遠洋水研報　第36号　55-60頁　平成11年3月
Bull. Nat. Res. Inst. Far Seas Fish., No. 36, 55-60, March 1999

Tracking Experiments of the Jumbo Flying Squid, *Dosidicus gigas*, with an Ultrasonic Telemetry System in the Eastern Pacific Ocean

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Vertical and horizontal movements of three individuals of *Dosidicus gigas* (35-43 cm in mantle length) were observed with an ultrasonic telemetry system in the area of the Costa Rica Dome and in Peruvian waters in October-November, 1997. Squid were tagged and released several hours after sunset and tracked for 8-14 hours. Swimming activity was usually above 200 m depth during night and they dived to bathypelagic (>1000 m) layer either at the time of twilight (two experiments) or at 0:55 in local time, five hours before the sunrise (one experiment). The diving speed varied between 2 and 28 m minute^{-1}. In every experiment, squid was lost since they probably dived beyond the limit of the transmitters used (1,020 m).

Key words: biotelemetry, jumbo flying squid, eastern Pacific

Introduction

The jumbo flying squid, *Dosidicus gigas* (Orbigny, 1835), is the largest species among the family Ommastrephidae attaining 120 cm in mantle length (ML) and has a distribution confined to the eastern Pacific Ocean, east of 120° W longitude, between latitudes of 35° N and 50° S (Nesis, 1983). This species was first exploited in the 1970's in the Gulf of California (Ehrhardt et al., 1983). In response to international criticisms to squid driftnet fishery, a large-scale commercial jig fishery targeting *D. gigas* was initiated in Peruvian waters in 1991 by Japanese and Korean fishers (Yokawa, 1996; Masuda et al., 1998; Yamashiro et al., 1998). The annual catch of this fishery has increased each year up to 165,000 metric tons (t) in 1994, then drastically decreased to 80,000 t in 1995 owing to the dispersion of the stock associated with environmental changes (Yamashiro et al., 1998). Recently, fishing grounds have expanded to the area of the Costa Rica Dome and revived within Mexican waters.

Since 1956, studies using biotelemetry have been carried out to observe in situ behaviors of various marine organisms (Kajiwara, 1972; Stasko and Pincock, 1977). With regard to pelagic cephalopods, Nakamura (1991, 1993, 1994) and Murata and Nakamura (1998) reported horizontal movement and diel vertical migration of neon flying squid, *Ommastrephes bartramii,* and Iizuka (1990) and Kosuge et al. (1997) studied on diamondback squid, *Thysanoteuthis rhombus.* The behavior and movement patterns of *D. gigas* has not been well documented and this paper presents preliminary results of three telemetry experiments of the *D. gigas* conducted in 1997 on board the Fisheries Agency of Japan research vessel *Kaiyo Maru.*

Materials and Methods

Three *D. gigas,* 35-43 cm ML, obtained from the area of the Costa Rica Dome (Experiment 1) and in Peruvian waters (Experiments 2 and 3, Table 1) were monitored for this study (Fig. 1). The squid were captured with hand jigs and kept in a tank for 20 to 30 minutes while preparations for tracking were tended to. The ultrasonic transmitter was attached to the mantle of a squid with a rubber band immediately forward of the fins (Fig. 2), measured for mantle length, and released. All three squid were judged to be females rather than males based on the configuration and softer body of the subjects. Body weight was estimated from mantle length. Specifications of the transmitters employed in

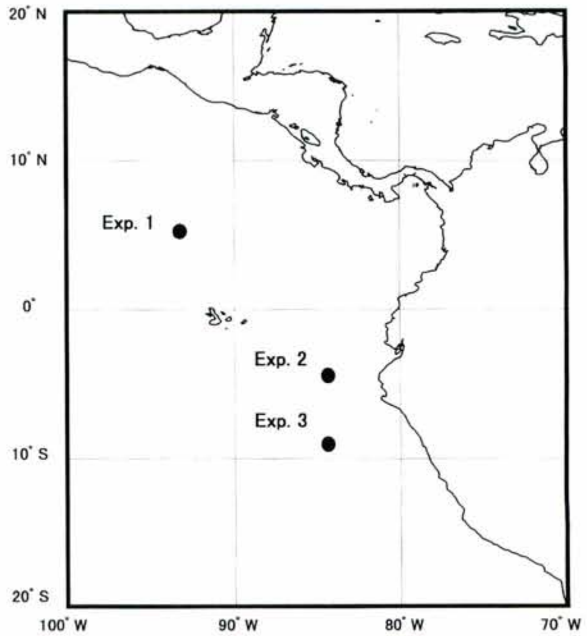

Fig. 1. Locations of tracking experiments of *Dosidicus gigas.*

1999年1月18日受理　遠洋水産研究所業績　第373号
Accepted on January 18, 1999. Contribution No. 373 of the National Research Institute of Far Seas Fisheries.
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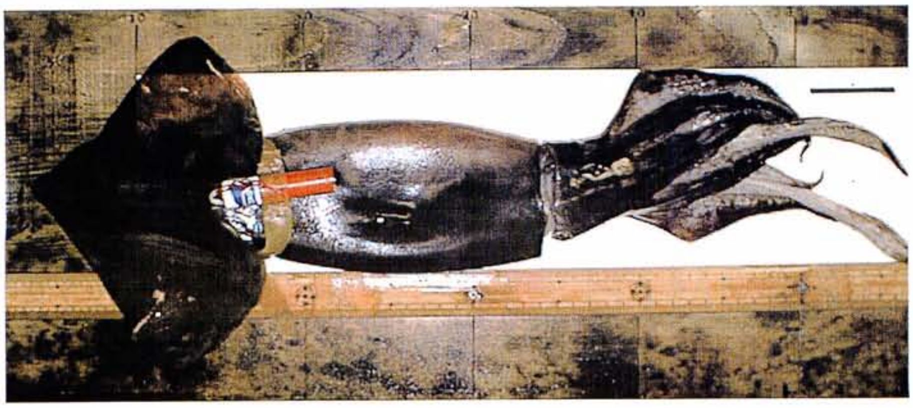

Fig. 2. *Dosidicus gigas* with an ultrasonic transmitter (V16P-1H). This squid was used for observation of swimming activities in a tank. Bar = 5 cm.

the study (model V16P-1H and V16P-4H, Vemco Co.) is presented in Table 2. The signals (pulses) were received with a hull mounted hydrophone, depth data were decoded with an ultrasonic receiver (model VR-60, Vemco Co.), and the data were stored on a personal computer at one-second intervals. The ship positions, obtained from an NNSS-GPS navigation system (model SNA90, Japan Radio Co.), were also recorded at one-second intervals. The local time used in this report was GMT -5 hr for the Costa Rica Dome area and GMT -6 hr for Peruvian waters, respectively.

Results

The vertical movement of *D. gigas* in the three experiments is presented in Fig. 3.

Experiment 1 (Fig. 3A)

The 35 cm ML squid dived quickly immediately after the release (19:53) and reached to 200 m depth at 20:06. Swimming depth was maintained between 220 and 240 m until 23:30 when the squid migrated upward and occupied 44-79 m depths. Communication with the squid was temporarily lost at 2:05 due to a problem with the receiver. Upon finding of the squid at 2:45, she dove to a depth of 150 m at a rate of 3.7 m minute^{-1} appearing to escape from the approaching ship. Swimming depths were subsequently 40-100 m after 3:47, then around the dawn (5:09) she began to dive quickly from 93 m at a rate of 21.6 m minute^{-1} to a depth of 396 m at 5:23. Except for a short interval from 5:28 to 5:51 at around 350 m depth, the squid descended at a rate of 19.4 m minute^{-1} and reached to 530 m at 6:00, two minutes after sunrise. The rate of descent decreased to 1.9 m minute^{-1} and reached about 990 m at 9:09. Signals received thereafter were too weak to extract reliable depth data and limited ship time forced abandonment of the experiment. During the 14 hours of tracking, the squid moved horizontally about 4 nautical miles ENE at an overall mean speed of 0.15 m second^{-1}. No difference in speed of horizontal movement before and after the sunrise was detected. From a conductivity-temperature-depth (CTD) cast conducted at the jigging site, temperature was 28°C

Table 1. Outline of telemetry experiments of *Dosidicus gigas.*

Experiment No. (Transmitter)	Mantle length (Body weight - estimated)	Assumed Sex	Start Location	End Location	Start Time of day	End Time of day
Exp. 1 (V16P-1H)	35 cm (1100 g)	♀	5°06'N 93°00'W	5°08'N 92°57'W	Oct.10 19:53	Oct.11 10:00
Exp. 2 (V16P-1H)	40 cm (1800 g)	♀	4°30'S 84°01'W	4°33'S 84°00'W	Oct.20 20:27	Oct. 21 03:50
Exp. 3 (V16P-4H)	43 cm (2200 g)	♀	9°00'S 84°01'W	9°01'S 83°56'W	Nov. 4 19:14	Nov. 5 09:00

Table 2. Specifications of ultrasonic transmitters.

Type	Weight in water/air(g)	Length (mm)	Diameter (mm)	Frequency (kHz)	Power (dB)	Range (m)	Life (days)
V16P-1H	9/23	62	16	50	152	1020	12
V16P-4H	12/28	80	16	50	153	1020	60

above 70 m depth, 15° C at 150 m, and 4.5° C at 1,000 m, with a thermocline between 70 and 150 m depth; concentrations of dissolved oxygen was over 4.0 ml L^{-1} above 100 m depth, less than 1.0 ml L^{-1} between 200 and 750 m, and 1.8 ml L^{-1} at 1,000 m depth.

Experiment 2 (Fig. 3B)

This squid (40 cm ML) remained between 27 and 50 m just after release (20:27) until 21:53, when she moved to a depth of 120 m at 22:09 and stayed between 110 and 220 m until 00:54. A sudden rapid descent at a remarkable speed of 27.6 m $minute^{-1}$ from 219 m to 578 m was observed at 01:08, followed by a reduction in speed to 4.0 m $minute^{-1}$ until she reached 926 m at 3:29. Beyond this depth acoustic signals became very unstable and irregular. We estimated, however, that a depth of 1200 m was attained at 3:49, resulting in a

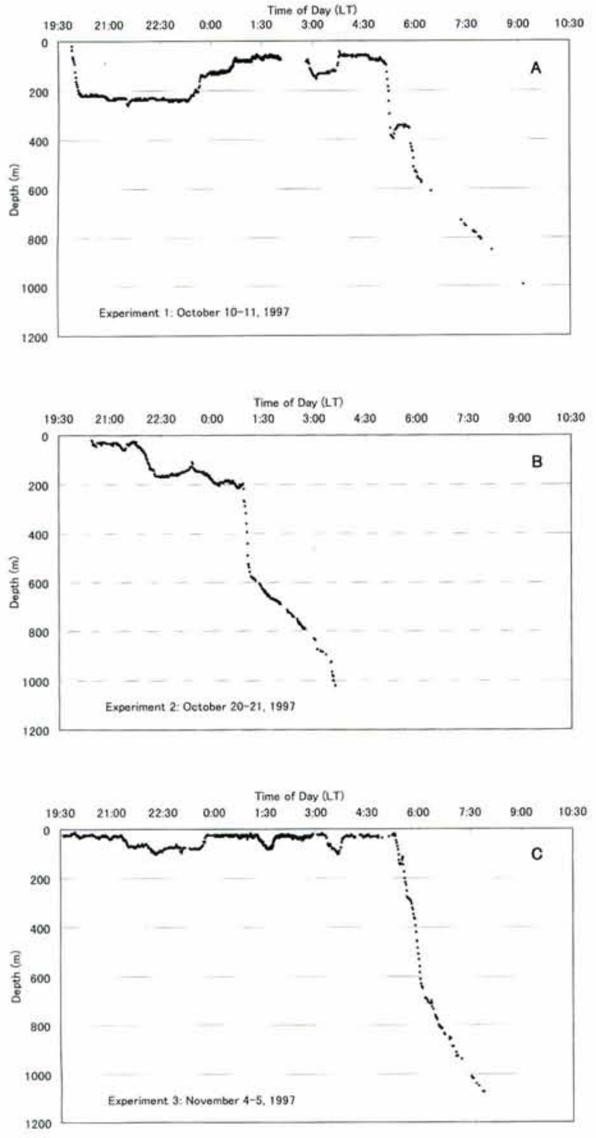

Fig. 3. Vertical movements of three *Dosidicus gigas* (A: Experiment 1, B: Experiment 2, C: Experiment 3). Depth data were indicated at one minute intervals when pulses were received in a good condition, but all data were included when pulses were so weak to obtain reliable data, according to great depth beyond the limit of the transmitters used (1,020m). LT = local time.

descending speed of 10.7 m $minute^{-1}$. Monitoring of the dive was suspended until 18:00 when we expected that squid would ascend to midwater or surface layer according to the pronounced diel vertical migration of ommastrephid squids (Moiseev, 1991; Nakamura, 1991, 1993, 1994; Yatsu et al., 1995; Kosuge et al., 1997; Murata and Nakamura, 1998). Unfortunately, communication was never re-established despite searching efforts for the squid until 24:00 in the expected area of reappearance. During the 8 hours of tracking, the squid traveled horizontally three nautical miles SSE; most of this movement was attained by 2:00. The overall average speed of horizontal movement was calculated to be 0.21 m $second^{-1}$, however, average speed could be 0.36 m $second^{-1}$ since the squid substantially stayed at the same position after 02:00. A CTD cast conducted at the jigging site measured temperatures of 25° C above 30 m depth, 21° C at 70 m, 14° C at 200m, and 4.5° C at 1,000m, with a thermocline between 60 and 70m depth; concentrations of dissolved oxygen exceeded 4.0 ml L^{-1} above 60 m depth, was less than 1.0 ml L^{-1} between 300 and 790 m, and 2.2 ml L^{-1} at 1,000 m depth.

Experiment 3 (Fig. 3C)

In this experiment, we attempted to minimize the handling time since two previous squid were lost. A larger squid (43 cm ML) than those used in the previous experiments was also selected because we intended to employ a heavier transmitter containing a longer-lived battery. The swimming layer of this squid during the night was the most stable among the three experiments, occupying between 14 and 103 m depth until 5:09. Two short excursions to 90 m were observed around 1:30 and 3:30 which may have been caused by the approaching ship. As dawn approached, she undertook a sudden dive from a depth of 30 m at 5:21 to 689 m at 6:12, with a short stay at 120-140 m for 8 minutes. The average speed of this dive (excluding the 8 minutes at 689 m) was 16.0 m $minute^{-1}$. Seven minutes after sunrise (6:06), her diving speed decreased to 8.1 m $minute^{-1}$ and appeared to reach 1,125 m at 8:06, although signals were few and weak. As in the Experiment 2, attempts to locate the squid during late afternoon were made but without success. This squid horizontally traveled 5 nautical miles ESE during the 14 hour tracking, with an average speed of 0.18 m secon d^{-1}. The average speed was slightly higher (0.31 m $second^{-1}$) after 5:00 when she moved east. A CTD cast made at the end of the tracking, measured temperatures of 24° C above 55 m depth, 19° C at 70 m, 14° C at 200 m, 4.6° C at 1,000 m, and 3.1° C at 1,500 m depth, with a thermocline between 55 and 70 m depth. Concentrations of dissolved oxygen was over 4.0 above 60m depth, less than 1.0 ml L^{-1} between 140 and 800 m, 2.1 ml L^{-1} at 1,000 m, and 3.0 ml L^{-1} at 1,500 m depth.

Discussion

All of the tagged squid were lost because they dove below 1,020 m deep, which exceeded the nominal limit of the transmitters. Conceivably, lost contact with the tagged squid may be due to the transmitters dropping off the animals or the death of the squid. The possibilities of dropping off and squid mortality as a cause were dismissed for the following three reasons. First, the rate of descent was reduced beginning at about 600 m depth in all three of the experiments, suggesting a common behavior of their dives. Second, possible physiological stress induced by the equipment is believed to be minimal since the weight of the transmitter in air is less than 2% of the total weight of the tagged squid, within the allowable transmitter-to-animal ratio that would not seriously affect the behavior of fishes and squids (2-3%; Kakimoto et al., 1990; Nakamura, 1993, 1994). Third, maximum depths of occurrence of five species of the ommastrephid squids are reported to be 780-1,947 m from submersible observations; i.e., 950 m for *Ommastrephes bartramii,* 1,200 m for *Sthenoteuthis pteropus,* 1,080 m for *Sthenoteuthis oualaniensis,* 780 m for *Hyaloteuthis pelagica,* 820 m for *Illex argentinus,* and 1,947 m for *Todarodes sagittatus* (Moiseev, 1991). We therefore speculate that *D. gigas* also inhabits bathypelagic waters during the day.

The swimming layer of *O. bartramii,* the most closely related species of *D. gigas* (Yokawa, 1994), during the day was about 600-800 m in the subtropical area around the Ogasawara (Bonin) Islands (Nakamura, 1994), and 160-320 m in the subarctic and transitional waters in the North Pacific Ocean (Nakamura, 1993, 1994). From 10 telemetry experiments of *O. bartramii* conducted by Murata and Nakamura (1998), it is shown that four squid tracked in the area of more northern latitudes (43-46°N) than other squid (41-44°N) occupied remarkably shallower depths (20-120 m) during the day. This north-south cline in the swimming layer may be supported from catch rates in the experimental daytime jigging operations for *O. bartramii* in the North Pacific Ocean (FAJ, 1996). Although the jig fishing gear are restricted to sampling depths less than 300 m (Inada et al., 1995), the daytime catch rates were generally lower in the Transitional Domain (40-42°N) in June than that in the Subarctic Domain (44°N) in August (FAJ, 1996). Nakamura (1993, 1994) suggested that the maximum depth of vertical migration of *O. bartramii* might be delimitated by light intensity and by water temperature. Nakamura (1994) also reported rates of vertical movement at around sunrise and sunset to be 4-5 m $minute^{-1}$, which corroborates observations made in the present experiments.

Commercial fishing for *D. gigas* with jigs in Peruvian waters are usually conducted during night (mostly 21:00-06:00 in the austral summer); daytime jigging is infrequent (Yokawa, 1996). Catch rates during the daytime hours are usually low, but in some years (e.g., from 1991 to 1993), higher catch rates (20 to 121 t $month^{-1}$ $vessel^{-1}$) were recorded, mainly in August and September, between 6:00-18:00 (Instituto del Mar del Peru, unpublished data). This suggests that the swimming layer of *D. gigas* in the daytime is usually beyond the effective fishing depths of jigging gear, although the resource can be accessible near the surface under certain oceanographic conditions such as low temperature.

Nesis (1993) summarized vertical migration of purpleback flying squid *S. oualaniensis* in the Indian Ocean, where he recognized three different biological forms: dwarf, middle and giant. The dwarf and middle forms undertake diel migration between surface and midwater layers. The giant form usually stays throughout the day in the midwaters (200-350 m depth) where oxygen minimum (0.2-0.4 ml L^{-1}) is evident below 150 m in the western Indian Ocean. In the present study, the oxygen minimum layer was also distinct between the depths of 200 m and 800 m. In the future, more powerful transmitters are required to confirm behavior of *D. gigas* in the bathypelagic layer. Concurrent environmental studies are also required to help determine the factors affecting their diel vertical migration.

Acknowledgements

We thank the officers and crew of the *Kaiyo Maru* for supporting the present experiments on board. We thank Dr. Yoshikazu Nakamura of the Hokkaido National Fisheries Research Institute for his kind advice for the experiments. We also thank staffs of Ministry of Fisheries of Peru and Fisheries Agency of Japan for allowing the experiments in Peruvian waters and for their financial support. Dr. Michael P. Seki of the National Marine Fisheries Service, Honolulu Laboratory, kindly reviewed the manuscript.

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東部太平洋におけるアメリカオオアカイカのバイオテレメトリー追跡

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摘　要

1997年10～11月にペルー沖とコスタリカドーム海域においてアメリカオオアカイカ(*Dosidicus gigas*)のバイオテレメトリー調査を3回行い，垂直および水平移動を観察した．超音波発信器を装着した外套長35～43cmのアメリカオオアカイカを日没後数時間後に放流し，8～14時間追跡した．アメリカオオアカイカは夜間に通常200m以浅を遊泳し，日出薄明時（実験1，3）または深夜（日出5時間前の0：55，実験2）から毎秒2～28mで急速に潜航して水深1000m以深に達した．3回の実験とも標識個体を見失ったが，これは発信器の最大到達距離である水深1020mを超えて潜航したためと思われた．

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