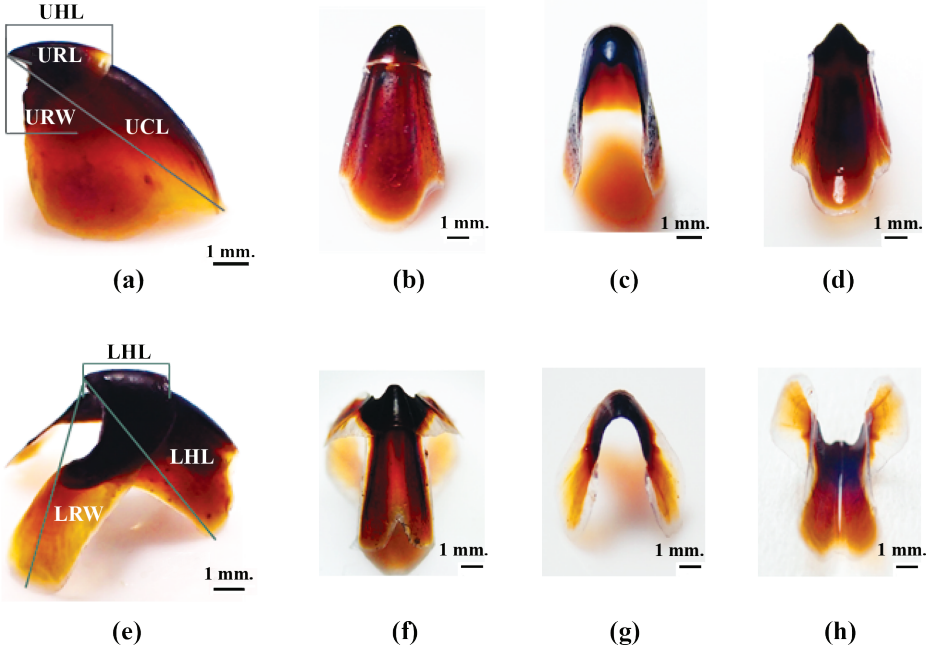

Figure 3. Beak of *Amphioctopus aegina*: (a) dimensions of upper beak; (b) dorsal view of upper beak; (c) front view of upper beak; (d) ventral view of upper beak; (e) dimensions of lower beak; (f) rear view of lower beak; (g) front view of lower beak; and (h) ventral view of lower beak.

The ratios of upper beak dimensions of the females were 1:2.95 for UHL:UCL, 1:3.59 for URW:UCL, 1:3.10 for URL:UHL, while for the lower beaks, the LHL:LCL ratio was 1:3.47 and LRW:LCL was 1:1.25.

Relationships between beak dimensions and body size

ANCOVA results indicated that there was no significant effect of sex on the relationships between beak dimensions (UCL, LRW, UHL, LCL, LWL, and ULWL) and octopus size (ML and TL), as shown in Tables 1 and 2. Relationships between beak dimensions (UCL, LRW, UHL, LCL, LWL, and ULWL) and octopus size (ML and TL) are illustrated along with regression equations in Figures 4-5. Values of mean squared residual (MS_{res}) and adjusted R square (R^2) were applied as criteria for model selection. Considering mantle length as a dependent variable, the best equation for describing the relationship between ML and any of the beak dimensions was ML = 0.531+2.108 UHL (R^2 = 0.704, MS_{res} = 0.238), while the best equation to describe the relationship between TL and a beak dimension was TL = 3.574+2.539UCL (R^2 = 0.731, MS_{res} = 2.791).

Table 1. Regression equations of mantle length (ML) on beak dimensions of male and female marbled octopus, slope comparison and probability between males and females, and elevation comparison and probability of total sample.

Sex	Regression equation	Slope comparison		Elevation comparison	
		F	p	F	p
M	ML = 0.625+2.072UHL	1.61×10^{-6}	0.9989	1.41×10^{-6}	0.9990
F	ML = 0.437+2.143UHL				
M	ML = 3.384+2.572URL	3.84×10^{-5}	0.9950	3.54×10^{-5}	0.9952
F	ML = 2.903+3.409URL				
M	ML = 3.363+1.618UWL	2.07×10^{-7}	0.9996	1.84×10^{-6}	0.9989
F	ML = 3.349+1.661UWL				
M	ML = 1.316+0.686ULWL	5.53×10^{6}	0.9981	2.01×10^{-6}	0.9988
F	ML = 1.021+0.730ULWL				
M	ML = 0.866+0.668UCL	6.41×10^{6}	0.9979	1.59×10^{-6}	0.9989
F	ML = 0.531+0.731UCL				
M	ML = 2.060+1.809URW	3.12×10^{-7}	0.9995	7.00×10^{-6}	0.9978
F	ML = 1.919+1.848URW				
M	ML = 4.615+0.571Ujw	3.14×10^{-6}	0.998587	2.08×10^{-5}	0.99636
F	ML = 4.527+0.759Ujw				
M	ML = 1.885+2.287LHL	4.48×10^{-6}	0.9983	1.42×10^{-5}	0.99699
F	ML = 1.704+2.462LHL				
M	ML = 3.726+2.349LRL	3.08×10^{-5}	0.9955	3.90×10^{-2}	0.9502
F	ML = 3.314+3.145LRL				
M	ML = 1.873+1.060LWL	4.57×10^{-6}	0.9982	2.56×10^{-7}	0.9996
F	ML = 1.605+1.136LWL				
M	ML = 1.135+1.022LRW	1.31×10^{-6}	0.9990	1.26×10^{-7}	0.9997
F	ML = 0.984+1.056LRW				
M	ML = 0.882+0.863LCL	2.84×10^{-6}	0.9986	7.37×10^{-8}	0.9997
F	ML = 0.656+0.905LCL				

Table 1. Continued

Sex	Regression equation	Slope comparison		Elevation comparison	
		F	p	F	p
M	ML = 5.285+0.071Ljw	6.95×10^{-6}	0.9978	1.65×10^{-5}	0.9967
F	ML = 5.105+0.340Ljw				

Note A: Reject the null hypothesis when F > F (0.05, 1,404); B: Reject the null hypothesis when F > F (0.05, 1,405)

Table 2. Regression equations of total length (TL) on beak dimensions of male and female marbled octopus, slope comparison and probability between males and females, and elevation comparison and probability of total sample.

Sex	Regression equation	Slope comparison		Elevation comparison	
		F	p	F	p
M	TL = 3.707+7.377UHL	5.89×10^{-8}	0.9998	1.22×10^{-5}	0.9972
F	TL = 3.848+7.427UHL				
M	TL = 13.035+9.771URL	1.85×10^{-5}	0.9966	9.36×10^{-5}	0.9922
F	TL = 12.386+11.822URL				
M	TL = 13.735+5.529UWL	1.45×10^{-6}	0.99904	2.08×10^{-5}	0.9963
F	TL = 13.700+5.939UWL				
M	TL = 5.355+2.573ULWL	1.21×10^{-8}	0.9999	1.34×10^{-5}	0.9970
F	TL = 5.656+2.566ULWL				
M	TL = 3.679+2.504UCL	7.64×10^{-5}	0.9930	1.61×10^{-6}	0.9967
F	TL = 3.651+2.547UCL				
M	TL = 8.594+6.541URW	1.06×10^{-7}	0.9997	1.97×10^{-6}	0.9988
F	TL = 8.879+6.458URW				
M	TL = 17.568+2.287Ujw	5.48×10^{-6}	0.9981	5.52×10^{-5}	0.9940
F	TL = 17.335+3.164Ujw				
M	TL = 8.426+7.984LHL	2.86×10^{-6}	0.9986	5.66×10^{-5}	0.9940
F	TL = 8.284+8.503LHL				
M	TL = 14.432+8.792LRL	8.71×10^{-6}	0.9976	6.80×10^{-5}	0.9934
F	TL = 14.209+10.332LRL				
M	TL = 7.776+3.878LWL	4.31×10^{-7}	0.9994	1.54×10^{-5}	0.9968
F	TL = 7.808+3.963LWL				
M	TL = 5.362+3.669LRW	8.12×10^{-7}	0.9992	1.97×10^{-5}	0.9965
F	TL = 5.286+3.766LRW				
M	TL = 3.964+3.194LCL	2.74×10^{-7}	0.9995	2.09×10^{-5}	0.9963
F	TL = 4.051+3.240LCL				
M	TL = 19.731+0.702Ljw	8.96×10^{-6}	0.9976	5.18×10^{-5}	0.9943
F	TL = 19.196+1.887Ljw				

Note A: Reject the null hypothesis when F > F (0.05, 1,404); B: Reject the null hypothesis when F > F (0.05, 1,405)

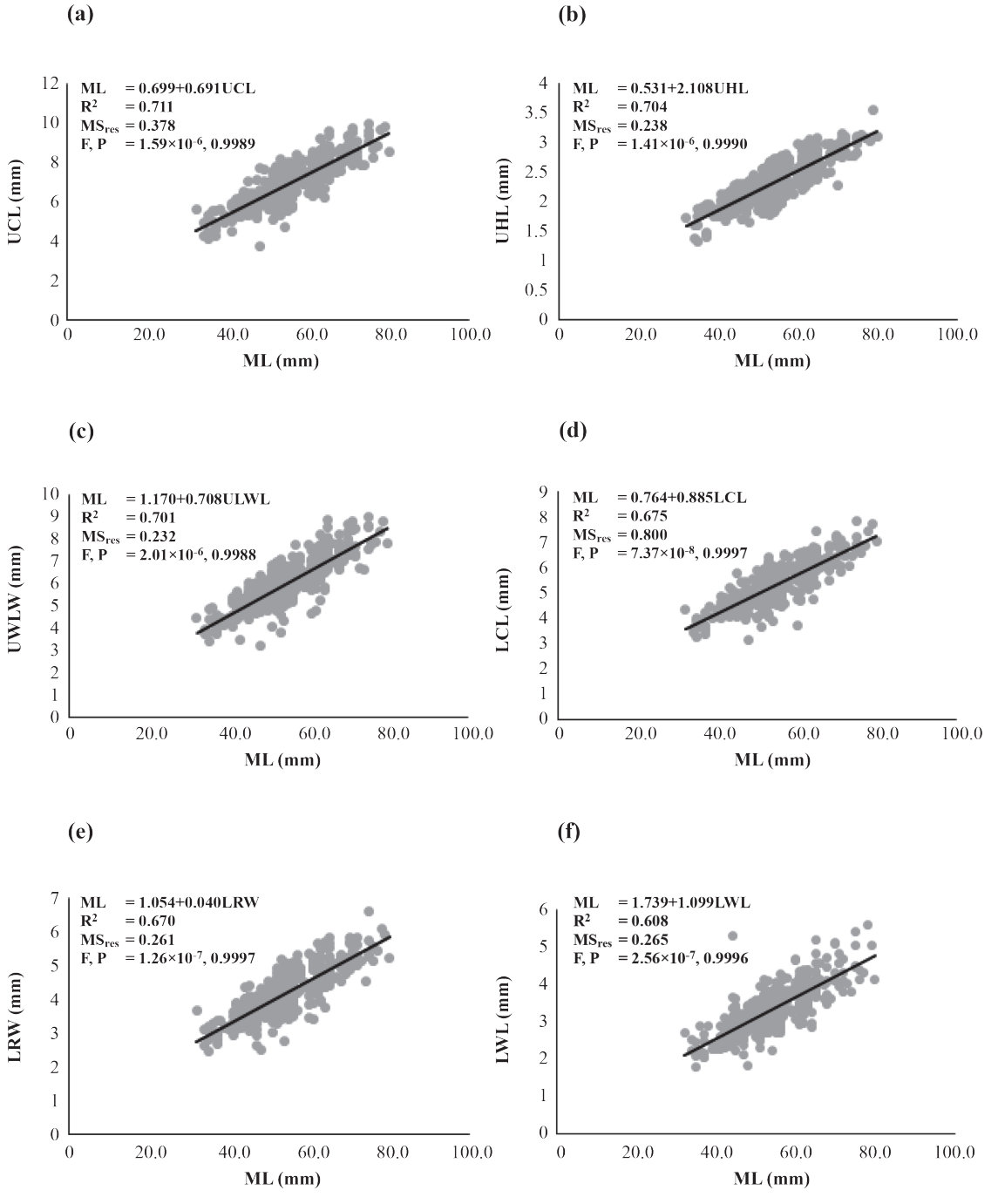

Figure 4. Scatter plots with regression equations of mantle length (ML) on (a) upper crest length (UCL); (b) upper hood length (UHL); (c) upper lateral wall length (ULWL); (d) lower crest length (LCL); (e) lower rostral width (LRW); and (f) lower wing length (LWL) of marbled octopus.

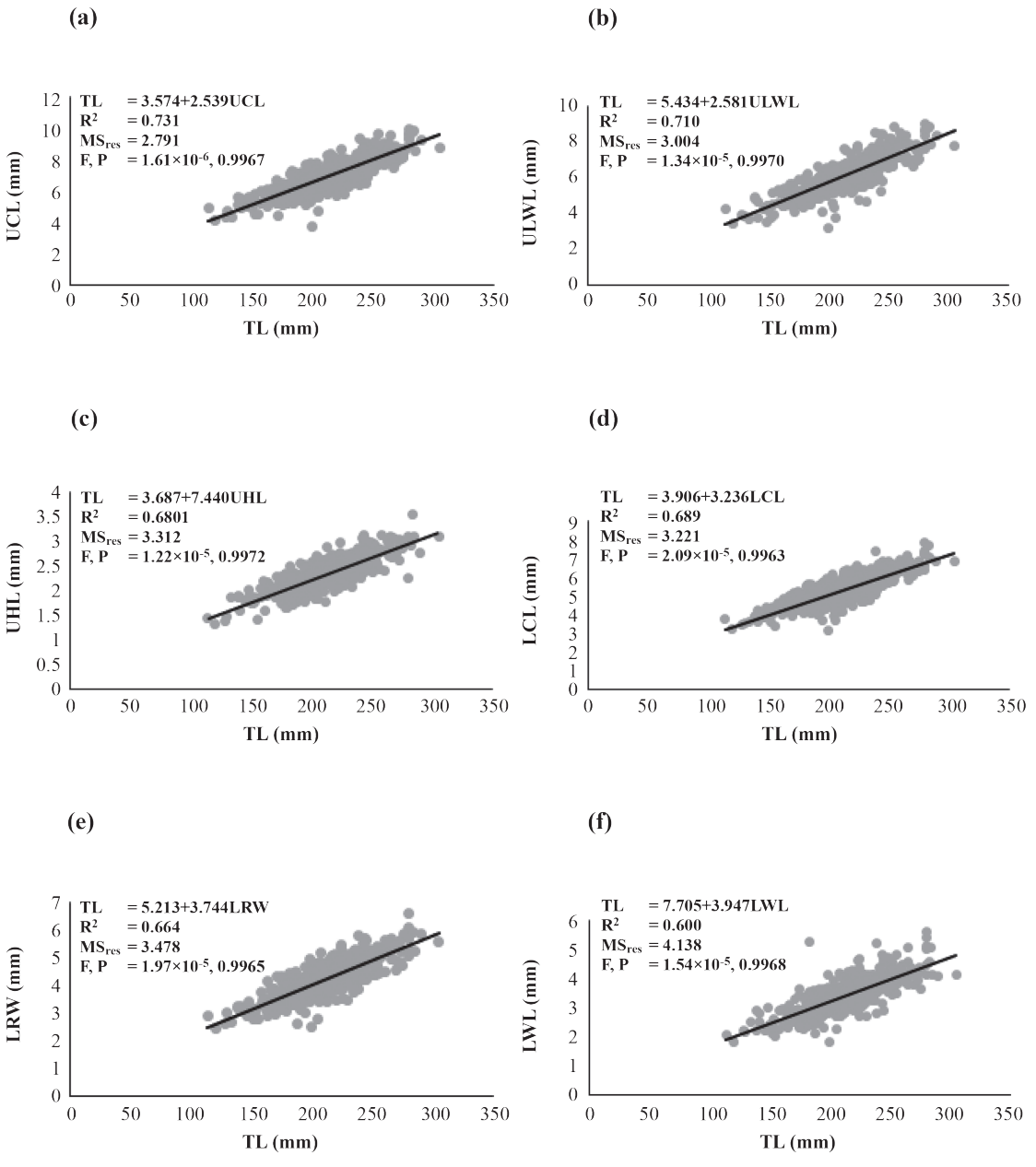

Figure 5. Scatter plots with regression equations of total length (TL) on (a) upper crest length (UCL); (b) upper lateral wall length (ULWL); (c) upper hood length (UHL); (d); lower crest length (LCL); (e) upper rostral width (URW); and (f) lower wing length (LWL) of marbled octopus.

DISCUSSION

The beaks of marbled octopus observed in this study had an upper beak with a short rostrum, a slightly curved rostral tip with a small hood, and a short and narrow crest. The lower beak had long wings and a concave edge at the posterior end. These characteristics are the same as those described by Clarke (1986) and Nateewathana (1997).

The beak of the marbled octopus has some characteristics that are similar to those of cuttlefishes, e.g., *Sepia aculeata* (Orbigny, 1848), *Sepia recurvirostra* (Steenstrup, 1875) and *Sepiella inermis* (Orbigny, 1848), especially the color of the beak, which is brown to black. However, the rostral tip of the beak of a cuttlefish is sharper than that of the marbled octopus, and the crest of its lateral wall is covered with large brown to black stripes (Promboon *et al*., 2011; Phuynoi *et al*., 2019).

Morphological characteristics of the beak of the marbled octopus can also be used to differentiate it from the Indian squid *Uroteuthis* (*Photololigo*) *duvaucelii* (Orbigny, 1835). In the Indian squid, the beak is transparent with a thin lateral wall, and the rostral tip has dark brown to black stripes that are found only at the corner of the jaw angle (Phuynoi *et al*., 2018).

Fang *et al*. (2015) reported that beak dimensions, such as UHL, UCL, ULWL, LCL, LRL and LLWL of the purpleback flying squid *Sthenoteuthis oualaniensis* (Lesson, 1830) could be used to estimate the body length of the species. Yue *et al*. (2018) also used these dimensions to determine the length of *Uroteuthis* (*Photololigo*) *edulis* (Hoyle, 1885) and *Uroteuthis* (*Photololigo*) *chinensis* (Gray, 1849). Kashiwada and Recksiek (1979) used UHL and LCL to study the relationship of the beak with body length in *Loliogo opalescens* (Berry, 1911). Rodrigues *et al*. (2013) reported that the relationship of morphological characteristics of the upper and lower beaks did not significantly differ by sex in *Sepiola atlantica* (Orbigny, 1840) and *Todaropsis eblanae* (Ball, 1841). Kashiwada and Recksiek (1979) reported that there was a highly significant difference in the ratio of URL:URW for different sizes of squid *Loligo opalescens*, but that this ratio did not differ by sex, and it could therefore not be used to separate sexes.

Beak dimensions can be useful as accurate predictors of the body size or mantle length in cephalopods, as has been shown for squids (Scharf *et al*., 1997; Staudinger *et al*., 2008). In addition, the beak color can also indicate the maturation stage of the squid. García (2003) reported that the pigmentation of the upper and lower beaks of cephalopods can be measured as eight degrees, i.e. from 0 to 7 degrees, which reflect the growth and maturation stages as well as the food intake during the development of the beaks in the cephalopod ontogeny.

Nonetheless, the morphological characteristics of the beak structures and their relationship to body size are still poorly documented for cephalopods in Thai waters. Also, current descriptions of beak morphology are inadequate for identifying all species. Therefore, further studies should be undertaken on these important structures for each of the species of squid, cuttlefish and octopus in order to create a biological database for these cephalopods.

CONCLUSION

Observations of the beaks of marbled octopuses in this study indicated that the rostral tips of the upper and lower beaks are slightly curved, short, with a narrow hood, and brown to black in color. These morphological characteristics differ from those of other genera found in Thai waters, such as *Uroteuthis* (*Photololigo*) and *Sepia*.

Some morphological characteristics of the beak can be used to estimate mantle length (ML) and total length (TL) of the marbled octopus. For instance, mantle length may be determined using the upper crest length (UCL) or lower rostral width (LRW) by the equation ML = 0.699+0.691 UCL (R^2 = 0.711) or ML = 1.054+1.040LRW (R^2 = 0.670), respectively. Likewise, total length may be determined using upper crest length (UCL) following the equation TL = 3.574+2.539UCL (R^2 = 0.73); and by lower crest length (LCL) using the equation TL = 3.906+3.236LCL (R^2 = 0.689).

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