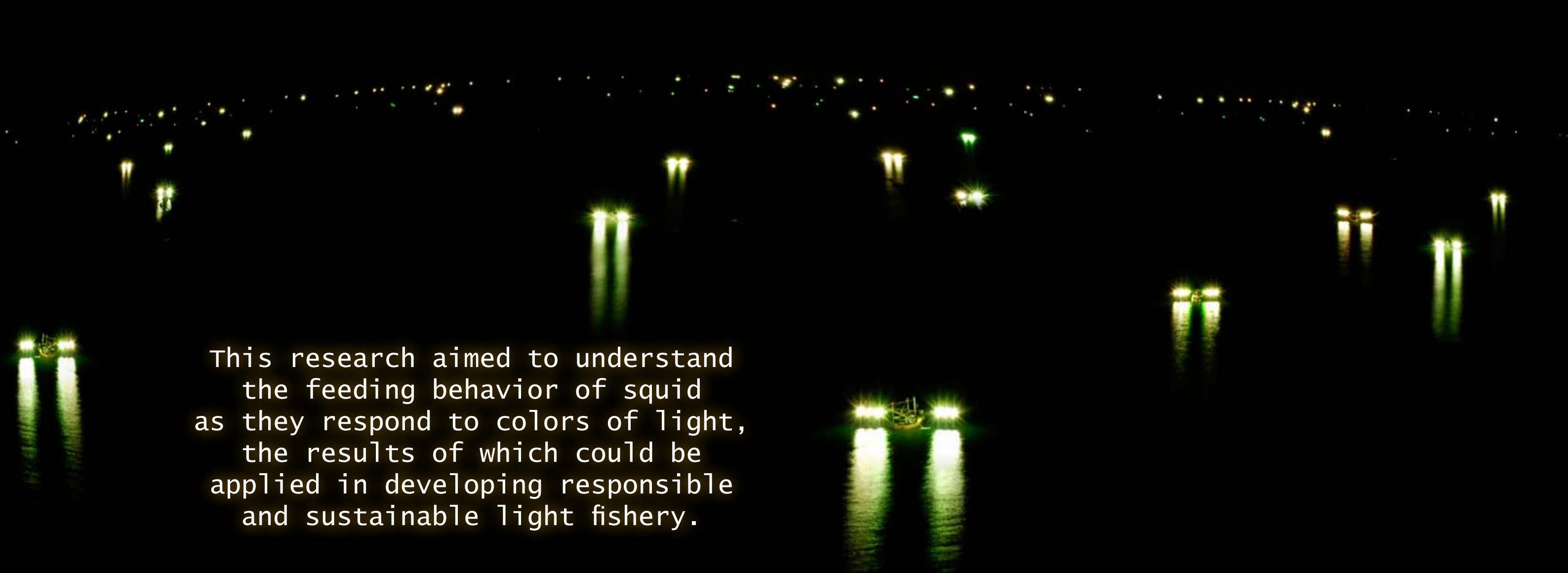

This research aimed to understand the feeding behavior of squid as they respond to colors of light, the results of which could be applied in developing responsible and sustainable light fishery.

Boosting the development of responsible squid light fishery: Assessment of squid feeding behavior

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The experiment using colors of light to monitor the feeding behavior of squid was conducted at the Eastern Marine Fisheries Research and Development Center in Ban Phea, Muang District, Rayong Province, Thailand. A dark room was constructed to accommodate a concrete tank (5 m in diameter). Five (5) channels of black plastic strips (40x125x70 cm each) were set at the inner part of the concrete tank. Five (5) black plastic pipes (6 cm in diameter and 86.5 cm in length) were hung above the first four (4) channels while the last channel served as the control (dark). A lamp was attached at the tip end of each pipe about 135 cm above the water surface (water level: 27 cm). Four color lights (white, blue, green and red) were generated by LED lamps (0.5 cm in diameter with a power supply of 12v 5mA). Each channel had a small aquarium (15x15x30 cm) with live fish baits to stimulate the squid to pass and enter the channel. A total of 44 squids were used in the experiment which was conducted at night time. The positions of the color light source were rotated for 10 batches with 8 replicates each. For each replicate, the number of squid entering each channel was counted. The results showed that the number of squids entering the 5 channels were significantly different ($P \leq 0.05$). The sequence of color lights preferred was: white, blue, green, red and control, respectively. White and blue were not different ($P \geq 0.05$), but white color was significantly more attractive than the green, red and the control ($P \leq 0.05$). Blue was significantly more attractive than the green, red and control ($P \leq 0.05$) and green was significantly more attractive than the red and control ($P \leq 0.05$). Red and the control were not different ($P \geq 0.05$).

Squid's Attraction to Different Colored Lights

Squids (*Loligo dauvauceli* and *L. chainensis*) are among the most economical marine resources and play significant role in Thailand's fish trade. The demand for squid is increasing for domestic consumption as well as for export. The rapid development of squid fisheries in Thailand occurred since trawl fishery was introduced. Presently, with more widespread use of luring lamps for attracting squid, falling nets and lift nets have increasingly been employed without any due consideration to the theatrical aspects of attraction. In 1995, there were 1894 squid falling net vessels in Thailand and this number increased to 3160 vessels in 2004 (http://www.fisheries.go.th/it%2Dstat/).

Unfortunately, even if these gears are able to increase squid production, such gears can damage the marine resources by capturing also the under-marketable sizes of aquatic animals.

Attracting to a light source is a common reaction among aquatic species, a behavior which is true not only in squids but also in other species such as the spotted mackerel (*Pneumatophorus tapeinocephalus*), sardines (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonica*), Japanese parrotfish (*Opleganathus fasciatus*), bluegill (*Lepomis macrochirus*) (Kawamura, 1986), grey mullet (*Mugil cephalus*), gilthead seabream (*Sparus auratus*), striped bream (*Lithognathus mormyrus*) (Marchesan et al. 2005), and Japanese anchovy and sardines (Awaiwanont et al., 2001).

Many studies have been conducted to determine the physiological and cellular levels of such behavior, including some works on assessing the role of visual sense to spectral sensitivity particularly the micro-electrode technique, spectral adsorption and behavior response. Results from such studies indicated that even though most marine aquatic animals can perceive light spectrum in the range of 400 to 750 nm, different species have different considerable scales of spectral sensitivities. For instance, the maximum spectrum sensitivity of the north anchovy (*Engraulis mordax*) is 530 nm (Bagarinao and Hunter, 1983), 482 nm for the sand lance (*Ammodytes hexapterus*) (Britt et al., 2001), 460-525 nm for the European sea bass (*Dicentrarchus labrax*) and 410-460 nm for grey mullet (*Mugil cephalus*) (Marchesan et al., 2004). However, if the preferred color (light spectrum) for squid could be determined, the results would provide useful information for improving the fishing technique for squid not only increasing catch efficiency but also reducing the problem of by-catch mortality. Therefore, this study was conducted to investigate the effect of variable light color design in the feeding behavior of the squid and also to obtain useful information for developing selective light fishing techniques for responsible and sustainable light fishery.

Observation of Squid Behavior

Squid specimens were collected by set net fishery in the morning of January 2007 at Had Maelampioen, Rayong Province, and were transferred to a 5 m diameter concrete test tank at the Eastern Marine Fisheries Research and Development Center (EMDEC), Banpae, Muang District, Rayong Province.

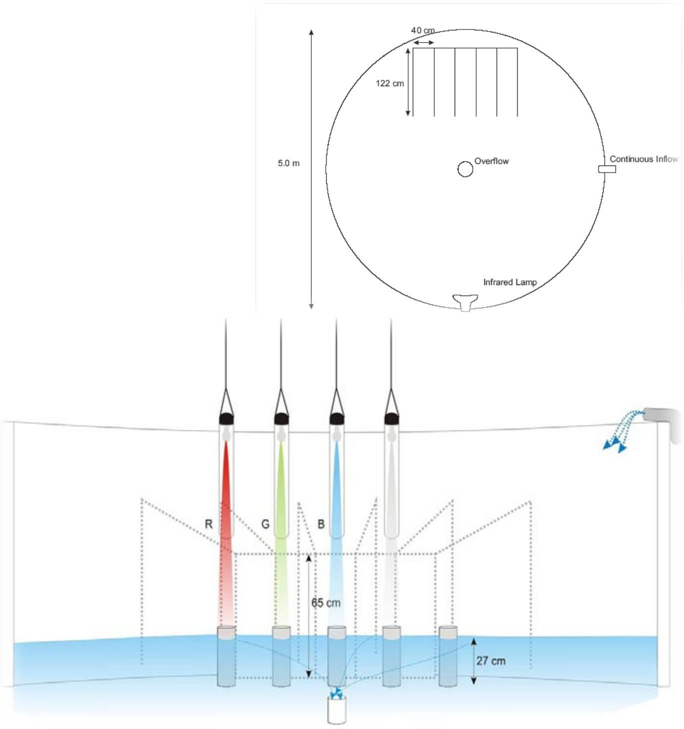

Fig. 1. Experimental setup: top view (top) and side view (above)

The experiment was performed at night time with 44 squids (32 individuals of *Loligo dauvauceli* with 9.75±2.29 cm mantle length and 34.55±21.41 g weight and 12 individuals of *L. chainensis* with 8.50±2.70 cm mantle length and 29.53±19.21 g weight). The depth of the water was 27 cm with continuous overflow to keep the squid alive. The tank was covered with black canvas serving as a temporary dark room to avoid the effects from the moonlight. Inside the tank, five (5) channels of black plastic fence (40x122x65 cm each channel) were constructed (Fig. 1). The sources of lights were the infrared lamp and Light-Emitting Diode (LED) lamps where the infrared lamp was mounted inside the room at the rim of the concrete tank opposite the entrance of the channels. In order to determine the spectral sensitivity, four (4) colors of the LED lamps (red, green, blue and white) were used as luring lamp, which were separately hung above each channel while the remaining channel served as the control (dark). The LED lamps were mounted about 135 cm above the water surface. Light beams were separated from each other by means of black plastic pipes (6.0 cm in diameter and 86.5 cm in length). Each LED lamp was 0.5 cm in diameter with 12v 5mA power supply. Small aquaria (15x15x30 cm each) with live fish baits inside were placed under the lighted areas to stimulate the squids to pass and enter the channels.

At the start of the experiment, the four (4) luring lights and infrared lamp were turned on for about 30 minutes for acclimatization. The infrared lamp was then turned off for 1 minute then turned on again to count the number of squids entering each channel. The turning on and off of the infrared lamp was conducted for 8 replicates per batch before the light position is rotated. The rotation of the light position was done for 10 batches to eliminate possible effects of both the light position and the channel (**Table 1**). The number of squids occupying the five (5) channels was compared by ANOVA ($P \leq 0.05$). The statistical differences were analyzed using the LSD test (Pongwichai, 1997).

Squid Behavior in the Tank

The squids were acclimatized for at least 12 hours in the test tank before the experiment, and no feeding was done to stimulate feeding behavior. The experiment started at 2100 h with both infrared and LED lamps turned on. The test squids showed an interesting behavior where they aggregated opposite the entrance of the five (5) channels and remained motionless but staring at the baits. Some squids swam slowly either clockwise or counter-clockwise with their mantle along the tank wall. While moving towards the entrance of the channels, their movement was rather slow but looking towards the baits. The squids appeared to be afraid to go inside the channels, leaving the channel entrance and swimming around the tank again. There were moments

Table 1. Rotation of light positions and number of replicates per batch

Number of batch	Channel of light position					Total replicates
	1	2	3	4	5	
1	Red	Green	Blue	White	Control	8
2	Green	Blue	White	Control	Red	8
3	Blue	White	Control	Red	Green	8
4	White	Control	Red	Green	Blue	8
5	Control	Red	Green	Blue	White	8
6	White	Red	Control	Blue	Green	8
7	Red	Control	Blue	Green	White	8
8	Control	Blue	Green	White	Red	8
9	Blue	Green	White	Red	Control	8
10	Green	White	Red	Control	Blue	8

when the squids showed jet-like propulsion behavior swimming near the black plastic fences. When the infrared lamp was turned off while the LED lamps were still on, most squids were swimming fast to the entrance of the channels without hesitation and swimming towards the lighted areas and the baits. The squid tried to catch the baits for a while before swimming out of the channels to the dimmed areas and swimming again back for the baits. When the infrared lamp was turned on, the squids inside the channels instantly moved out from the channels showing the same behavior as before the infrared lamp was turned off.

Color Attraction by the Squid

The results of the study indicated the sequence of the preferred colors by the squid, i.e. white, blue, green, red, and control, at 327, 285, 151, 18, and 9 individuals, respectively. The means of squids occupying per batch of the white, blue, green, red colors and the control were 1.80, 15.10, 28.50, 32.70 and 0.90 individuals, respectively (**Table 2**).

Table 2 shows that the number of squids entering the five (5) channels was significantly different ($P \leq 0.05$). The number in the white and blue colors was not different ($P \geq 0.05$). The number in the white color was significantly different from those in the green, red colors and control ($P \leq 0.05$). The number in the blue color was significantly different from those in the green, red colors and control ($P \leq 0.05$). The number in the green color was significantly different from those in the red color and the control ($P \leq 0.05$) while those in the red color and the control were not different ($P \geq 0.05$).

There are about 700 species of cephalopods living between the tides, in the deep ocean, and in the surface waters throughout the seas of the world (Hanlon and Messenger, 1996). Cephalopods are invertebrates which can be classified under Mollusca but many features of their behavior are more in common with fishes than with other invertebrates (Hanlon and Messenger, 1996). They have highly developed sense organs and complex behavior (Abbott et al., 1995; Hanlon and Messenger, 1996). However, most cephalopods have only one visual pigment and are completely color blind (Hanlon and Messenger, 1996; Shashar and Cronin, 1996). Only the mid-water firefly squid (*Watasenia scintillans*) can see colors because they have three visual pigments (Seidou et al., 1990). The color blind squids can see only the differences in polarized lights but can also create patterns using these differences on their bodies (Shashar and Cronin, 1996; Shashar et al., 1996).

Conclusion

This experiment evaluated the behavioral attraction to colored lights preferred by *L. dauvauceli* and *L. chainensis* which have no reported record of being color blind. The two species were considered because these are the target

Table 2 Batch and number of squids occupying each channel of light colors

Light color	Number of squid per batch										Total	Avg.
	1	2	3	4	5	6	7	8	9	10		
Red	1	1	1	3	2	3	5	0	1	1	18	1.80
Green	3	17	18	28	17	13	12	11	23	9	151	15.10
Blue	10	33	25	33	47	31	33	27	28	18	285	28.50
White	13	10	28	50	41	26	35	55	28	41	327	32.70
Control	0	2	1	3	1	0	0	0	1	1	9	0.90

Table 3. Diffuse attenuation of light wavelengths

Wavelength (nm)	Diffuse attenuation
400	0.017
450	0.015
500	0.026
550	0.064
600	0.244
650	0.349
700	0.650

species for the development of squid capture technique using colored lights. From the results of this experiment, the different number of squids entering the five (5) channels indicated their reactions to different colors. The squid were observed to be swimming forward to both white and blue more often than the green, red and control while the red color and the control seemed not to attract the squids. Thus, it could be concluded that the squid was strongly attracted to blue and white colors but could not perceive the red color.

Light attraction behavior importantly depends on the physical characteristic of lights, especially their wavelengths (Marchesan et al., 2004). Based on the characteristics of the LED lamp produced by Toyoda, the maximum wavelengths emitted by LED red, green, blue and white are 620-625 nm, 520-530 nm, 465-475 nm and 465-475 nm, respectively (http://www.toyoda-gosei.com/led/). This showed that blue and white emitted the necessary color spectrum although light attraction was reduced in green and red, respectively. Thus, squids could be attracted to the blue light. In nature, blue light can penetrate and transmit blue color into the deeper seawater than the other lights (**Table 3**). A summary of diffuse attenuation in seawater between 400 to 700 nm showed that the blue light (wavelength: 440-490 nm) penetrates deeper and farther than the other colors and the red light (wavelength: 630-670) can be extinguished even in not so deep waters by the scattering and absorption phenomena (Smith and Baker, 1981) in (Arimoto, et al., 2001). Jerlov (1968) explained that the maximum spectral distribution is shifted towards the longer wavelength in turbid areas because of selective absorption by particles and the yellow substance.

Knowledge on the preferred colors of light by squid and on the diffuse attenuation of color lights are fundamental tools for developing potential methods of selective fishing. This could enhance catch efficiency and reduce by-catch mortality especially when using appropriate luring lamps that emit monospectrum or monocolor. The color of the light that attracted the squid most in this experiment was blue. Squids can see their baits more clearly when illuminated with blue light than with the other colors.

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