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[Report]

Tracking Vertical Movement of the Moon Jelly *Aurelia aurita* using a Micro Data Logger

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Abstract

Vertical movement of the moon jelly *Aurelia aurita* was investigated in the southwestern area (5.8~9.4m deep) of Omura Bay, Nagasaki. We examined the influence of attaching micro data loggers on the behavior of six moon jellies in an aquarium. No significant difference was observed in mean bell pulse frequencies in experimental animals vs. controls (p>0.05). In addition, micro data loggers remained attached to the bells for at least 5h. From June to July and October to November, 2009, the vertical movements of 10 moon jellies were recorded in the field. Moon jellies that were tracked remained within the 2m-depth layer during the daytime in June, but were closely associated with the seabed in October to November. Eight out of 10 individuals exhibited the initial descending behavior when released, which might be a reaction of the moon jellies to handling and/or micro data logger attachment.

1. Introduction

Moon jellies are the most commonly observed jellyfish in the coastal waters of Japan. Blooms of this species frequently cause damage to fisheries[1], particularly in the coastal fisheries of the Seto Inland Sea[2)~4)], Sagami Bay[5] and Lake Nakaumi[6]. In this study, we examined the effect of these blooms on the bottom trawl fishery in Omura Bay, Nagasaki, where moon jelly bycatch is a particularly severe problem as this fishing technique typically trawls through large volumes of water. When large quantities of moon jellies are caught in the fishing net, the increase in drag results in a decrease in trawl speed, undesirable net shape, damage to equipment, and the risk of the boat capsizing. Bycatch of moon jelly also causes heavy labor during sorting of catch and deterioration of the catch quality[1].

Knowledge on the spatiotemporal distribution of moon jellies could provide us with information on optimal trawling times that may result in the minimizing of bycatch. Spatiotemporal observations of moon jelly distribution have employed time series sampling and observation[6)~11)]. Most of these studies have been conducted by simultaneously towing several nets at different depths at different intervals and durations[1),7)~10)]. Other studies have employed underwater camera/acoustic cameras suspended from a boat[1),7),10)~11)]. While both of these experimental designs provide information on the vertical distribution of moon jellies, jellyfish movement during sampling intervals has yet to be clarified. If moon jellies frequently moved up-and-down, then above observations would only be a snapshot of the vertical movement. Consequently, more precise information on these movements is important in the understanding of the spatiotemporal distributions of moon jellies.

In order to resolve this issue, we attempted monitoring the vertical movements of moon jellies by attaching micro data loggers to the organisms. However, the use of bio-logging techniques to monitor jellyfish species is relatively recent[12)~14)] and attachment criteria still needs to be established. We therefore developed and evaluated a method of attaching micro data loggers to moon jellies, and conducted a series of field surveys on the vertical movements of these organisms

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Table 1 Details of the aquarium experiments for assessing the impact of the micro data logger attached to moon jellies

Date in 2009	Bell diameter (mm)	Water temperature (℃)	Observation time* before attachment (hh : mm)	Mean bell pulse frequency (pulses/min)	Observation time* after attachment (hh : mm)	Mean bell pulse frequency (pulses/min)
April 28	175	20	15 : 23-17 : 39	29.8	18 : 30-20 : 50	25.6
May 7	102	21	12 : 30-13 : 30	35.0	13 : 40-20 : 10	35.7
May 13	124	24	15 : 00-15 : 45	29.1	15 : 50-22 : 10	31.0
May 21	130	24	13 : 50-14 : 45	17.7	14 : 53-20 : 50	18.7
May 27	76	23	13 : 00-14 : 00	30.7	14 : 05-18 : 40	32.0
June 25	105	25	14 : 35-15 : 25	19.9	15 : 42-16 : 42	19.6

* Duration that bell pulse frequency was counted

in the shallow waters of Omura Bay in Nagasaki, Japan.

2. Material and methods

1) Aquarium experiments

(1) Experimental animals

Experimental animals were collected at the south coast of Omura Bay and kept in the 120L tank for a week before the experiment. Six moon jellies (7.6～17.5cm bell diameters) were used in the experiment. Water temperature of the tanks were adjusted to that of the sampling site (20～25℃) and a small fluorescent lamp was turned on above the tank to make recording available in the nighttime. Details of this experiment are shown in **Table 1**.

(2) Attachment of data loggers

The micro data loggers used in this study (DST micro-TD, Star-Oddi, Reykjavik, Iceland; diam.: 8.3mm, length: 25.4mm, weight: 1.9g in water), which record depths and ambient temperatures, were adjusted using neoprene jackets to have a neutral buoyancy in water. Hays *et al.*[12] attached a time-depth recorder to the compass jellyfish *Chrysaora hysoscella* using a nylon line tied around the peduncle (connecting the bell to the oral arms) and tracked the descending behavior of the organisms along the coast of Ireland for several hours. Honda *et al.*[13] attached pop-up archival transmitting tags and ultrasonic pingers to the giant jellyfish *Nemopilema nomurai* in a similar manner and tracked the jellyfish for more than 24h. Seymour *et al.*[14] attached a pinger directly to the bell using a superglue used by surgeons and observed the jellyfish overnight. The pioneering studies used to attach data loggers to jellyfish either tied the data logger around the peduncle, or glued the data logger directly to the body.

The first method used in Hays *et al.*[12] and Honda *et al.*[13] cannot be employed because moon jellies do not have peduncles and have short oral arms. When we examined the method of gluing the data logger to the bell, exposure to air resulted in bubbles being trapped under the bell; consequently damaging the bell. We therefore decided to suture the data logger onto the bell. We pushed a strand of polyethylene line (diam.: 0.13mm, length: approx. 0.2m) through the bell at a point halfway between the bell edge and the gonad in the center. We affixed a small plastic plate to the leading end of the line (i.e. the end inside the bell) to serve as a latch and attached the micro data logger to the other (trailing) end of the line. The entire procedure was performed underwater.

(3) Observation and recording of captive moon jelly behavior

We examined the influence of attaching a micro data logger on moon jelly behavior in a 72L indoor aquarium during the period between April and June 2009. Behavior in the tank was recorded for 1～3h prior to attachment of the micro data logger using a digital video camera (HDC-SD5, Panasonic, Osaka, Japan). The moon jelly was then captured to attach the micro data logger. Upon release, recording of the behavior was then resumed for 5～24h.

We used bell pulse frequency as an indicator of moon jelly activity[15]. Pre-attachment bell pulse frequencies were calculated by counting the number of bell pulses over a 1min period, for every 5min of recorded video; the average value was then used as the pre-attachment bell pulse frequency. Post-attachment bell pulse frequencies were obtained in same manner, except that intervals of 10min were used

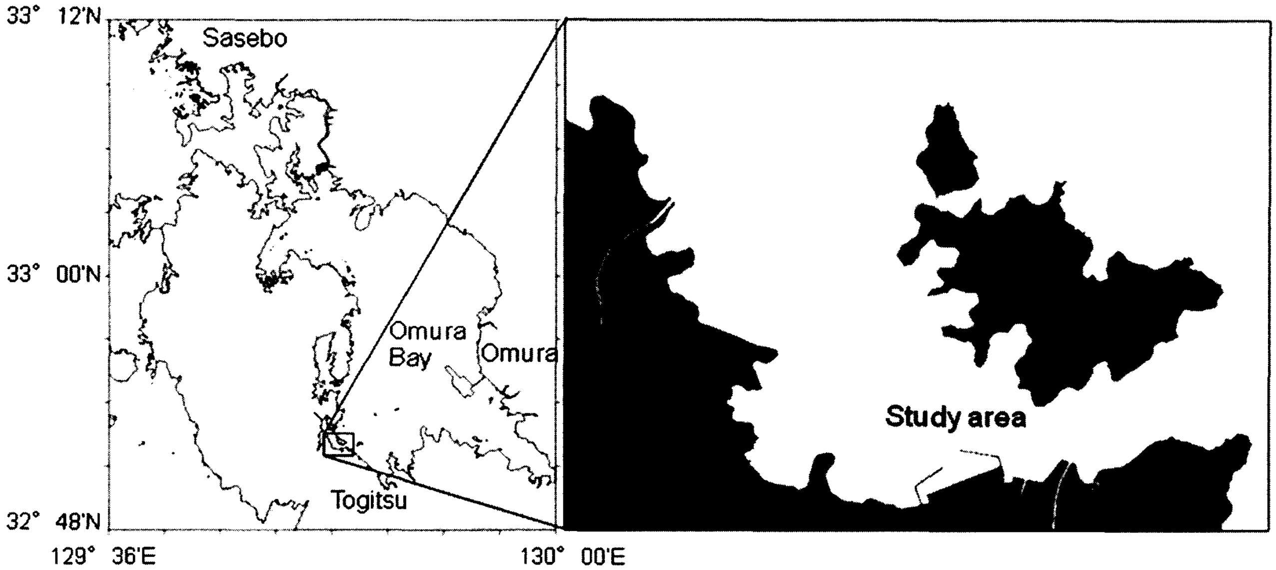

Fig.1 Site of the tracking experiment.

instead of 5min. The difference in bell pulse frequencies for pre- and post attachment periods was examined by Wilcoxon test ($p<0.05$). In addition, the duration of attachment of micro data logger to the bell was also assessed using the video recordings.

2) **Field experiments**

We attempted tracking the vertical movement of 16 moon jellies with bell diameters ranging from 11.2～22.0cm during the period from May 22 to November 7 at the site shown in **Fig.1** (5.8～9.4m deep). We used a rowboat to collect moon jellies in shallow waters (approximately 0～1m deep). Moon jellies were scooped using a bucket so as not to expose them to the air. Attachment of the data logger was then performed in the bucket. A safety line (polyethylene line, diam.: 0.13mm, length: 100m), which was coiled on the fishing reel, was attached to the micro data logger to prevent loss of the device. After mooring the boat at the experiment site, the moon jelly was released in the surface layer (0～0.3m) and excess polyethylene line was extended to provide slack (**Fig.2**). The micro data logger was set to record both depth and temperature at 10s intervals.

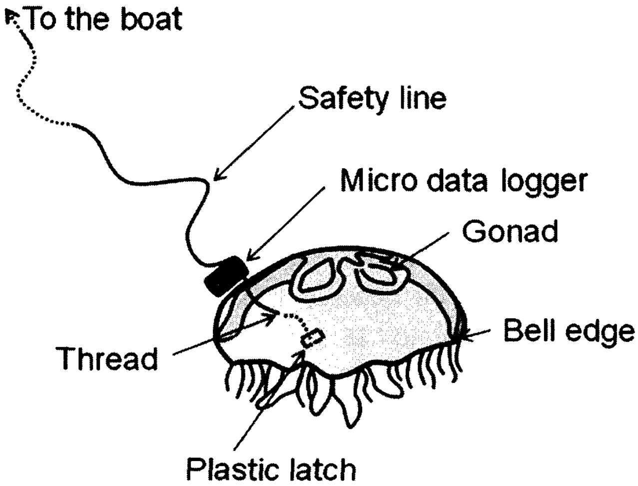

Fig.2 Schematic diagram of the micro data logger attached to the moon jelly.

Micro data logger: 8.3×25.4mm, neutral buoyancy, Thread: polyethylene 0.13mm diameter, 0.2m long, Plastic latch (tied to the line inside of the bell), Safety line: polyethylene 0.13mm diameter, max. 100m long.

Conditions of moon jellies after release were checked by snorkeling at 0.5～2h intervals during the day. Tracking was suspended in cases where the micro data logger had fallen off, or where the line interrupted the natural behavior of the moon jelly. We defined tracking duration as a duration between start time and time when moon jelly was normally observed at the last snorkeling. To familiarize ourselves with the apparatus and its use, tracking was initially conducted during the day. After we became more familiar with the equipment, we tracked the moon jellies at nighttime and for longer durations. After tracking, the moon jelly was retrieved by snorkeling and the bell diameter was measured (**Table 2**). In cases where tracking was disrupted, e.g. when the micro data logger was detached during the experimental run, the bell diameter was not recorded and is not included in **Table 2.**

During tracking, a quantum data logger (MDS MkV-L, Sampling interval: 1 sec., JFE Advantech Co. Ltd., Nishinomiya, Japan) was placed at the side of the boat to monitor photon flux density as an index of light condition.

Table 2 Details of the field experiments and average values of swimming depths, ambient water temperatures, and photon flux densities at the water surface

ID	Date in 2009	Bell diameter* (mm)	Observation time (hh : mm)	Duration (min)	Swimming depth (m)**	Ambient water temperature (℃)**	Photon flux density (μmol/m²s)**
F1	June 8	200	12 : 15-13 : 48	93	1.1 (0.33)	23.7 (0.30)	3841 (459)
F2	June 8	209	12 : 20-14 : 25	125	0.3 (0.09)	25.6 (0.44)	3841 (459)
F3	June 15	–	12 : 20-14 : 30	130	0.2 (0.18)	26.3 (2.01)	1495 (941)
F4	July 23	–	17 : 00-18 : 32	92	4.3 (0.98)	27.1 (0.12)	1046 (815)
F5	July 27	–	14 : 20-15 : 31	71	1.5 (0.68)	26.3 (0.43)	2124 (519)
F6	Oct. 9	–	12 : 38-14 : 03	85	3.1 (0.42)	23.5 (0.08)	796 (160)
F7	Oct. 16	220	09 : 51-11 : 55	124	6.9 (1.74)	22.9 (0.17)	3831 (479)
F8	Oct. 30	135	01 : 20-07 : 20	300	5.2 (0.41)	21.9 (0.05)	111 (140)
F9	Nov. 6	135	09 : 44-17 : 27	463	6.8 (0.51)	20.3 (0.20)	1651 (1167)
F10	Nov. 7	120	01 : 22-06 : 30	308	6.4 (0.56)	20.6 (0.14)	–

* Bell diameters were not recorded when the micro data loggers detached during the experiments
** Average value (standard deviation)

3. Results

1) Aquarium experiments

The bell pulse frequencies of the moon jellies before and after attachment of the micro data loggers are summarized in **Table 1**. Data were used as the baseline for the experiment. The mean bell pulse frequencies varied among moon jellies, ranging from 17.7 to 35.0 pulses/min and from 18.7 to 35.7 pulses/min for the pre- and post-attachment frequencies, respectively. No difference in the frequency between pre- and post attachment of the micro data logger was observed within an individual (Wilcoxon test, $p>0.05$). In addition, video recordings were done until the next morning of the experiments and these observations confirmed that the micro data logger remained in the desired position (on the bell) for at least 5h in the 6 moon jellies tested. After concluding that attachment of the micro data logger did not interfere with the activity of the moon jellies, we proceeded to the field experiments.

2) Field experiments

A total of 16 tracking experiments were conducted from May to November. However, six of the tracking experiments conducted from May to July were completed within 60min in order to establish a protocol for field experiment (e.g. checking the condition of the safety line). Thus, 10 trackings with sufficient durations were obtained (71 to 463min) (**Table 2**). No moon jellies were observed in the study area during the period between August and September of 2009.

(1) June to July

A total of five tracking experiments were successfully done from noon (12 : 15) until before sunset (18 : 32) during the time when water temperature has risen to the highest level of a year. When the first long tracking experiments were initiated on June 8, the sea surface temperature was approximately 25℃; by July 27, it was approximately 30℃. **Fig.3** shows the vertical movements of moon jellies (black lines) and changes in photon flux density (grey lines) during experiments.

F1, which was released at 12 : 15 on June 8, gradually descended to a depth of 2.0m at 12 : 43 and ascended to 0.0m in depth at 12 : 57. This animal made a series of vertical excursions until 13 : 15, and then remained mostly in the depth between 1.0 and 1.5m. On the other hand, maximum depth of F2, released at 12 : 20 on June 8, was 0.5m and stayed in the shallow layer throughout the experiment. During tracking of these two animals, photon flux density reached an upper limit of its measurement range (approx. 4000μmol/m²s) when the quantum logger was under direct sunlight between 12 : 15 and 14 : 02, then gradually dropped to 2500 to 3000μmol/m²s levels due to the clouds that appeared by the end of tracking (14 : 25). F3 exhibited descending behavior shortly after it was released and returned to the surface layer after approximately 10min. It was cloudy at the beginning of this experiment but the weather became fair after 13 : 30. Data was not logged between 12 : 56 and 13 : 30.

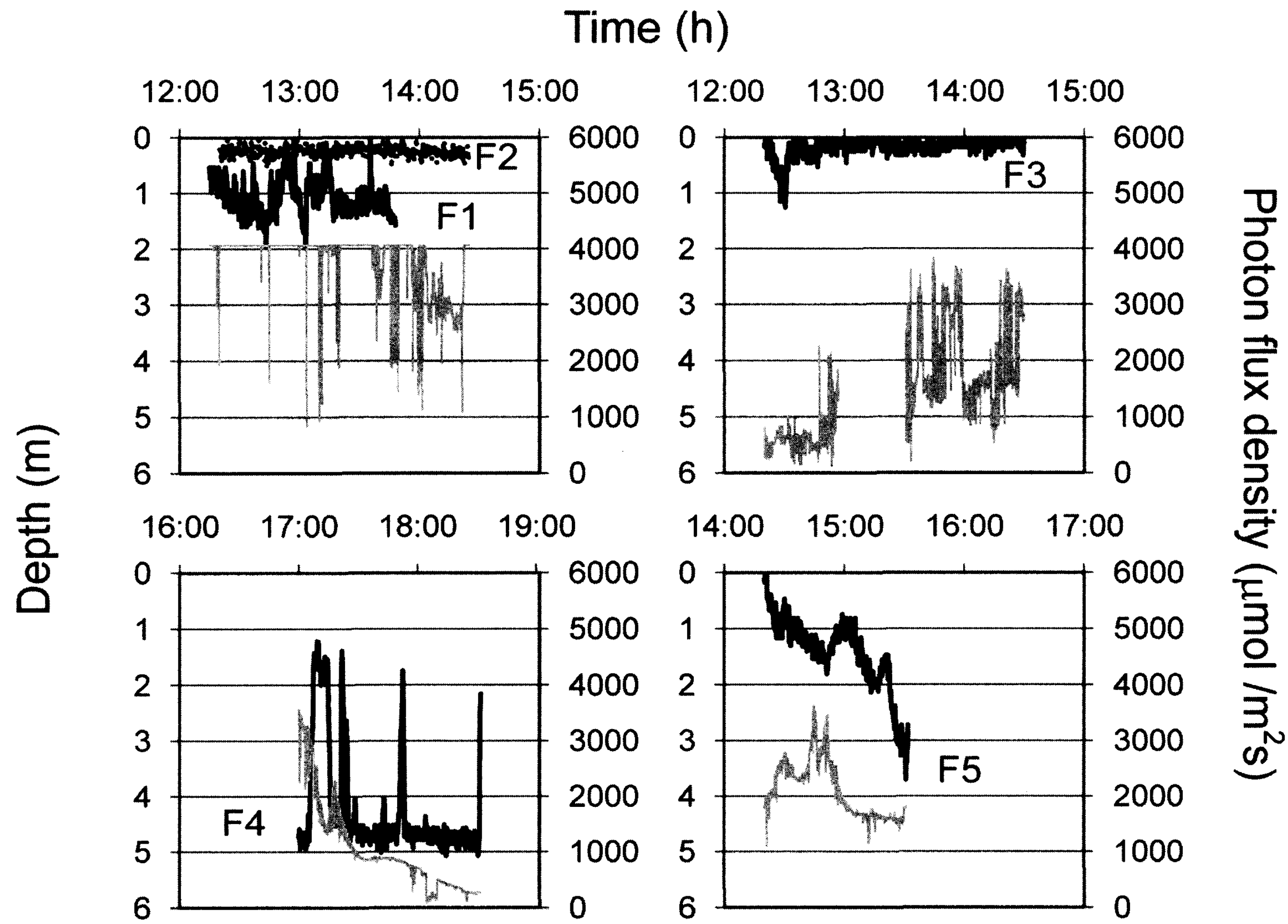

Fig.3 Changes in vertical depth profiles of moon jellies and variation in photon flux densities in June and July. Solid lines show depths and grey lines for the photon flux densities.

The initial behavior of F4, which was released on July 23, could not be quantified as the micro data logger was set to start recording at 17：00 (the time after the animal was released). This animal remained in the depth between 4.0 and 5.1m (approx. 1 to 3m above the bottom), but made upward and downward excursions with a maximum vertical speed of 0.7m/min. These excursions became less frequent as sunset approached (the time of sunset was at 19：26). During this experiment, the photon flux density was monotonously decreased from 3000 to approximately 250μmol/m^{2}s toward sundown.

F5, which was released at 14：20 on July 27, exhibited descending behavior and reached a depth of 1.8m after 31min (14：51), before ascending to a depth of 0.8m (14：59). This animal then resumed descending behavior and descended to a depth of 2.1m where it remained for 14min before ascending again. This type of short distance vertical excursions were repeated until 15：31 when the micro data logger was retrieved. Between 15：20 and 15：31, the same jellyfish took 11 min to descend from a depth of 1.5m to 3.7m, showing a maximum vertical speed of 0.2m/min. It was cloudy during this experiment and photon flux density was increased from 1800 to approximately 3600μmol/m^{2}s between 14：20 and 14：45, then decreased to approximately 1800μmol/m^{2}s at the end of the experiment (15：31).

Thus, three moon jellies (F1 to F3) tracked between 12：15 and 14：30 remained in the shallow layer (<2m). An individual (F4) tracked from 17：00 to 18：32, when the light level monotonously decreased, mostly remained aapproximately 1 to 3m above the bottom, exhibiting several vertical excursions to depths of 1～2m. Another individual (F5) tracked from 14：20 for 71min showed descending behavior from the surface to a depth of 3.7m at the end of the experiment.

(2) **October to November**

In this period, tracking experiments were conducted for longer durations than June to July season and we were able to perform experimental runs for most of the day (**Fig.4**). Sea surface temperature decreased over time in this period. In the earliest experiment

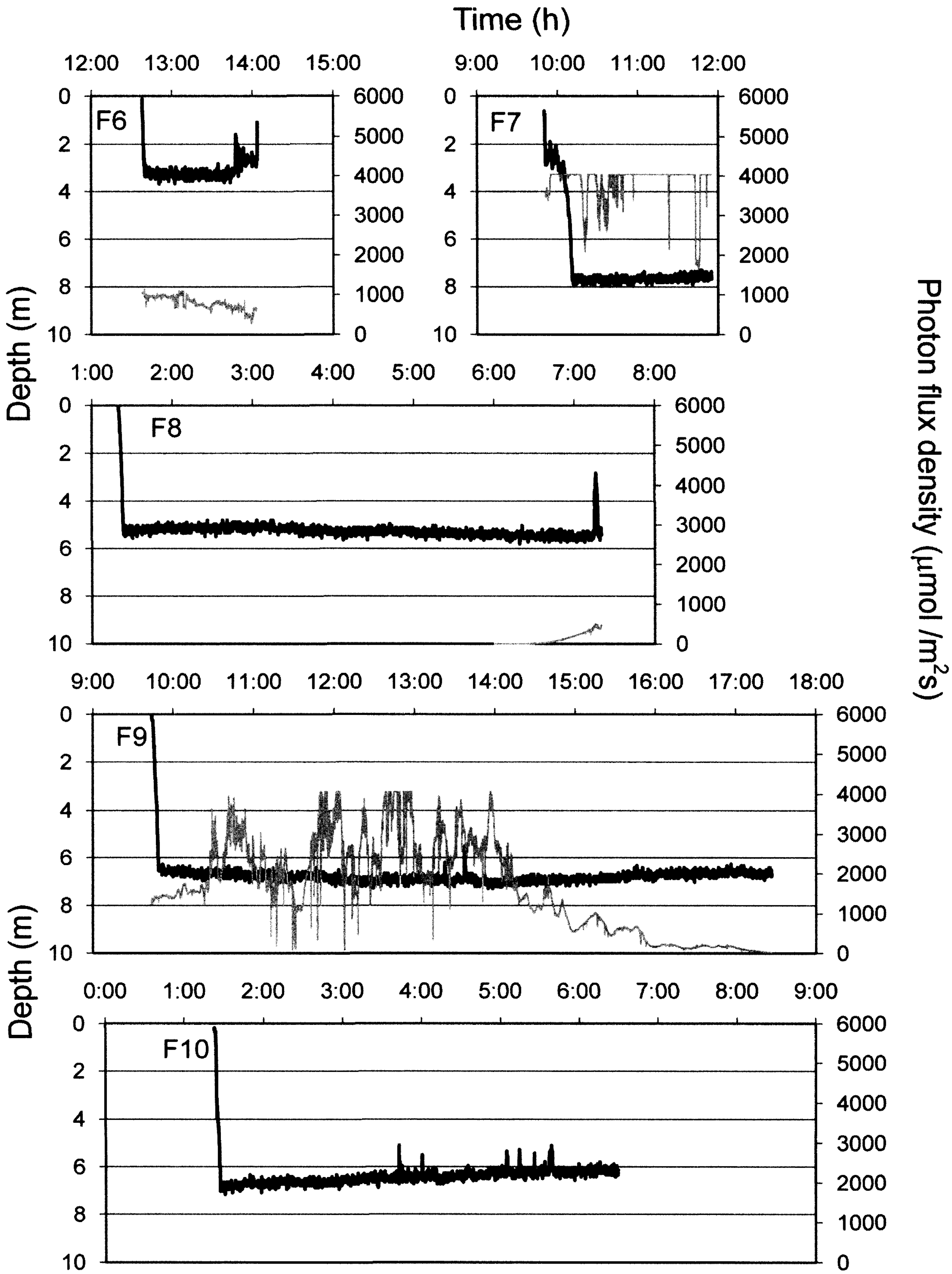

Fig.4 Changes in vertical depth profiles of moon jellies and variation in photon flux densities in October and November. Solid lines show depths and grey lines for the photon flux densities.

conducted on October 9, sea surface temperature was at 23.5℃ and dropped to 20.6℃ on November 7. All of the moon jellies (F6～F10) used in this period exhibited obvious descending behavior through the water column when released. Vertical speeds during descent ranged from 1.0 to 1.7m/min.

F6 descended after release, and then remained in the mid-water layer (2.8～3.6m) between 12：40 and 13：49. Thick clouds covered the whole sky during this experiment and the light condition was less than 1000μmol/m^{2}s.

Conversely, four moon jellies tracked after October 16 (F7～F10), descended and remained in the bottom layer (4.8～8.0m) in spite of periods of time. F7 was tracked in the late morning of October 16, when the sky was clear (approx. 2000～4000μmol/m^{2}s). This animal started descending at 9：51, reached a depth of 8.0m at 10：12, and then stayed at the same layer until the end of the experiment (11：55). F8, which was released at 1：20 on October 30, was tracked for 6h. This individual also showed initial descent for 5min when released and reached 5.4m deep. It continued to remain in the 5～6m depth until 7：13. The photon flux density became measurable after 6：20 and the light level gradually increased. This individual once exhibited upward and downward excursions for approximately 5min, reaching 2.8m deep around 7：15. A similar excursion behavior was observed for F9, although this experiment was conducted in daytime (9：44～17：27) on a fine day (November 6). The individual showed short distance (<1.6m) vertical excursions twice at 13：22 and 13：37.

The vertical movement of F10, tracked between midnight and sun rise (1：22～6：30) on November 7, was also similar with the others. It showed initial descent after release, staying in the deeper layer (6～7m deep) and a repetition of vertical excursions. The distances covered by these vertical excursions observed at 3：42, 4：00, 5：04, 5：14, 5：25 and 5：38, ranged from 1.0 to 1.5m.

4. Discussion

1) Validity of the attachment system

In the aquarium experiment, no significant difference was observed in the mean pulse frequencies of animals before and after attachment of micro data loggers (p>0.05), and it took at least 5h for the micro data logger to fall off. Conversely, the micro data logger was fallen off only within 30min (3 cases, not presented in **Table 1**) in the field experiments (May to July).

This difference in the length of available tracking time may be due to the attachment system that we employed. We attached the safety line to a micro data logger that is generally not employed in experiments for similar studies, because the safety line may impede the natural behavior of animals when it is under tension. Although the earlier study on compass jellyfish employed a similar attachment system and revealed its efficacy[12], the difference in flow condition between the field and the aquarium in our experiments may have an influence on the length of tracking time. Under aquarium experimental conditions, the detachment of the micro data logger was caused by water resistance of the micro data logger generated by bell pulse. In the case of the field experiment, the tidal range in the interior region of Omura Bay is known to be very small and simulation analyses revealed no existence of strong currents[16]. We also did not observe any movement on the surface water and/or of the rowboat due to currents during the field experiment, and ensured that the safety line was not under tension. However, in spite of careful handling, the combined effect of the micro data logger and the safety line on the water resistance of the bell is uncertain.

Individual differences in hardness of moon jelly's bodies may also be another reason. It was reported that the hardness of the bell of the giant jellyfish *Nemopilema nomurai* were 2.3～4.0times different, regardless of sizes and seasons[17]. For the moon jelly, the hardness of the bell would relate to the length of available tracking time.

The application of smaller pingers[18)～19] for tracking moon jellies would reduce or obviate the concerns regarding water resistance and hardness of moon jelly's body. In addition, the safety line for recovering the equipment is not necessary for these pingers since data is transmitted by acoustic signals.

2) Vertical behavior of moon jellies

When we released the moon jellies, the initial descents through the water column were observed for 8 individuals except F2 and F4. Five individuals tracked in October and November showed especially fast descent (1.0～1.7m/min) and this was within the range of the descent speed of the compass jellyfish (0.4～2.3m/min) in Ireland[12]. The other three tracked in June and July were between 0.1 and 0.2m/min. Individuals tracked in October and November remained close to the seabed after descent, even though they were collected in the shallow layer (0～0.3m). These might be the reaction of the moon jellies to handling and/or the attachment of the micro data logger. Similar initial descents were reported in studies for the compass jellyfish[12] and the giant jellyfish[13] .

Moon jellies released in June (F1~F3) tended to stay near the surface layer in the afternoon. F4, tracked after 17 : 00 of July, remained near the seabed and exhibited vertical excursions. In the afternoon of July, F5 descended gradually through the water column from the surface to approx. a depth of 3.5m between 14 : 20 and 15 : 31. Then 3 individuals tracked in the daytime of October remained in the midwater layer (approx. 3m deep) and near the seabed (approx. 5~8m deep). The other two individuals tracked in November were observed near the seabed regardless of day or night.

Thus, swimming depths of moon jellies varied between experiments. We examined relationships between the swimming depth of moon jelly and several factors (photon flux density at the water surface, ambient water temperature, and date), by comparing average values. As a result, no correlation was found for average values of the swimming depth and photon flux density (r=0.24, p=0.53). On the other hand, a significant correlation was found between the swimming depth and ambient water temperature (r=0.72, p <0.05), but it did not explain monotonous increase in swimming depth with the lapse of days, while water temperature reached highest at the end of July. The average and variance of swimming depth in each experiment was plotted against the date in **Fig.5**. This figure clearly suggests that the average swimming depth of moon jelly shifted to the deeper layer in relation to the date (r=0.90, p<0.01), while variance seems

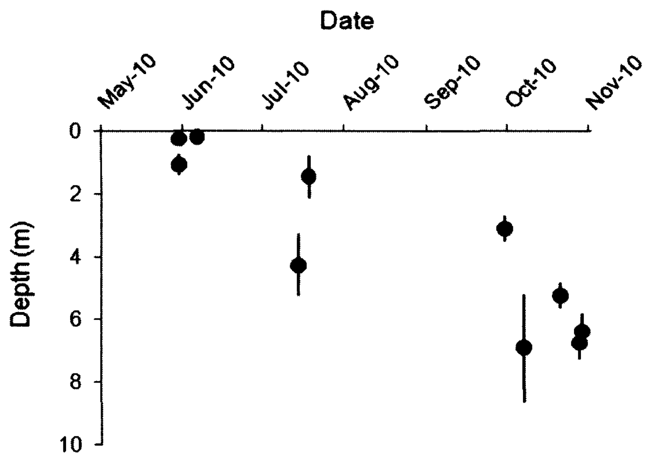

Fig.5 Time series changes in the average and standard deviations of swimming depths of moon jellies. Solid circles designate average depths of moon jellies, and bars, standard deviations.

almost constant during the period. This time related change in moon jellies' swimming depths may be influenced by the age of moon jellies. Negative buoyancy and an innately lower swimming ability of gerontic moon jellies observed in October and November may result to individuals staying close to the seabed.

Based on the findings of this study, a risk of moon jelly bycatch for a trawl fishery in Omura Bay increases in October and November, when most individuals remain closely associated with the seabed. In addition, an individual tracked in July (F4) tended to remain on the seabed in the evening. It is probably difficult to avoid bycatch of moon jellies by controlling the trawling time, since these trawlers target the tiger prawn *Penaeus semisulcatus* and mantis shrimp *Oratosquilla oratoria* and operate mainly in the nighttime throughout the year. Further studies that consider three-dimensional movement of moon jellies in relation to environmental parameters need to be undertaken to develop bycatch mitigation measures that exploit the behavioral characteristics of moon jellies.

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【報　文】

超小型データロガーを用いたミズクラゲの鉛直移動追跡

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和　文　要　旨

ミズクラゲに超小型データロガーを装着して鉛直移動を記録した。データロガーは水槽内では５時間以上装着可能で，装着前後の傘の拍動数に有意差はなかった。大村湾浅海域においてこの方法で，2009年６～７月と10～11月に10個体について記録を得た。ミズクラゲは６～７月の日中には表層付近に，10～11月には時間帯にかかわらず海底付近に滞在することが多かった。10個体中８個体がデータロガーを装着して放流した際に沈降した。この沈降行動は取り付け作業に対する反応かもしれない。

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