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Abundance and distribution pattern of two common Loliginid squids, *Uroteuthis (Photololigo) chinensis* (Gray 1849) and *Uroteuthis (Photololigo) duvaucelii* (d'Orbigny 1835), in the Gulf of Thailand

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Abstract

This study was carried out to assess the distribution pattern of two loliginid squid species; *Uroteuthis (Photololigo) chinensis* (Gray 1849) and *Uroteuthis (Photololigo) duvaucelii* (d'Orbigny 1835) at different depth contours along the lower part of the Gulf of Thailand sampled by bottom trawl during April to July 2015. Hydrological parameters including temperature, salinity, pH, dissolved oxygen, conductivity and transparency were simultaneously measured. The average abundance, weight and density for *U. (P.) chinensis* were 32.7±37.9 individuals.hr^{-1}, 2.1±1.7 kg.hr-^{1} and 1,268.8±1,370.3 individuals.nm^{-2} and for *U. (P.) duvaucelii* were 13.6±17.3 individuals.hr^{-1}, 0.3±0.3 kg.hr^{-1} and 554.5±755.0 individuals.nm^{-2}, respectively. It was found that depth affected both weight and density of both species combined (ANOVA, $p < 0.05$) and *U. (P.) chinensis* (ANOVA, $p < 0.05$) but not for *U. (P.) duvaucelii*. This study addresses the lack of scientific information on the species, serves to provide fundamental scientific data for their proper management and provides a reliable reference for the advancement of science.

Keywords: cephalopods, trawl fisheries, squid ecology, environmental factors, Gulf of Thailand

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Introduction

The world fish stocks, in both marine and freshwater, are declining while cephalopod catches increase continuously (Hilborn et al. 2003). Although the production from squid fisheries contributes less to world landings compared to global fish production, the proportion of squid in total landings has increased steadily over the last decade. Total world squid capture was 2.98 million tonnes which was about 82 % of the total cephalopod production in 2010 (Arkhipkin et al. 2015). Of this, 48 % was Ommastrephids, 30 % was Loliginids, 2 % Gonatids and 20 % unidentified squids.

The Gulf of Thailand is a shallow basin of the southern part of the South China Sea with average and maximum depths of 45 m and 80 m, respectively. Salinity and temperature ranged from 31.2–33.7 psu and 27.8–30.8 ^{0}C, respectively (Chotiyaputra et al. 2002). The rapid development of marine fisheries in Thailand in the past two decades has led to its current ranking among the top ten fishing nations in the world. Marine fishery production in 2007 was 1.5 million tonnes accounting for 53 % of the total fishery production from all fishery sectors. Of this, 70 % was from the Gulf of Thailand and 30 % from the Andaman Sea (Supongpan and Boonchuwong 2010). Approximately 6–8 % of the production was cephalopods including squids which were mainly caught by otter trawl (Chotiyaputra et al. 2002). The catches of squid from Thailand contribute about 3 % of the global squid capture (FAO 2010). *Uroteuthis (P.) chinensis* (Gray 1849) and *Uroteuthis (P.) duvaucelii* (d'Orbigny 1835) are the two major commercial squid species in the Gulf of Thailand (Sukramongkol et al. 2007). They are generally found together in the same geographical area, thus presumably regularly encountering one another (Chotiyaputta 1993; Futuyma and Agrawal 2009). *U. (P.) chinensis* is a neretic species and can be found within the 15–170m depth range. It is widely distributed in the South China Sea, the East China Sea, the Arafura Sea and the Timor Sea to northern Australia (Roper et al. 1984; Chotiyaputta 1993; Carpenter and Niem 1998). It is the most abundant loliginid squid in the area (Sithigornkul 1974; Chotiyaputta 1993; Chantawong and Suksawat 1997). *U. (P.) duvaucelii* is found in the 30–170 m depth range along the South China Sea, the Indian Ocean, the Red Sea and the Philippines Sea, and northward to Taiwan (Carpenter and Niem 1998; Sabrah et al. 2015).

Environmental variables may cause differences in species composition and distribution of squids (Coelho and O'Dor 1993; Jackson and Moltschaniwskyj 2001; Rodhouse 2013). Yeatman and Benzie (1994) reported that higher distribution of *Photololigo* spp. was found in deeper Australian waters. Some studies reported that many species of squid spent most of the day time in deeper waters (Hatfield et al. 1990; Arkhipkin et al. 2003; Gilly et el. 2006). Temperature, dissolved oxygen and pH strongly influence population, distribution and biological process of squids (Kao et al. 1983; Pecl and Jackson 2008; Rodhouse 2010). However, details of scientific information on hydrological parameters and the effect of depth on distribution of squids in the Gulf of Thailand remains unknown, despite the fact that this area is one of the most important squid fishing grounds in the world.

This study is, therefore, aimed at investigating the hydrological conditions at different depths and impacts of depths on the distribution and abundance of the two common squids *U. (P.) chinensis* and *U. (P.) duvaucelii* along the lower part of the Gulf of Thailand in order to serve as basic scientific information for both local utilisation and global knowledge.

Materials and Methods

Study area

The study area is located between latitudes 6° 41' 42” and 9° 18' 10.8” N and longitudes 100° 2' 13.2” and 102° 3' 7.2” E in the southern part of the Gulf of Thailand (Fig. 1). In all, 22 sampling stations were set up based on four depth contours (10–20 m; 20–30 m; 30–40 m; and 40–50 m).

Sampling method

The research vessel “MV PRAMONG 9’’ from the Southern Marine Fisheries Development Centre (SMFDC) was used to undertake a bottom trawl sampling. The vessel was 25 m long and well equipped with all navigational and oceanographic equipment. A bottom trawler was attached with a trawl net; 39 m headline, 40 mm mesh size at the body of the trawl net and 25 mm at the cod end. Three replicated bottom trawl cruises were conducted at each station by MV PRAMONG 9 during 22–30 April, 26 May–4 June and 19–29 July in 2015 (Table 1). The trawl sampling was carried out during the day, with a speed of 2.5 knots. The duration of each trawl haul was 60 minutes. The two target squid species were sorted out from whole catches, identified, counted and weighed. Prior to trawling, bottom hydrological parameters including temperature, salinity, pH, dissolved oxygen, conductivity and transparency were recorded simultaneously by an oceanography instrument CTD (Sea Bird Model SBE19 Plus).

Data analysis

The squid catch was used to estimate catch per unit of area (CPUA) based on Sparre et al. (1989) by the following formula:

$$\text{CPUA} = \text{Cw}.a^{-1}$$

Where, Cw is the catch of squid; a is the swept area (nm^2) which can be calculated by:

$$a = d \times h \times X_1$$

Where, d is the towing distance calculated as nautical miles (Veness 2012); h is the headline of the net (nm); and X_1 is the wing spread coefficient of 0.5 (Pauly 1980).

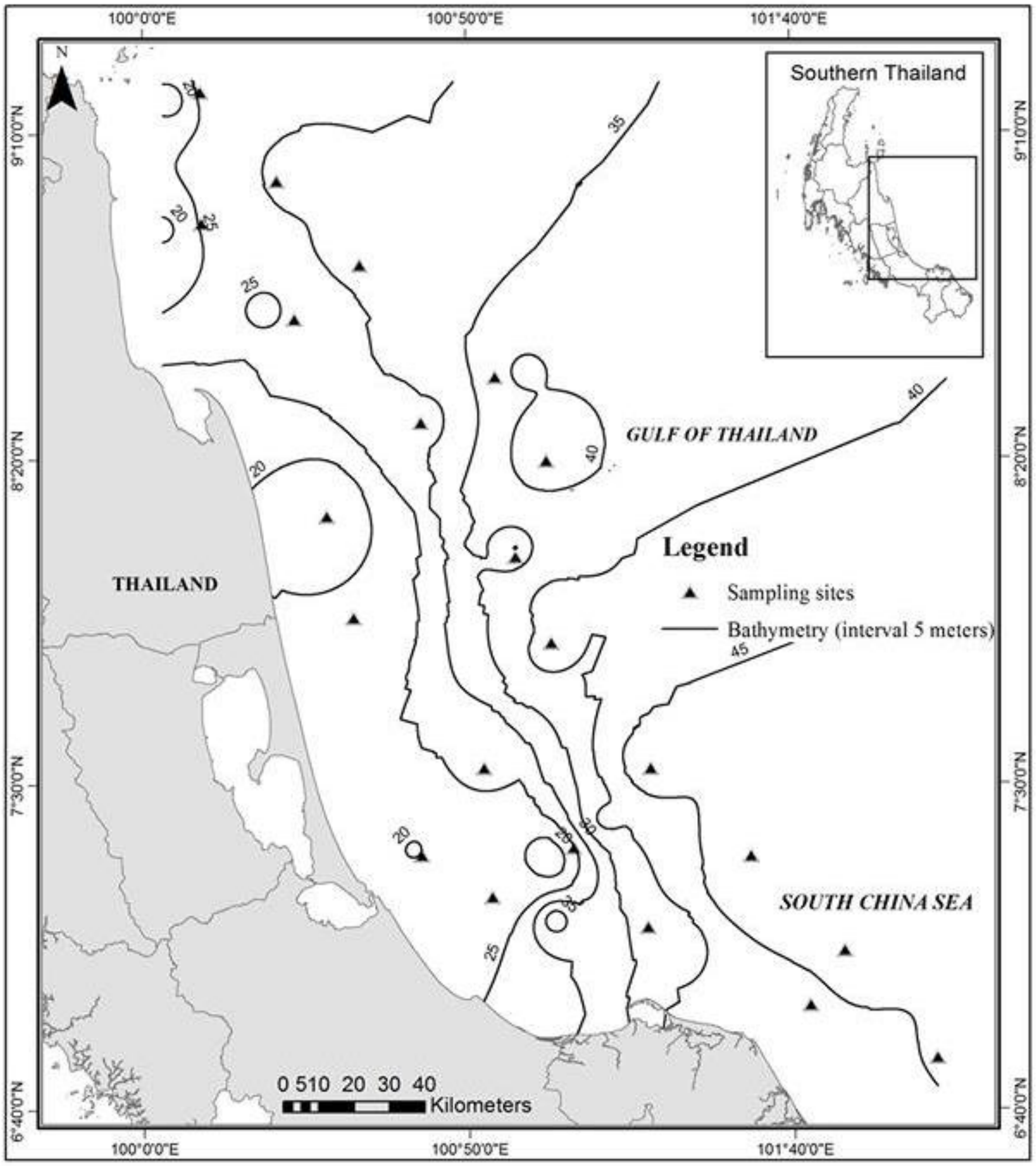

Fig. 1. Map of the study area with depth contours along the southern part of the Gulf of Thailand

Statistical analysis

To assess the variation of water temperature, salinity, pH, dissolved oxygen, conductivity and transparency based on depth of the study area, one-way analysis of variance (ANOVA) was used. Relative occurrence (% O), weight (% W) and total number (% N) of *U. (P.) chinensis* and *U. (P.) duvaucelii* were calculated. Abundance (ind.hr^{-1}), weight (kg.hr^{-1}), density (ind.nm^{-2}) and catch per unit area (CPUA) (kg.nm^{-2}) of *U. (P.) chinensis, U. (P.) duvaucelii* and overall squid catch were calculated. ANOVA was used to test the impact of depth on density and weight of *U. (P.) chinensis* and *U. (P.) duvaucelii***.** The raw data was transformed by Log (X+1) prior to analysis to reduce non-normality**.**

Table 1. Details of cruise operation by bottom trawler at 22 sampling sites along the southern part of the Gulf of Thailand

Station	Date			Time		
	1st Cruise	2nd Cruise	3rd Cruise	1st Cruise	2nd Cruise	3rd Cruise
1	4/29/2015	6/3/2015	7/28/2015	16:18	16:38	06:37
2	4/29/2015	6/3/2015	7/27/2015	13:18	13:51	15:59
3	4/30/2015	6/3/2015	7/28/2015	06:22	11:23	10:00
4	4/29/2015	6/2/2015	7/27/2015	10:05	17:41	13:05
5	4/30/2015	6/3/2015	7/27/2015	09:53	08:19	10:46
6	4/28/2015	6/2/2015	7/26/2015	15:11	10:56	15:00
7	4/29/2015	6/2/2015	7/27/2015	06:23	13:36	06:39
8	4/28/2015	6/2/2015	7/26/2015	12:17	07:41	11:45
9	4/30/2015	6/4/2015	7/28/2015	13:47	09:01	16:47
10	4/28/2015	6/1/2015	7/26/2015	09:31	17:20	09:09
11	4/30/2015	6/4/2015	7/29/2015	16:34	11:55	07:23
12	4/28/2015	6/1/2015	7/26/2015	06:23	14:22	06:34
13	4/27/2015	5/28/2015	7/22/2015	14:29	12:38	09:14
14	4/23/2015	5/27/2015	7/25/2015	07:13	14:01	14:42
15	4/27/2015	5/28/2015	7/22/2015	11:26	15:49	12:09
16	4/22/2015	5/28/2015	7/20/2015	16:08	06:49	07:40
17	4/23/2015	5/26/2015	7/20/2015	10:54	10:00	14:25
18	4/22/2015	5/28/2015	7/19/2015	12:31	09:20	15:00
19	4/25/2015	5/26/2015	7/20/2015	06:35	06:44	10:54
20	4/23/2015	5/26/2015	7/21/2015	14:51	13:24	13:49
21	4/24/2015	5/26/2015	7/21/2015	06:29	16:05	06:43
22	4/24/2015	5/27/2015	7/21/2015	12:34	06:15	10:10

Results

Water parameters

Results from ANOVA indicated water temperature, dissolved oxygen, conductivity and transparency significantly varied within different depth contours ($p < 0.001$). However, salinity and pH remained unchanged along different depths ($p > 0.05$). Details of bottom water parameters measured during this study are in Table 2.

Table 2. Bottom water parameters (mean ± SD) at different depth contours along the coastal water off the southern part of the Gulf of Thailand.

Water parameters	Depth contours				Average	
	(10–20 m)	(20–30 m)	(30–40 m)	(40–50 m)		*P*-value
Temperature (^oC)	30.0±0.7	30.1±0.8	29.1±0.6	28.9±0.8	29.5±0.9	**<0.001**
Salinity (psu)	32.3±1.1	31.9±1.0	31.5±1.8	31.8±1.7	31.8±1.5	0.687
pH	9.0±0.2	9.0±0.2	9.0±0.2	8.9±0.2	8.9±0.2	0.650
Dissolved oxygen (ppm)	6.3±0.1	6.3±0.1	6.4±0.1	6.4±0.1	6.4±0.1	**<0.001**
Conductivity (Sm^{-1})	54.9±0.5	54.6±0.6	54.1±0.4	53.8±0.5	54.3±0.6	**<0.001**
Transparency (m)	8.6±3.2	11.1±4.0	13.7±3.3	16.4±2.9	13.0±4.4	**<0.001**

The catch

A total of 2,156 squids, yielding 135.6 kg of *U.(P.) chinensis* and 899 squids, yielding 20.1 kg of *U. (P.) duvaucelii* were collected from this study. Both total number and weight of *U. (P.) chinensis* were much higher than those of *duvaucelii*. Details of % O, % W and % N for both species are in Table 3.

Table 3. Relative occurrence, weight and total number of *U. (P.) chinensis* and *U. (P.) duvaucelii* collected in the lower part of the Gulf of Thailand. (% O = % occurrence, % W = % by weight (kg), % N = % by number)

Species	Occurrence	% O	Weight (kg)	% W	Number	% N
U. (P.) chinensis	66	100.0	135.6	87.1	2,156	71.6
U. (P.) duvaucelii	59	89.4	20.1	12.9	899	29.4

The average abundance, weight and density of *U. (P.) chinensis* were 32.7±37.9 $ind.hr^{-1}$, 2.1±1.7 $kg.hr^{-1}$ and 1,268.8±1,370.3 $ind.nm^{-2}$, respectively. For *U. (P.) duvaucelii*, the average abundance, weight and density were 13.6±17.3 $ind.hr^{-1}$, 0.3±0.3 $kg.hr^{-1}$ and 554.5±755.0 $ind.nm^{-2}$. Details of the catches for both species and overall catch at each depth contour are shown in Table 4.

Effect of depth

Overall catch including density and weight of both species combined and *U. (P.) chinensis* varied significantly between depth contours ($p < 0.05$) (Table 5). However, there was no difference between density and weight of *U. (P.) duvaucelii* collected from different depths.

Table 4. Abundance (ind.hr^{-1}), weight (kg.hr^{-1}), density (ind.nm^{-2}) and CPUA (kg.nm^{-2}) (mean±SD) of *U. (P.) chinensis* and *U. (P.) duvaucelii* and overall catch collected at each depth contour along the southern part of the Gulf of Thailand during April to July 2015.

Species	Depth stratum	Abundance (ind.hr^{-1}) ±SD	Wt.±SD (kg.hr^{-1})	Density ±SD (ind.nm^{-2})	CPUA ±SD (kg.nm^{-2})
U. (P.) chinensis	10–20 m	21.6±24.1	1.3±1.1	878.2±963.6	51.3±44.1
	21–30 m	23.2±20.2	1.7±1.1	935.1±771.0	68.4±42.2
	31–40 m	31.3±31.1	2.0±1.2	1,204.8±1,178.5	78.4±52.1
	41–50 m	47.2±53.5	2.8±2.2	1,792.9±1,878.6	106.9±81.1
	All	32.7±37.9	2.1±1.7	1,268.8±1,370.3	80.5±62.3
U (P.) duvaucelii	10–20 m	16.6±28.2	0.4±0.6	709.1±1259.8	16.2±25.7
	21–30 m	8.1±8.6	0.2±0.3	335.5±366.0	8.6±11.8
	31–40 m	12.3±7.5	0.3±0.2	466.0±267.1	11.6±7.9
	41–50 m	17.8±19.9	0.4±0.3	722.8±871.7	14.0±13.3
	All	13.6±17.3	0.3±0.3	554.5±755.0	12.3±14.7
Overall	10–20 m	38.2±43.6	1.6±1.5	1,587.3±1,923.9	67.5±61.9
	21–30 m	31.3±22.2	1.9±1.2	1,270.7±857.4	77.0±43.7
	31–40 m	43.6±30.0	2.3±1.3	1,670.8±1,140.0	90.0±56.4
	41–50 m	65.0±56.7	3.1±2.3	2,515.6±2,093.5	121.0±85.2
	All	46.3±43.0	2.4±1.8	1,823.3±1,647.7	92.8±67.5

Table 5. Results of one-way ANOVA and Tukey's test on density (ind.nm^{-2}) and weight (kg.hr^{-1}) of *U. (P.) chinensis* and *U. (P.) duvaucelii* at different depth contours from the southern part of the Gulf of Thailand (10–20 m, 20–30 m, 30–40 m and 40–50 m)

Density/Weight	Species	df	MS	*p*-value
Density	*U. (P.) chinensis*	3	0.12	**0.028**
	U. (P.) duvaucelii	3	0.23	0.308
	All	3	0.14	**0.024**
Weight	*U. (P.) chinensis*	3	0.04	**0.047**
	U. (P.) duvaucelii	3	0.01	0.419
	All	3	0.04	**0.049**

Discussion

Vertical movement due to diurnal and nocturnal behaviour of squids from the bottom during the day to the water surface for feeding during the night has been well documented (Young 1978). Squids spend most of the day time at greater depth to avoid predation (Gilly et al. 2006), thus collecting squid samples during the day by bottom trawler is able to feature the real condition of squids in this habitat. *Dosidicus gigas* is another example of a squid with preference to remain at the bottom during the day time hours and may swim up to the surface at night (Rosa and Seibel 2010). However, horizontal distribution at the sea bottom of many squid species remains understudied. It was found from this study that *U. (P.) chinensis* was by far more predominant at the bottom area in the lower part of the Gulf of Thailand during the day compared to *U. (P.) duvaucelii*. Both species were distributed throughout all the sampling areas, but the trend of abundance between species was different. It was also observed from this study that depth played an important role in the distribution structure of these two loliginid species. The catch of *U. (P.) chinensis* increased with increasing depth with the highest catch found at 40–50 m, indicating that this species prefers deeper rather than shallower areas.

For *U. (P.) duvaucelii,* no such trend was recorded in this study indicating that it is equally spread throughout the Gulf of Thailand. This coincides with the inshore study of Carpenter and Niem (1998) and Jereb and Roper (2010) which showed that *U. (P.) duvaucelii* is normally found within 30–170 m depth and spawns throughout the year. Depth was earlier reported to have an effect on abundance and distribution of some squids. *Loligo forbesi* was more abundant in the shallow areas of Scottish waters compared to deeper areas (Pierce et al. 1998). The long-fin squid (*Loligo gahi)* had a pattern of distribution according to depth based on some biological phenomena (Arkhipkin et al. 2003). Yeatman and Benzie (1994) found a positive correlation between depth and the distribution pattern of *Photololigo* spp. in Australian waters. *Loligo chinensis* is the most common squid species throughout the water column in the coastal waters off Kuala Terengganu, Malaysia (Ashirin and Ibrahim 1992). There are many reasons for squids to remain in some depth areas. For example, Hatfield et al. (1990) indicated that the largest species composition of *Loligo gahi* occurred at greater depths during maturation while adults would migrate to shallow waters to spawn.

Moreover, it is known that the population size, distribution pattern and life history of squids were regulated by environmental conditions (Coelho and O’Dor 1993; Forsythe 1993; Hatfield 2000; Jackson and Moltschaniwskyj 2001). For instance, the distribution of a short-finned squid (*Illex illecebrosus*) was reported to be closely related to changes in the oceanographic environment (Trites 1983; Dawe and Warren 1993; Dawe et al. 2000). Temperature and salinity have a great impact on distribution of squids especially in the higher latitude areas. Chen and Chiu (1999) revealed that a high abundance of *Ommastrephes bartramii* in the Eastern North Pacific was significantly related to temperature and salinity. Brodziak and Hendrickson (1999) observed that *Illex illecebrosus* preferred lower temperatures than *Loligo pealeii* in the northwest Atlantic.

The distribution and abundance of *Loligo forbesi* in the North Sea were also strongly related to the bottom temperature and were poorly influenced by salinity (Pierce et al. 1998). Another study by Agnew et al. (2002) found that recruitment of *Loligo gahi* stock was strongly related to temperature. The latest study by Yu et al. (2016) reported that the habitat of *Dosidicus gigas* could be affected by climate variability due to temperature.

Apart from temperature and salinity, there are some studies reporting the effect of dissolved oxygen on squids. Howell and Simpson (1994) found that the abundance pattern of squids was mostly sensitive to inadequate level of dissolved oxygen due to the fact that squids require more oxygen for their faster metabolism process because of their short lifespans and more rapid growth. This was confirmed by Pecl and Jackson (2008) who found that dissolved oxygen significantly affected abundance and catch rates of loliginids squids. Unfortunately, this study focused only on the impacts of depth and did not take into account the relationship between water parameters and distribution pattern of squids in the study area. Further study is therefore greatly required.

Conclusion

It can be concluded that there are two dominant loliginid species inhabiting the bottom areas of the lower part of the Gulf of Thailand during the day with higher domination of *U. (P.) chinensis* compared to *U. (P.) duvaucelii*. Depth is an important factor structuring the distribution of these two species. *U. (P.) chinensis* prefers to inhabit the deeper areas, whereas *U. (P.) duvaucelii* is spread throughout the whole area of the Gulf of Thailand. This information is essential to serve as fundamental scientific data for proper management of these squids in the Gulf of Thailand and as a reference for the advancement of the study on squid fishery.

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