# Observations of mesopelagic large squids in the wild using recently developed underwater visual equipment

Tsunemi Kubodera

National Museum of Nature and Science

E-mail : kubodera@kahaku.go.jp

## Introduction

The oceans occupy about 70 % of the surface of the globe and provide vast and diverse living space for marine organisms, not only horizontally from tropical to boreal regions, but also vertically from the surface to the abyss. In the mesopelagic waters of the world oceans there should exist a huge biomass of large squids, an expectation deduced beyond doubt by the large sperm-whale population and their squid-eating feeding habits. However, there has been no evidence from capture of these presumed mesopelagic large squids in shoals by previous research gear, nor have they been observed by deep-sea submersibles at the forefront of science and technology. So far, the only knowledge on mesopelagic large squids has been based on examination of stomach contents of sperm whales (Okutani and Satake, 1978; Clarke, 1980; among others).

**Fig. 1.** Sperm whale, off Ogasawara Islands
(Photo by Ogasawara Whale Watching Association)

Sperm whales are the largest toothed whale and grow to nearly 16 m and 11 m body length in mature males and females, respectively (Fig. 1). Females and their calves form a school and live in warm water. Mature males are solitary and migrate widely from warm waters to the cold Antarctic waters. Sperm whales have an extraordinary diving ability and make long and deep dives (40-60 min; >1000m). They feed mainly on mesopelagic large squids during their long and deep dives. Daily food consumption of sperm whales is estimated to be about 3-4 % of the body weight; hence females feed on about 500 kg and males on about 1,500 kg of prey in a day (Kato, 1995). Sperm whale populations in the Western North Pacific is estimated to be over 200,000 individuals (Ohsumi per. com.). Assuming one individual consumes 1000 kg food daily, nearly 200, 000 tons of squids are eaten by sperm whales in a day in this region. Thus, 73 million ton of huge squids are consumed by sperm whales annually. By comparison, squid fisheries of the world have landed around 3 million ton annually (FAO Fisheries Statistic, 2000).

However, we have very limited knowledge on the basic biology and ecology of deep-sea large squids due to the difficulties in capturing them and observing them in the wild. We imagined that these large squids, with their remarkable swimming and sensory abilities, could and would easily escape from fishing gear and submersibles approaching them with such threatening water movements, noise and strong lights. Therefore, we proposed a research project using small underwater visual equipment which might give a minimum disturbance to the deep-sea environment and to the deep-sea large squids.

Since 2002, in cooperation with Dr. Mori of the Ogasawara Whale Watching Association, we have conducted research on the biology and potential biomass of large mesopelagic squids in their natural environment in the waters off the Ogasawara Islands, where female sperm whales and their calves school and stay every year between September and November. We used compact underwater digital cameras and video camera systems to capture live images of these large squids by suspending the equipment at the depths to which sperm whales frequently dive for feeding.

**I. Years 2002-2004: Underwater Digital Camera System**

The origin of the present project started when Dr. Naito and his team, of the National Institute of Polar Research, introduced to us their bio-logger (DSL-1000DV) which was developed by cooperation with Little Leonardo Co. in 1995. This logger is similar in appearance to a binocular telescope, consisting of two cylinders each measuring 60 mm in diameter and 250 mm in height, one cylinder containing a digital camera, depth sensor and data logger and the other containing a strobe light. The system was controlled by a timer and a depth-activated switch, and could capture JPEG images of around 135 KB with the shortest interval of 30 s and keep about 600 images during one operation. This system was originally developed for monitoring diving behaviors of southern elephant seals and Weddell seals in the Antarctic as well as recording what they saw during diving (Sato et al., 2002) (Figs. 2-3). Dr. Naito kindly permitted us to use of 2 or 3 of his loggers for our research.

**Fig. 2.** Weddell seal and remote camera system on the back. (Photo by National Institute of Polar Research)

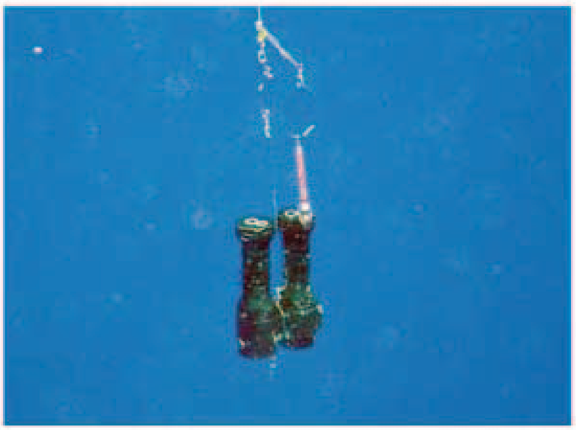

**Fig. 3.** Remote camera system with under-water pencil light. (Photo by K.Mori)

We also knew that fishermen in the Ogasawara Islands catch large neon flying squid and diamond-back squid as well as huge bill fish and blue fine tuna weighing over 100 kg from a 600-800m depth layer, using a free-drifting vertical long-line. We thought we might capture squid images by hanging a camera system at the end of a vertical long-line below which something attractive for deep-sea large squids was attached. For the lure, we designed bait rigs which were suspended from the system with a 3 m nylon monofilament line, weighed down by a 23 cm lead squid jig with a fresh Japanese common squid, *Todarodes pacificus* of 22-25 cm mantle length. Two 0.5 m side branches, each with a hook and a bait squid of 22-25cm mantle length, were attached to the first. The second branch also bore a mesh bag filled with freshly-mashed euphausid shrimps as an odor lure (Fig. 4).

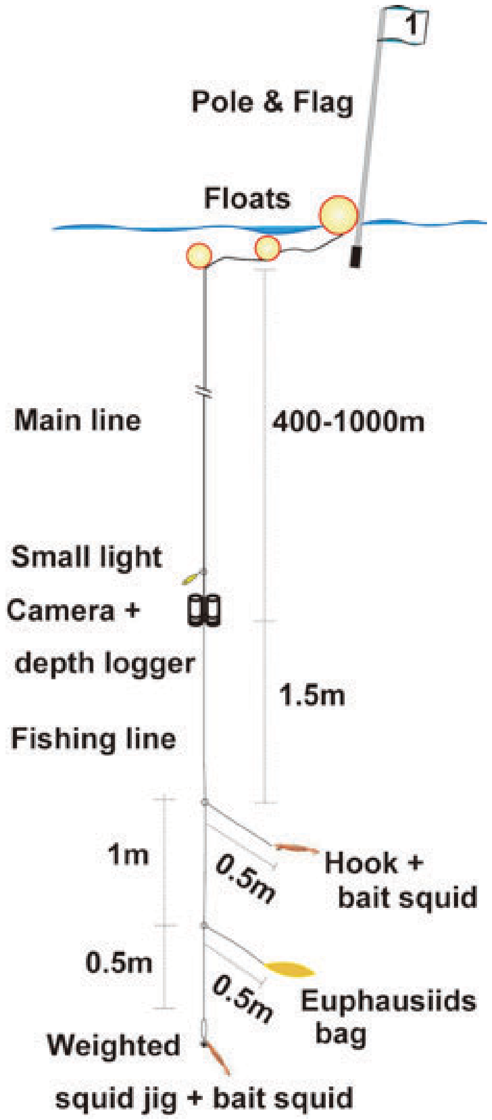

**Fig. 4.** Diagram of vertical long-line system used for survey.

Over three seasons (2002-2004) in September and October, we carried out 6-7 days research each year. We left Chichijima Port in the early morning for the target area, released 2-3 vertical research long lines at 400-1000 m depths and after 4-5 hours of free drift retrieved them and returned to port in the late afternoon. We improved the research gear little by little each year, adjusting the lengths of the main line and bait rigs, and conducted over 30 deployments, in 23 of which we obtained images.

Here are examples of our research images. Neon flying squids, *Ommastrephes bartrami,* were the squid most frequently observed in the depths between 400 m and 800 m and they were abundant at 600 m deep during the day-time (Kubodera, 2003). Judging from the bait squid size, neon flying squid observed were full-grown individuals about 45-50 cm mantle length. They swam forward spreading all arms to attack the bait and then hold the bait squid with all arms except the tentacles (Fig. 5). Pomfrets, *Taractichthys steindachner,* of 45-50 cm in body length, were often captured by the camera at the depths between 400 m and 600 m and were sometimes hooked up brought up on the boat when we retrieved the system (Fig. 6). When the vertical long-line drifted into shallower bottoms, deep-sea shark, *Squalus* sp. and small fishes living just on the bottom were captured on camera (Fig. 7). At 800 m deep, large fishes of over 1 m in body length, *Ruvettus pretiosus* (Fig. 8) and *Lepidocybium flavobrunneum,* were also captured. The system hanging at 1000 m depth provided almost nothing except one miraculous shot of a blue shark attacking a bait squid attached to the special jig. A full-frame camera image was obtained (Fig. 9). This is concrete evidence that blue sharks feed on prey at great depths during the day.

**Fig. 5.** Neon flying squids, *Ommastrephes bartrami,* filmed by remote camera system at around 400 m deep.

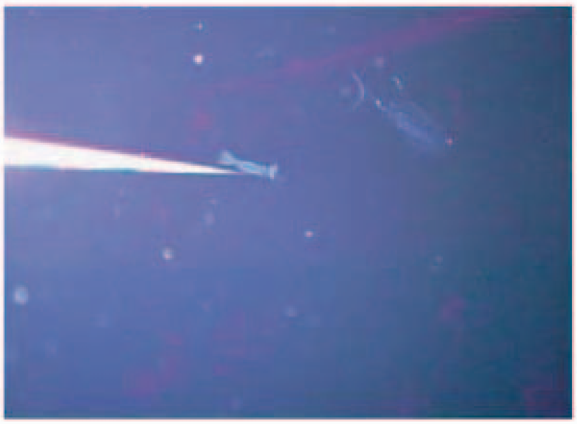

**Fig. 6.** Pomfret, *Taractichtys steindachner,* filmed by remote camera system at around 400 m deep.

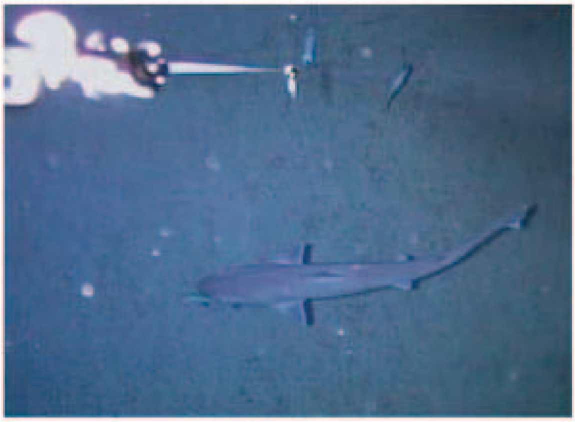

**Fig. 7.** Bottom shark and fish filmed by remote camera system at around 500 m deep.

**Fig. 8.** Black escolar, *Ruvettus pretiosus,* filmed by remote camera system at around 800 m deep.

**Fig. 9.** Blue shark, *Prionace glauca,* filmed by remote camera system at around 1000 m deep.

## I-1. First-ever observations of a live giant squid in the wild

During the third year of the project, at 09:15 hrs on 30 September 2004, an individual giant squid attacked the lower squid bait of one of our camera systems at 900 m over a seafloor depth of 1,200 m southeastern off Chichijima Island at 6°57.3'N, 142°16.8'E. The squid's initial attack was captured on camera (Fig. 10) at the 50th frame and showed head and parts of arms with the two long tentacles characteristic of giant squids wrapped in a ball around the bait. The following several frames (about 5 min) captured nothing but our squid jig and a rope-like tentacle which came into the frames after short while. The club of one of the long tentacles of this giant squid had become snagged on the squid jig. More than 500 digital images were taken over the subsequent four and one half hours, recording the squid's repeated attempts to detach itself from the jig.

For the first 20 minutes, the squid disappeared from view as it actively swam away from the camera system. For the next 80 minutes, the squid repeatedly approached the line, spreading its arms widely (Figs. 11-13) or enveloping the line. During this period the entire camera system was drawn upwards by the squid from 900 m to a depth of 600 m (Fig. 14). Afterwards, the squid was often out of the camera frame, suggesting that the squid was tired and could not pull at the line strongly enough to make the camera face it. Over the subsequent three hours, the squid and system slowly returned to the planned deployment depth of 1,000 meters.

**Fig. 10.** The first image of the giant squid, *Architeuthis* sp., filmed by remote camera system at around 900 m deep (50th frame).

**Fig. 11.** Spreading arms (98th frame).

**Fig. 12.** Wrapping bat squid with tentacles and ventral arms (99th frame).

**Fig.13.** Wrapping bat squid with additional arms (100th frame).

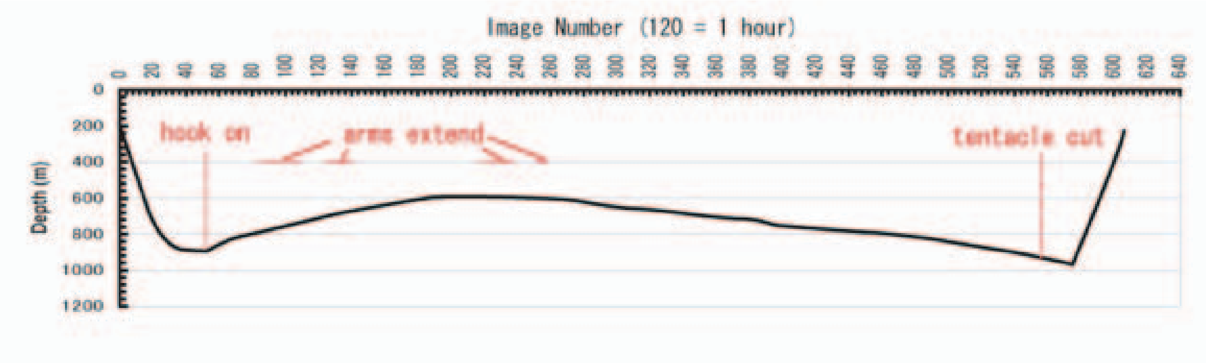


**Fig. 14.** Summary of depth, image number and the giant squid behaviors recorded by the remote camera system.

**Fig. 15.** Tentacle attached to jig, one frame before the tentacle break (555$^{th}$ frame).

**Fig. 16.** Subsequent image (30 s later) at moment of tentacle break, as seen by sudden slackness in the line (556$^{th}$ frame).

Four hours and 13 minutes after becoming snagged, the attached tentacle broke, as seen by sudden slackness in the line (Figs. 15-16). Judging from the depth recorder, the tentacle cut occurred 10 minutes before retrieving the system. This means that the squid cut the tentacle off by itself.

The severed tentacle remained attached to the line and was retrieved with the camera system (Figs. 17a-c). The recovered section of tentacle was still functioning, with the large suckers of the tentacle club repeatedly gripping the boat deck and any offered fingers. The tentacle section was 6 m long. The tentacle club was 720 mm in length with four longitudinal rows of suckers of which median two rows of suckers were much bigger than marginal ones and with a fixing apparatus at the proximal portion of the club. The largest sucker was about 28 mm in

a

b

**Fig. 17.** Severed tentacle remained attached to the line, a: squid jig with tentacle attached, b: tentacle on board, (Photo by H. Okamoto, NHK)

diameter. Based on available data sets for *Architeuthis* morphology (Roeleveld and Lipinski, 1991; Förch, 1998; Kubodera, 2004), mantle length (ML) was estimated from tentacle club length (TCL) and diameter of the largest sucker on the tentacle club (LSD).

c

**Fig. 17.** c: the largest sucker on tentacular club.

(Photo by H. Okamoto, NHK)

ML = 2393 TCL - 107.956 (in mm, n=7, r=0.941, ML= 1200-2020mm)

ML = 61.69 LSD - 18.105 (in mm, n=9, r=0.791, ML=1040-2020mm)

The mantle length estimates are 1615 mm by TCL and 1709 mm by LSD. The head and arm portion of *Architeuthis* usually occupies 60-70% of the body length, so that this animal would have been approximately 4.7 m in length from tip of fin to tips of normal arms and over 8 m in total length including the long tentacles (assuming that the 6 m long recovered tentacle portion was severed at its base).

From fresh tissue obtained form the severed tentacle, a 1276 bp sequence of mtDNA COI gene was extracted(Carlini and Graves, 1999; Kano and Kase, 2004). This sequence had a 99.7-100% match with the sequence extracted from five intact *Architeuthis* specimens collected around Japanese waters (Kubodera, 2004)

## I-2 New Fndings

Our knowledge of *Architeuthis* biology and ecology is very scarce. Studies on the giant squids have been poor, based only on a few dead or dying animals that have been washed ashore or on badly damaged animals caught by trawl net. Histological studies suggested that *Architeuthis* would be a sluggish, neutrally buoyant squid due to having numerous tiny vesicles filed with an ammonia solution within their flesh, enabling them to obtain neutral buoyancy in the deep-sea. These tiny vesicles make muscle flabby and *Architeuthis* had been considered to have poor swimming ability (Clarke et al., 1979; Roper and Boss, 1982; Hanlon and Messenger, 1996; Norman, 2000; Nixon and Young, 2003). The long tentacles characteristic of *Architeuthis* are also flabby and thin, leading biologists to consider that giant squid might dangle their tentacles below to capture prey below (O'Shea, pers. com.).

Our research obtained sequential still images of a live giant squid's hunting behavior and crisis-response in its natural environment, making it possible to add new information on *Architeuthi* behavior and ecology that had previously been only speculation:

- Giant squids hunt at 900 m during the day.
- Giant squids are much more active predators than previously thought and appear to attack their prey from a horizontal orientation.
- Giant squid can retract their long tentacles once a prey has been captured.
- The tentacles appear to coil into an irregular ball in much the same way that pythons rapidly envelop

their prey within coils of their body immediately after striking.

- The tentacles are clearly not weak fishing lines dangling below the body over 4 hours.
- The squid can break off its tentacle by itself.

The new findings were summarized in a scientific paper and published in the Proceedings of the Royal society B on 28 September, 2005 (Kubodera and Mori, 2005).

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**First-ever observations of a live giant squid in the wild**

**Tsunemi Kubodera**[1,*] **and Kyoichi Mori**[2]

[1]*Department of Zoology, National Science Museum, 3-23-1 Hyakunin-cho, Shinjuku-ku, Tokyo 169-0073, Japan*
[2]*Ogasawara Whale Watching Association, Aza Higashi-machi, Chichijima, Ogasawara, Tokyo 100-2101, Japan*

The giant squid, *Architeuthis*, is renowned as the largest invertebrate in the world and has featured as an ominous sea monster in novels and movies. Considerable efforts to view this elusive creature in its deep-sea habitat have been singularly unsuccessful. Our digital camera and depth recorder system recently photographed an *Architeuthis* attacking bait at 900 m off Ogasawara Islands in the North Pacific. Here, we show the first wild images of a giant squid in its natural environment. Recovery of a severed tentacle confirmed both identification and scale of the squid (greater than 8 m). *Architeuthis* appears to be a much more active predator than previously suspected, using its elongate feeding tentacles to strike and tangle prey.

**Keywords:** giant squid; *Architeuthis*; first observation in natural habitat; feeding behaviour

## II. Years 2003-2005: Compact Movie Recorder System

In order to study and clarify behavior and biology of the deep-sea large squids more precisely, in 2003 we developed and assembled a compact underwater digital movie camera system, again in cooperation with Little Leonardo Co. (Figs. 18 a-b). This system consisted of three pressure-resistant cylinders measuring 77 mm in diameter and 225 mm in length. The three cylinders were combined with two supporting plates. The central cylinder contained a movie camera which could take 15 frames (768 kbps) of MPEG4 images per second (Panasonic, SV-AV30). Both side cylinders contained a DC light (Panasonic, VZ-LDD9, 10W), and camera and lights were controlled on and off with built-in timers. This system was hung at the end of a main line along with bait rigs attached, similar to the digital camera system.

We had deployed 8 times without success (at 600-800 m depth) during 2003-2005, at the same research area of the Ogasawara Islands.

**a**

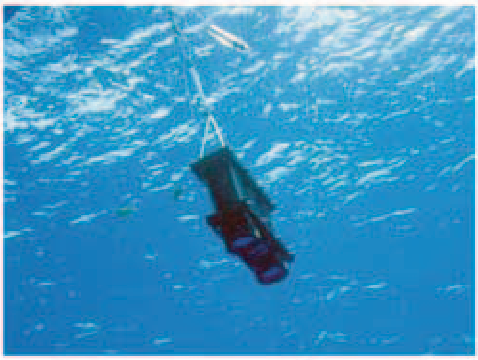


**Fig. 18.** A compact underwater digital movie camera system developed in 2003, a: a view from below, (Photo by K. Mori)

We thought that the main reasons for our previous failures were: 1) low light sensitivity of the movie camera; 2) insufficient light intensity of the DC lights. To provide enough light to take movies at bait rigs, it was necessary to shorten the rig line considerably (to 1-1.5 m) from the camera system that often placed the bait rigs outside of the camera frame. The narrow angle of the camera lens as well as low resolution of images at low light intensity were also problems to be solved.

b

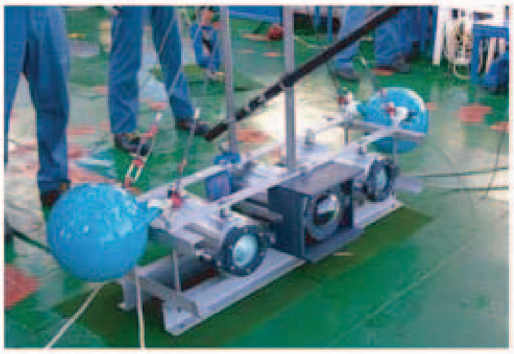
**Fig. 18.** b: system with bait rigs. (Photo by K. Mori)

## III. Year 2005: High Definition Video Camera System

Our success at capturing still images of a live giant squid in 2004 drove NHK (Japan Broadcasting Corporation), which had earlier filmed our research activities, to promote the project of filming a real movie of a giant squid in the wild. With their financial support, we developed a new underwater high definition video camera system in cooperation with Goto Aquatics Co. in 2005. The basic concept was the same as for the compact movie recorder system, consisting of three pressure-resistant cylinders measuring 216 mm in diameter and 500 mm in length. The central cylinder contained a high definition video camera (Sony, HDR-FX1) which came on the market in 2004. Considering defects of the compact movie-camera system, a fish eye lens was attached to the video camera and put on dome-shaped glass shield in front of the cylinder to cover the wide angle of the lens. A strong halogen light (24V, 150W) was set in each side cylinders. The three cylinders were mounted on a stainless steel frame horizontally (Fig. 19a) and a 2.2 m glass fiber pole was attached obliquely from the frame. A bait rig was suspended from the tip of the pole with a 1.5m line, weighted with a pencil-shaped underwater torch (ca 15 cm). Therefore, differing from the vertical angle of the previous systems, this camera took movies horizontally. The entire system weighed nearly 170 kg in air. Two large floats were attached to the frame to reduce its weight in water (Fig. 19b). In order to examine the effects of different lighting colors, blue and/or red filters were attached to the main halogen lights on some deployments.

From September to October in 2005, we conducted total of 26 deployments in the same area as our previous giant squid investigation off Ogasawara Islands. Eight,

a



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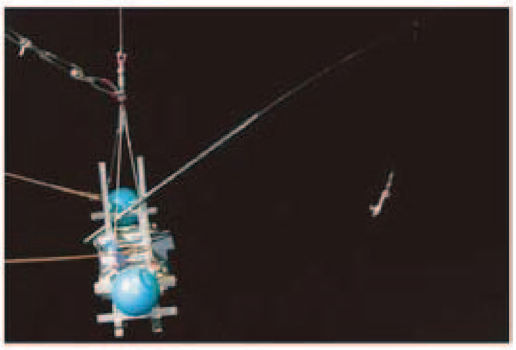


**Fig.19.** A new underwater high definition video camera system developed in 2005, a: camera system on deck, b: system with pole and bait rig.

were conducted by the R/V "Natsuhsima", Japan Agency for Marine-Earth Science and Technology, 16 by the R/V "Koyo", Ogasawara Fisheries Center and 2 by the F/V "Youdai-Maru" Ogasawara Fishermen's Union. The camera system was suspended in mid-water at designated depths of 800-950 m for 1-2 h and occasionally recovered with stops at intermediate depths for 30-40 min before retrieval. The depth at which video footage was taken was monitored by a digital depth-temperature recorder attached to the system.

### III-1 Filming of hunting behavior and bioluminescence of *Taningia danae*

Although we had no luck filming the giant squid, we could obtain high definition video footage of swimming and hunting behavior as well as bioluminescence of the large deep-sea eight-armed squid, *Taningia danae,* during 12 out of 26 deployments. *T. danae* is also known to be one of the huge mesopelagic squids distributed widely in the tropical and subtropical world oceans. The largest hitherto reported was a mature female of 1.32 m in mantle length, weighing 124 kg, caught by fisheries trawl net in eastern Atlantic (Gonzalez et al., 2003). *T. danae* has a heavy conical mantle with large thick triangular fins and eight relatively short equal-length arms with biserial strong hooks. The feeding tentacles degenerate in their very early stage of life, thus adults lack both tentacles, so *T. danae* is classified in the taxonomic family Octopoteuthidae. The most dramatic character of this species is having extremely large oval photophores on the distal dorsolateral arms. The photophores are cream-white in color and usually covered by thin, dark epidermal lids (Figs. 20 a,b). Observation on a young individual caught by mid-water trawl

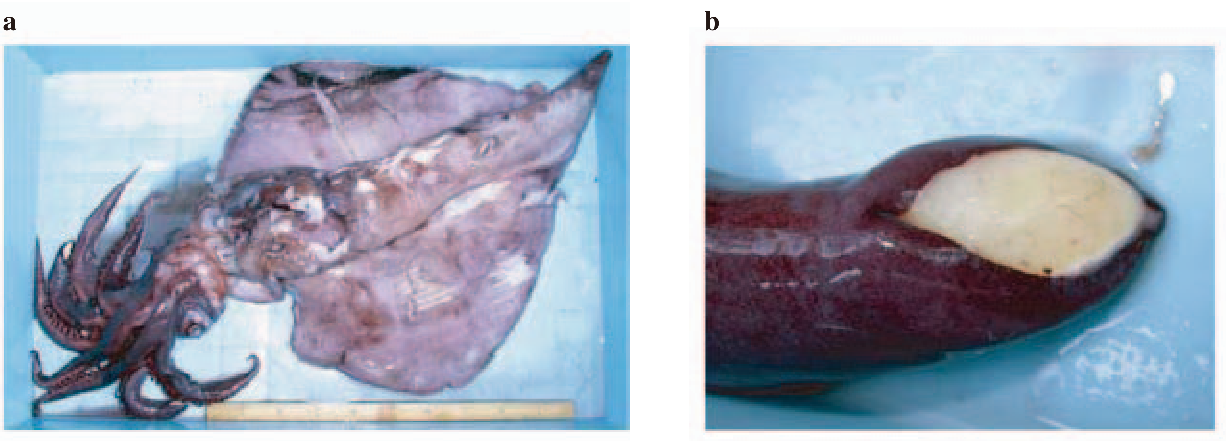



**Fig. 20.** Deep-sea large eight armed squid, *Taningia danae,* a: ventral view of the specimen from the stomach contents of sperm whale (scale:50cm), b: a large oval photophore on the distal dorsolateral arm.

net kept in a shipboard aquarium revealed that when it was stimulated, bright flashes of brilliant blue-green light emitted simultaneously from both arm-tip photophores (Roper and Vecchione, 1993).

Although full-grown *Taningia danae* have rarely been captured by research trawl net, large number of their beaks have been reported from the stomach contents of sperm whales, from which *T. danae* was estimated to have a huge potential biomass in the deep-sea (Clarke, 1980; Clarke and MacLeod, 1982). The same as the giant squid, *T. danae* has numerous tiny vesicles filed with ammonia solution within their flesh that make muscle flabby, and *T. danae* had also been suggested to have poor swimming ability (Clarke et al., 1979; Hanlon and Messenger, 1996; Norman, 2000; Nixon and Young, 2003). But no observation on adult *T. danae* in its natural environments had previously been made and knowledge of their wild habitats and behavior was extremely limited.

## III-2 New Findings

***Vertical distribution and dial migration***: Ontogenetic descent from the surface to depths of 200-300 m by juvenile and young *T. danae* (6-15 mm ML) has been reported (Roper and Vecchione, 1993). Adults have been suggested to live at depths of over 1000 m based on the foraging depths of their main predators, sperm whales and deep-sea sharks (Clarke and Merrett, 1972; Clarke, 1977). Our camera took video footage of *T. danae* around 600-900m during the day and around 240-500 m at night, indicating that *T. danae* appears to undertake short distance diel vertical migrations.

***Swimming behavior and ability***: Our video camera recorded *T. danae* swimming freely both forward (head and arms forefront) and backward (fin tip forefront) by flapping the large and muscular triangular fins (Fig. 21a-h). When swimming, all arms were joined together to reduce water resistance. It was also recorded that *T. danae* rapidly changed direction by flexibly bending its body. Fin movement of *T. danae,* used to generate forward propulsion, is similar to that of rays, Dasyatidae. Although rays can only swim forward smoothly, *T. danae* can reveres fin undulation to generate backward propulsion. This swimming method is different from common squids that generate propulsion by pumping their mantles to eject water from the funnel. Undulation of large fins for swimming has advantages over jet propulsion, in that it generates the same acceleration power for either direction, without the pumping pause and is considered to be more efficient locomotion with less energy than jet propulsion.

Based on the video footage that shows *T. danae* swimming straight forward to the bait rigs, this individual moved 2-2.5 m in a second with a one cycle of fin undulation. By comparing it size with that of the bait squid, this individual was more than 1 m in total length. Attack speed of *T. danae* of this size was estimated to reach 7.2-9 km/h. Up to now, mesopelagic large squids containing ammonium solutions in tissue had been considered neutrally-buoyant, sluggish inhabitants, but our video footage revealed for the first time that they are truly active and are great swimmers. According to the presentation by Miller in this Symposium, recent research on sperm-whale diving behavior using a bio-logger shows they frequently make an abrupt dash, attaining over 9 km/h during their deep dives. In those cases, sperm whales might be chasing such large squids like *T. danae* in the deep.

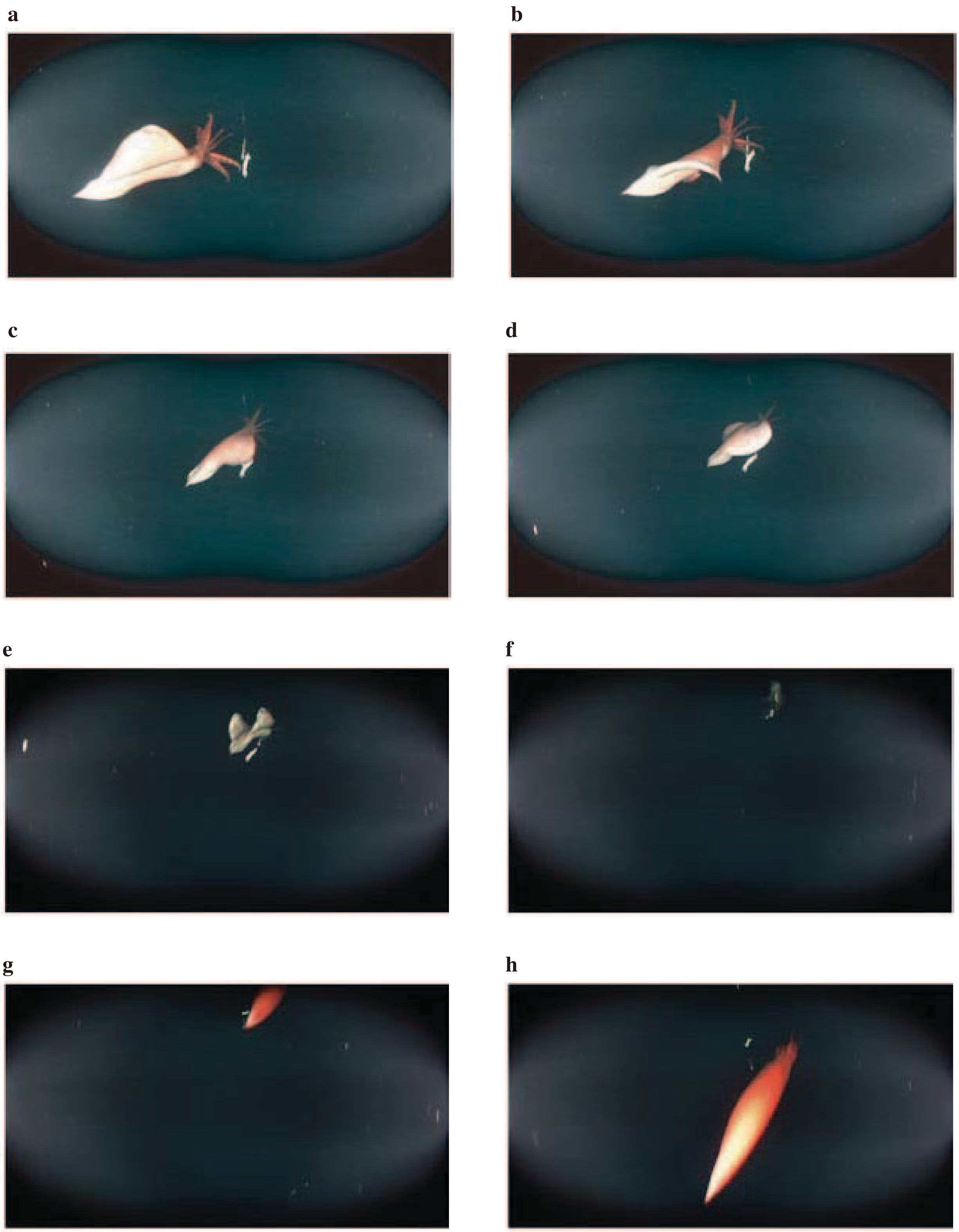


**Fig. 21.** Forward and backward swimming of *Taningia. danae,* a: holding up fins dorsally, b: moving down anterior edge of fins, c: wrapping whole fins ventrally, d: moving up anterior border of fins, upward movement of lateral and posterior portions of fins, e: holding up fins dorsally, f: turn a somersault quickly, g: change direction to backward, h: rush backward with holding fins tightly. (By courtesy of NHK)

***Hunting behavior and bioluminescence***: From 14 observations on *T. danae* approaching bait rigs, we recognized three different attack behaviors. The first behavior was observed twice in white light

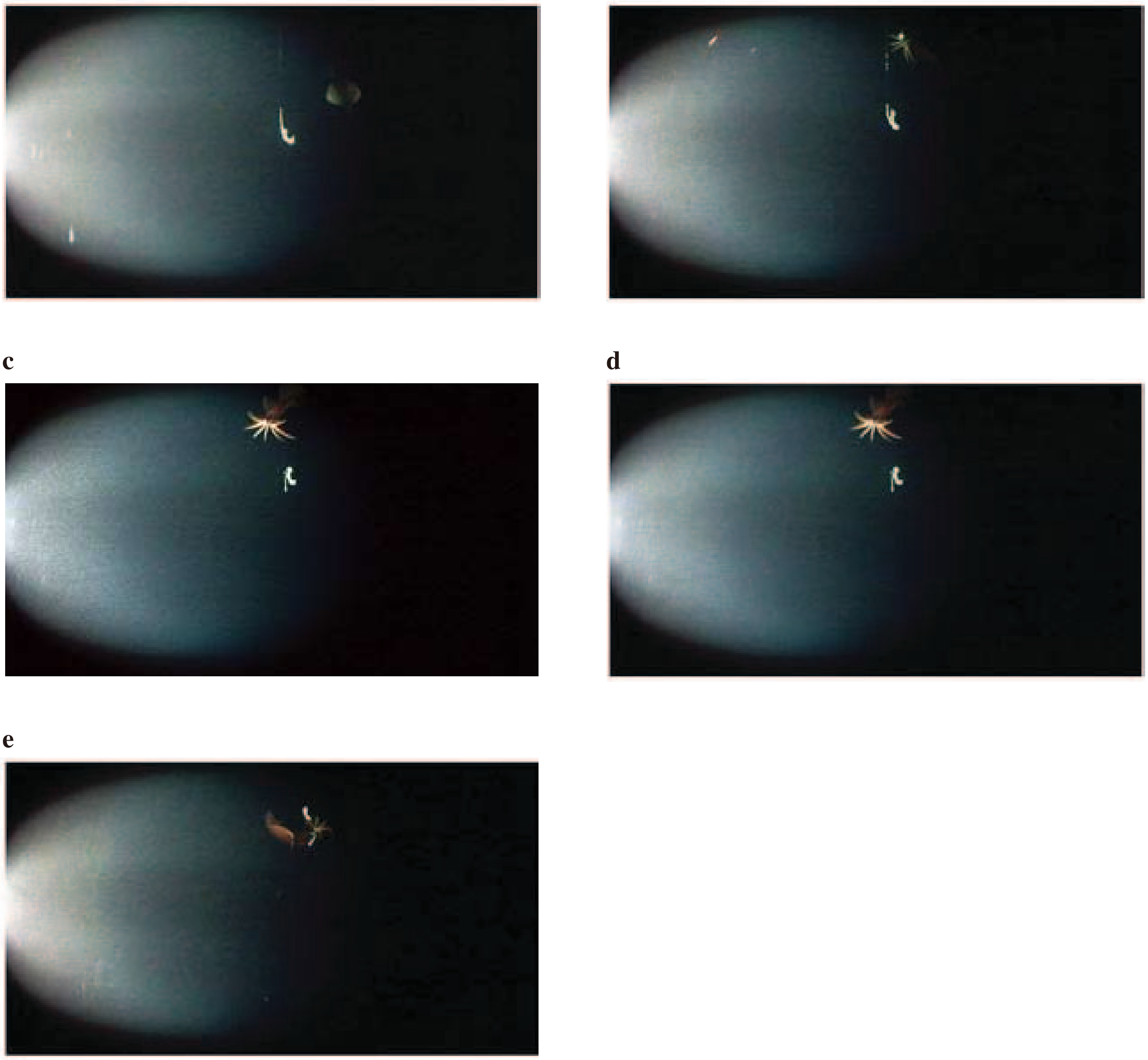
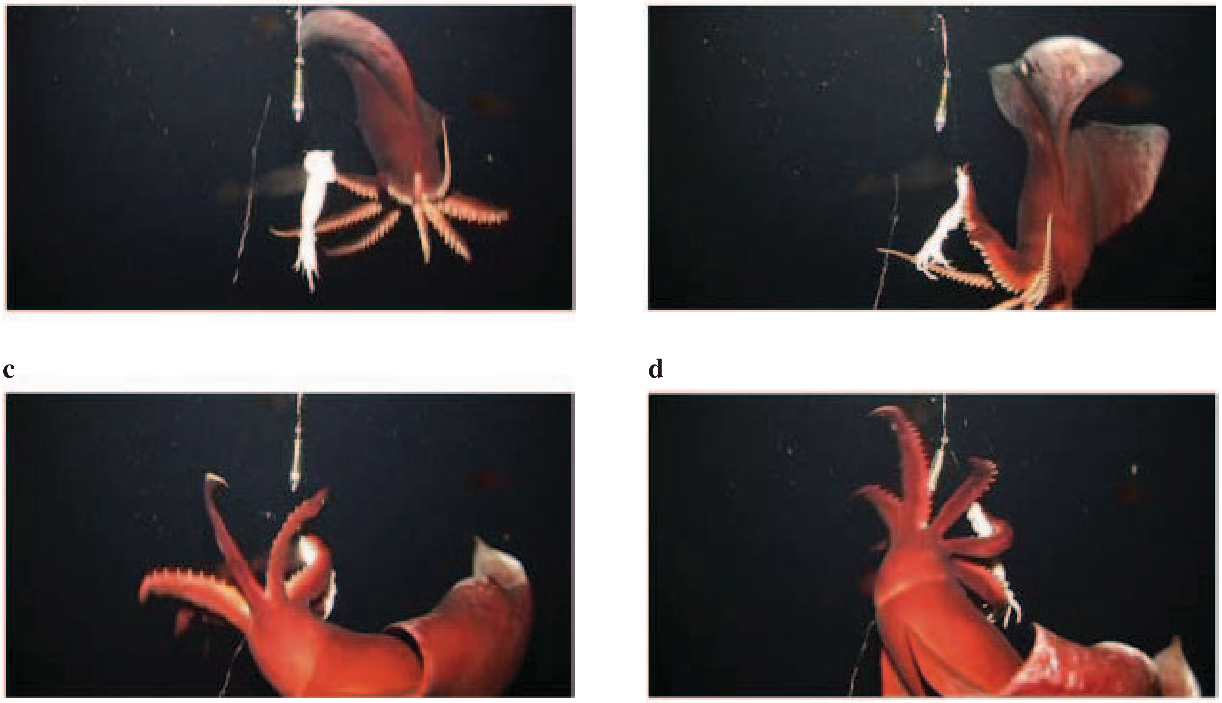



**Fig. 22.** Hunting behavior and bioluminescence, a: approaching with a little distance from the bait, b: emitting a short strong flash from arm-tip photophores, c: stopping light emission, d: turning the body abruptly to the bait, e: holding the bait from behind with all arms. (By courtesy of NHK)

conditions and twice in blue light. This behavior involved: 1) swimming forward spreading all arms widely; 2) passing by within a little distance from the bait; 3) emitting a short strong flash from arm-tip photophores (1.2-1.6 s); 4) stopping light emission and turning the body abruptly to the bait; 5) holding the bait from behind with all arms; 6) swimming away backward, detaching the bait from the hook (Fig. 22a-d). This method of attack is considered to be typical hunting behavior for their suitable prey in the wild. The emission of light just before attacking may work as a blinding flash for the prey, as well as a means of illumination and measuring the target distance in an otherwise dark environment. This emission was stopped in a twinkling and followed by rapid turning of the body to attack the bait from behind. This motion might cause the prey to mistake the true direction of the attack in the dark. It is a very clever surprise-attack strategy using bioluminescence. Close-up movies showed that *T. danae* leaned its body a b



c d

**Fig. 23.** Close up images of attacking the bait, a: approaching the bait with spreading all arms, b: catching the bait with ventral and ventrolateral arms, c: turning flexibly its body, d: holding the whole bait with all arms. (By courtesy of NHK)

when approaching the bait and caught the bait with ventral and ventrolateral arms, then flexibly turned its body to hold the whole bait with all of its arms (Fig. 23a-d). (Common squids have two tentacles, each one between the ventral and ventrolateral arms.)

The second behavior was observed twice in white light, once in red light and once in blue light conditions. This behavior was involved: 1) swimming forward; 2) extending all arms with a relatively long flash of light (2.1-2.2 s); 3) colliding with the rig line or torch light straight forward without turning the body. This behavior was hard to define but may be due to reflection of the nylon monofilament line and/or the connecting swivel, which might attract or dazzle the squid. This long flash seemed to be a precautionary signal used by the squid when approaching unidentified objects.

The third behavior was observed three times in blue light conditions. This behavior involved: 1) swimming forward; 2) extending all arms; 3) occasionally swimming around the bait (once out of 3 observations); 3) banging hard at the light straight forward (Fig. 24a-e). Blue light seemed provocative. Attacking the blue-filtered halogen light might be an aggressive behavior against potential adversaries.

The most interesting behavior was bioluminescence without attack and was observed four times in red light conditions. This behavior involved: 1) swimming forward, approaching the bait while emitting a long glow (4.4-8.5 sec.); 2) keeping a certain distance from the bait; 3) emitting several short glows separated by intervals, maintaining a short space between photophores; 4) extinguishing the light and swimming away (Fig. 25a-e). We propose that the light given off by the double-torch lights may resemble the long glows of the arm-tip photophores of *T. danae* and may attract them, eliciting long glows when approaching. Short glows were emitted when investigating the double-torch lights but in the absence of an appropriate response the squid moved on. This is the first movie recorded conspecific communication with bioluminescence among deep-sea squids in the wild.

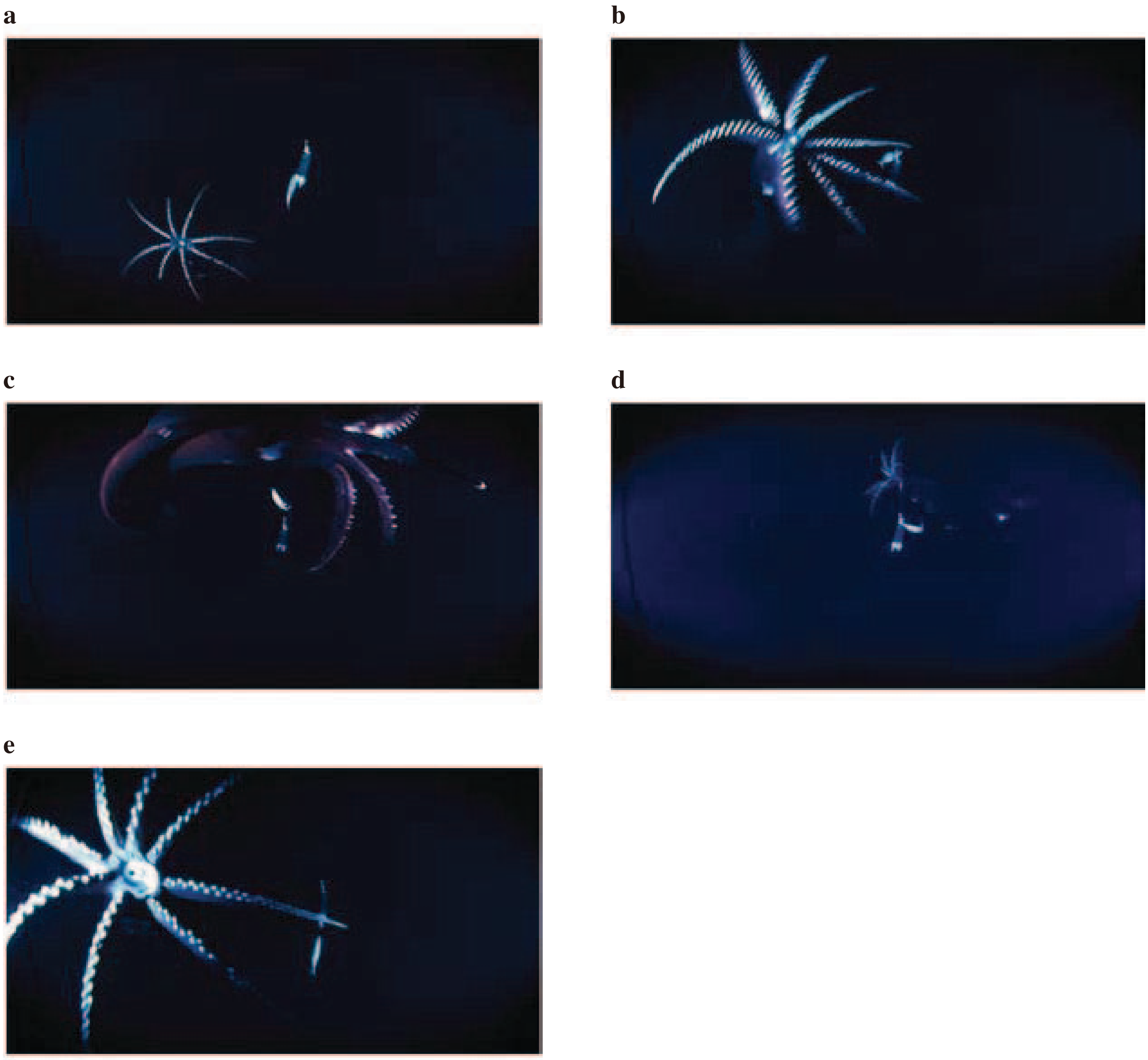



**Fig. 24.** Blue-filtered halogen light attacking behavior, a: approaching the bait with spreading all arms, b-d: swimming around the bait, e: straight forward to the light. (By courtesy of NHK)

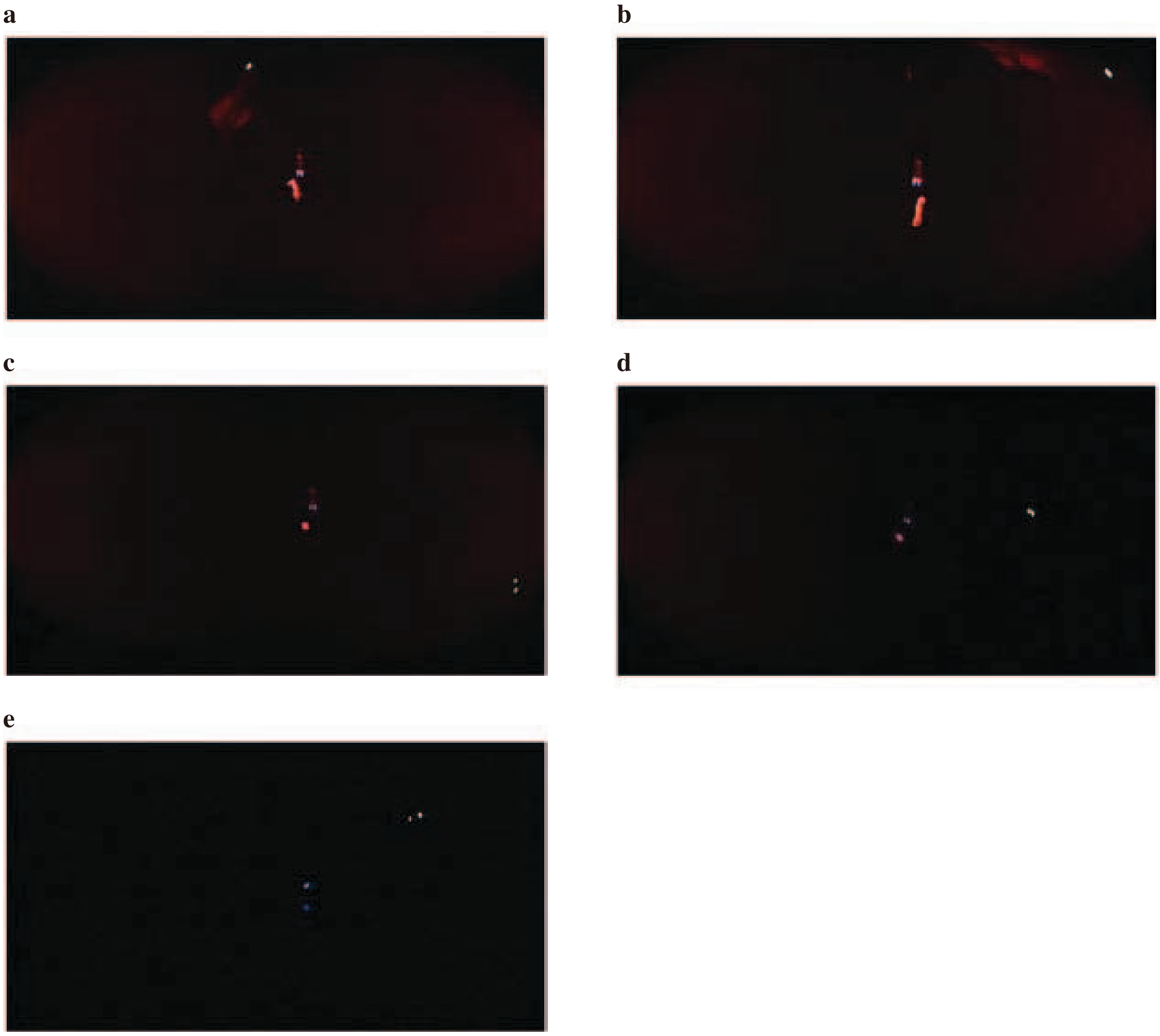



**Fig. 25.** Bioluminescence without attacking, a-b: approaching the bait while emitting a long glow, c-d: emitting several short glows, maintaining a short space between photophores. (By courtesy of NHK)

***Light conditions and effect of torch light***: Many mesopelagic squids possess eyes which are characterized by having a single visual pigment with peak absorbance at 480 nm wavelength (Seido et al. 1990); because of blue light penetrate water the deepest. Therefore *T. danae* has high sensitivity of vision only in a blue light spectrum. We applied two strong halogen lights (150W) for lighting and *T. danae* recognized bait squid/mackerel as suitable prey under such artificial light conditions and successfully hunted. In some cases, strong white light caused erroneous responses. Strong blue light may cause overexposure in their high blue sensitivity, which may explain aggressive attacks on the blue-filtered halogen light.

On the other hand, *T. danae* has no sensitivity of vision in red light spectrum. Therefore observations in red light condition would appear natural behavior in the dark environment that made it possible to record gentle forward and backward swimming around the bait rigs as well as conspecific communication with bioluminescence. The faint blue light from the torch may have been less visible under strong white and blue halogen light so that *T. danae* was unable to recognize it. It was only in the red light conditions that they appeared to interact with the torch lights, as a potential form of bioluminescent communication.

The new findings were summarized in a scientific paper and published in First Cite e-publishing from the Proceedings of the Royal society B on 13 February, 2007 (Kubodera et al., 2007).

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**Observations of wild hunting behaviour and bioluminescence of a large deep-sea, eight-armed squid, *Taningia danae***

**Tsunemi Kubodera[1,*], Yasuhiro Koyama[2] and Kyoichi Mori[3]**

[1]*Department of Zoology, National Science Museum, Tokyo, 3-23-1 Hyakunin-cho, Shinjuku-ku, Tokyo 169-0073, Japan*
[2]*Science and Environmental Department, Japan Broadcasting Corporation, 2-2-1 Jinnan, Shibuya-ku, Tokyo 150-8001, Japan*
[3]*Ogasawara Whale Watching Association, Aza Higashi-machi, Chichijima, Ogasawara, Tokyo 100-2101, Japan*

Our newly developed underwater high definition video camera system took the first live images of adults of the mesopelagic large squid, *Taningia danae*, between 240 and 940 m deep off Ogasawara Islands, western North Pacific. The resulting footage includes attacking and bioluminescence behaviours, and reveals that *T. danae* is far from the sluggish neutrally buoyant deep-sea squid previously suspected. It can actively swim both forward and backward freely by flapping its large muscular triangular fins and changes direction quickly through bending its flexible body. It can attain speeds of 2–2.5 m s$^{-1}$ (7.2–9 km h$^{-1}$) when attacking bait rigs. They emitted short bright light flashes from their large arm-tip photophores before final assault, which might act as a blinding flash for prey as well as a means of measuring target distance in a dark deep-sea environment. They also emitted long and short glows separated by intervals while wandering around the double torch lights attached to the bait rig, suggestive of potential courtship behaviours during mating.

**Keywords:** large deep-sea squid; underwater high definition video camera system; Ogasawara Islands; swimming ability; attacking behaviours; bioluminescence

## IV. And then Year 2006

During the course of our research on deep-sea large squids off Ogasawara Islands in 2006, an individual of *Architeuthis* was brought to the surface when we retrieved a research vertical long line hung down about 650 m depth at about 15 miles northeastern off Otohto-jima Island on 4 December, 2006. The giant squid was still alive, holding a neon flying squid of about 55 cm in mantle length with its long arms. Probably, neon flying squid was first hooked on the jig when it attacked the bait squid (Japanese common squid of ca. 25 cm mantle length) and when it became enfeebled the giant squid attacked it and several long arms were hooked on the squid jig while holding the neon flying squid (Fig. 26a-c).

At the surface, the giant squid waved its long arms and ejected a large volume of sea water repeatedly form the thick funnel to escape from the jig. Judging from the force of the water ejection, it would have a considerable swimming power when disturbed. Our suggestion proposed in 2004 that "the giant squid is much more active predator than previously thought based on still images taken by 30 s interval" was reinforced by the present video footage. The body color was reddish purple on the dorsal surface and silvery white on the ventral surface. It was extremely beautiful when seen alive.

After observing and recording video of the giant squid at the surface, we tried to retrieve the giant squid on board for scientific specimen but there was a crew of only three including myself and we had a serious trouble. One guy dove into sea with a blanket and lap the giant squid with blanket then we pulled it on the board by using all our strength. Epidermis of the giant squid was very loose and most part of them were peeled off when retrieving. Posterior portion of mantle was also damaged with a hand-hook. This individual measured about 1.4 m in mantle length and 3.5 m from tip of fin to tip of the longest arm on board. Both long feeding tentacles characteristics of the giant squid had been tear off at the base. Judging from the recovery of cutting surface, it would lose the tentacle fairly a long time ago. In addition, several arm tips were also damaged. The giant squid hooked up was far form healthy condition. An immature ovary which came out from the injured mantle indicated it was a young female. It weighed nearly 50 kg when we landed it at fishing port.

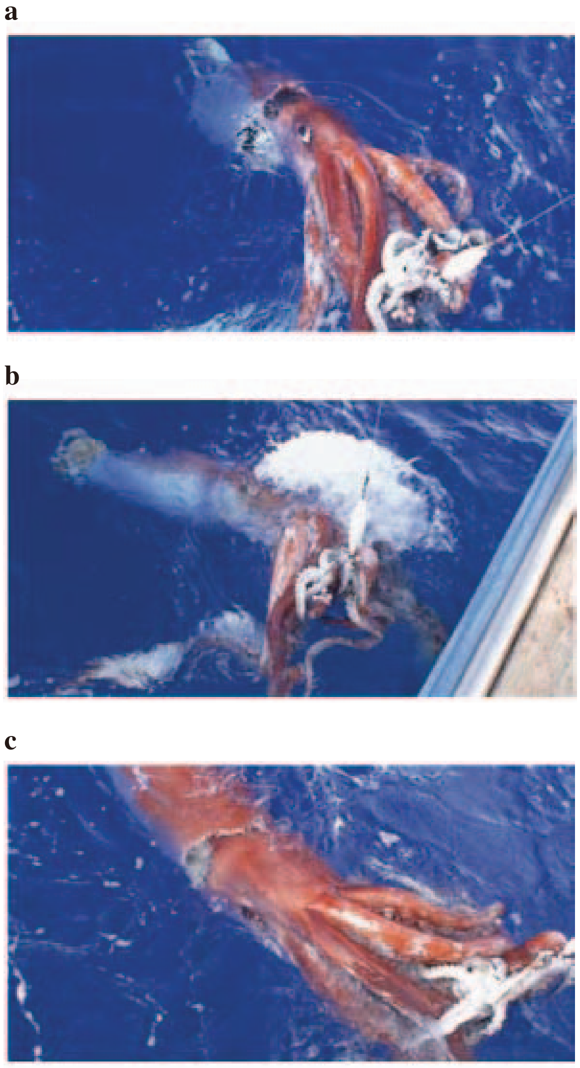


**Fig. 26.** The giant squid fished in alive and brought to the surface off Ogasawara Islands in 2006, a: holding a neon flying squid hooked on the jig, b: strong water ejection, c: dorsal view of the animal.

## VI. Significance of the present observation

The giant squid has been occasionally fished by local fishermen in the waters off Okinawa Islands and Ogasawara Islands. Photos of hooked up giant squid at the surface off Okinawa are available through the internet (Hashimoto:http://homepage1. nifty.com/ozok/kimamana-ryounisshi.htm). Thus fishing up the giant squid was not for the first time but it was significant that we have recorded all the details of appearing the giant squid at the surface and its hard fighting at the surface by high definition video camera from the boat. Although it was far from natural condition for the giant squid, this would be the first movie to record actual fighting behavior of live giant squid.

Following lines summarize new findings of giant squid behaviors and ecology figured out from the present observation as well as questions and future subjects arisen through our research.

- Giant squid is distributed in 650-900 m depth and searching prey during the day in the water off Ogasawara Islands. This depth range agrees the occurrence of *Taningia danae* and also overlaps with the diving depth of sperm whales. It is safe to say that sperm whales dive to feed on these huge mesopelagic squids, but observation of the interaction between sperm whales and large squids in natural environment requires further development of new under-water visual equipments and also the research project which stands on new point of view.
- Giant squid can capture prey with arms even in the condition when it has lost both feeding tentacles. This is an answer for the question that I have received after 2004 publication that "Can giant squid survive after loosing one tentacle?" But, when and how the present giant squid had lost both tentacles and such an injured individual could survive whole life span until spawning are remained in questions.
- Giant squid attacked live neon flying squid (55 cm ML) hooked on squid jig and also fed on dead Japanese common squid (22 cm ML) attached squid jig in 2004. Available information on feeding habits of giant squids is very limited and only relatively small rat-tail fishes and squids have been reported for their prey (Perez-Gandarez and Guerra, 1978; Forch, 1998). Adult neon flying squids are nearly as large as one third of giant squids and very active. It is remained in question that the giant squids were able to feed on healthy neon flying squid in the wild. It is probable that the giant squid attacked enfeebled neon flying squid hooked on squid jig. Concerning to the feeding habits of the giant squid, detailed study on stomach contents from healthy individuals is badly needed.
- Swimming method of giant squid depends mainly on water ejection from the funnel as same as most common squids. Judging from the force of the water ejection and volume of the water ejected, giant squids would have a considerable swimming ability. Based on the video footage analysis, we are going to clarify detailed swimming behavior of giant squid, such as propulsive power and maximum swimming speed, by computer simulation.
- Body color of live giant squid was reddish purple on the dorsal surface and silvery white on the ventral surface. This body color pattern is a characteristic common to most animals living in shallow waters into which the sun light penetrates and is explained as a camouflage against lighter or darker backgrounds for the predators which look up or down to search prey. The nearest ancestor of giant squid would be a shallow water inhabitant and the giant squid itself would have been on the process of adapting the deep-sea environments. Further studies from this view point are essential.

## VI. Prospective

By means of using under-water visual equipment, we have obtained invaluable images and video footage of large deep-sea squids, *Architeuthis* and *Taningia*. This has increased our understanding of the behavior and ecology of these deep-sea large squids. But our knowledge of deep-sea large squids is still fragmentally and their ways of lives in the wild still remain mysteries.

This type of research needs specialists for developing the gear as well as kind cooperation with people in various research fields. Needless to say, research money to support such surveys is critical. We have obtained research funding from Japanese Society for Promotion of Science (JSPS), for three years between 2006 and 2008. Based on collaboration with related people and research funding from JSPS, we will continue to investigate the biology and ecology of deep-sea large squids around Japanese waters by developing new under-water visual equipment at least until 2008.

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