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ON THE FLYING BEHAVIOR OF NEON FLYING SQUID *ONMASTREPHES BARTRAMI* OBSERVED IN THE CENTRAL AND NORTHWESTERN NORTH PACIFIC

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1988 September

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Murata, Mamoru. 1988. On the flying behavior of neon flying squid *Onmastrephes bartrami* observed in the central and northwestern North Pacific. (Document submitted to the Annual Meeting of the International North Pacific Fisheries Commission, Tokyo, Japan, 1988 October.) 8 p. Fisheries Agency of Japan, Hokkaido Regional Fisheries Research Laboratory, Kushiro Hokkaido, Japan 085

Nippon Suisan Gakkaishi 54(7), 1167-1174 (1988)

On the Flying Behavior of Neon Flying Squid *Ommastrephes bartrami* Observed in the Central and Northwestern North Pacific

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(Received December 12, 1987)

The flying behavior of neon flying squid was observed at 8 different locations in the subtropical region between long. 160°E and 172°W along lat. 37°N (surface temperature: 17–24°C), on board the R/V *Omi-Maru* in the period from July to August, 1984. Roughly 10–300 squids (estimated mantle length: 14–18 cm) flew a distance of 10–20 m at a height of 1–2 m above the sea surface in the same direction both by day and by night. The form of squid in flight closely resembled that of purpleback flying squid. Judging from these results, it is beleived that the smaller individuals under about 18 cm in mantle length of neon flying squid live mainly near the surface of the sea, by day and night, and that they have a gliding-type flying behavior like flying fish, mainly to escape from their enemies.

Several species of the family Ommastrephidae are known to show a leaping, or flying behavior.[1-5] Arata[1] reported on the flying behavior of neon flying squid, *Ommastrephes bartrami*, or webbed flying squid, *O. calori*, observed off the Atlantic coast of North America. Akimushkin[2] and Clarke[3] also referred to the flying behavior of these species, and reported that the name "flying squid" was applied to *O. bartrami* because of this behavior. It was also reported[4] that purpleback flying squid *Sthenoteuthis oualaniensis* was observed flying over the sea surface off the Pacific coast of the southern Japan. Moreover, Azuma[5] inferred from photographs of purpleback flying squid in flight in the Indian Ocean that their arms and instant membranes would play a vital role in flight.

However, none of the reports have included such information as the size of the squids observed flying, their numbers, flight condition, and associated oceanographic and weather conditions. Although the neon flying squid stock is quite considerable in the northern part of the North Pacific,[6] and yields an estimated 182,000 tonnes per year (1982–86 average) to Japan's squid gillnet and jigging fisheries,[7] virtually no information has yet been reported on the flying behavior of this species from this area.

During a survey on the distribution of squid in the North Pacific in 1984, 8 flights of neon flying squid were observed. The results of the observations and some considerations on the relationship between flying behavior and body length of the squid, the possible causes of the flight behavior, and the swimming depths of the squid, are presented here.

Materials and Methods

The survey on the distribution and abundance of neon flying squid, as well as on marine mammals, in the central and northwestern North Pacific, was carried out between July 1 and August 3, 1984, using the research vessel *Omi-Maru* of the Yamaguchi Prefectural Fisheries High School (417.47 GT, 47.10 m in overall length). The cruise track, locality of station for operations, and the principal survey items, are shown in Fig. 1.

Squid jiggings were operated at 22 stations by night (2000–2300); while gillnets were set at 17 stations before sunset, and retrieved in the early morning hours (0300–0600) of the next day. The sighting survey for mammals was carried out each day in the daytime between sunrise and sunset on the run between Honolulu, Hawaii, and Kushiro, Hokkaido. All times given in this report are local times. Sunrise and sunset occurred at 0341 and 1819, respectively, at lat. 37°N, long. 172°W; and at 0447–0449 and 1913–1916, respectively, at lat. 37°N, long. 158–175°E.

To avoid size bias in the catch from mesh-size selectivity, the gillnet used was constructed of 13 different mesh sizes as follows: 33, 37, 42, 48, 55,

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Table 1. Data relevant to observations on flying behaviors of neon flying squid on board the R/V *Omi-Maru* in 1984

Obs. No.	Date	Location	Time	Number of squid in flight	Range & Mode of Mantle Length (cm)	Sea Surface Tem. (°C)	Sea Surface Sal. (‰)	Wind Direction & Scale	Weather
1	7 July	37°03′N, 172°00′W	0700	ca. 100	15–44, 17·18	19.2	34.12	ESE 4	BC
2	20 July	37°09′N, 175°06′E	0530	20–30	16–42, 18	17.4	33.94	ENE 5	C
3	20 July	37°01′N, 173°06′E	1633	200–300	16–29, 18	21.0	34.66	ENE 4	C
4	20 July	37°01′N, 173°05′E	1638	ca. 50	16–29, 18	21.0	34.66	ENE 4	C
5	20 July	37°01′N, 173°03′E	1648	10–20	16–29, 18	21.0	34.66	ENE 4	C
6	23 July	37°00′N, 162°–163°E	0700 –1100	Several tens	16–30, 17	21.7	34.63	SE 3	F
7	23 July	37°00′N, 160°32′E	1810	Several hundreds	13–18, 14	24.0	34.45	Calm	BC
8	23 July	37°00′N, 160°20′E	2100	ca. 100	13–18, 14	24.0	34.45	Calm	BC

63, 72, 82, 93, 106, 121, 138 and 157 mm.

Results

Flight Observations

During the survey, the flight of neon flying squid was observed eight different times during July 7–23, 1984 (Fig. 1) and the relevant data are shown in Table 1. The present author witnessed one flight of neon flying squid in a group during a squid jigging operation (No. 8 in Table 1) and two others when the gillnet was being retrieved (Nos. 1 and 2 in Table 1), while another researcher (Hiroyuki Yamawaki) on board observed 5 flights (Nos. 3–7 in Table 1) along the vessel's track during sighting surveys.

All of these observations were made at the southernmost extremity (near lat. 37°N) of the survey area (lat. 37–43°N) (Fig. 1). The results of the flight observations were as follows:

(1) Observation 1 (No. 1 in Table 1)

At lat. 37°03′N, long. 172°00′W (Station 1) at around 0700 on July 7, approximately 100 squids became airborne near the floatline of the gillnet, about 20–30 m from the ship, as the net was being retrieved. The squids flew a distance of 10–20 m at right angle to the gillnet, at a height of 1–2 m above the sea surface. The squids were estimated to be of about the same size as neon flying squids that were being caught in large numbers by the gillnets of 48 and 55 mm in mesh size (range in dorsal mantle length: 15–19 cm; modal length, 17 cm). The flight occurred immediately after the rolling ship had caused the floatline of the gillnet to slap sharply against the sea surface. At this station, the surface temperature was 19.2°C; salinity, 34.12‰; winds, E-SE'ly at Beaufort 4; and the weather was clear.

(2) Observation 2 (No. 2 in Table 1)

At lat. 37°09′N, long. 175°06′E (Station 26), at around 0530 on July 20, about 20–30 squids broke surface and became airborne about 20 m from the vessel as the gillnet was being retrieved. These squids flew a distance of 10–20 m in the direction of the vessel at a height of about 2 m above the surface of the sea. Three of the squids landed on the gillnet and were caught in the 72-mm mesh section (Fig. 2). The flight direction coincided with the wind direction, and the flight lasted only about 3–4 s. In flight, the squid resembled purpleback flying squid,[5] with fins and arms spread out in the horizontal directions. Moreover, the dorsal surface of the mantle and fins blended with the color of the sea, appearing very dark, while

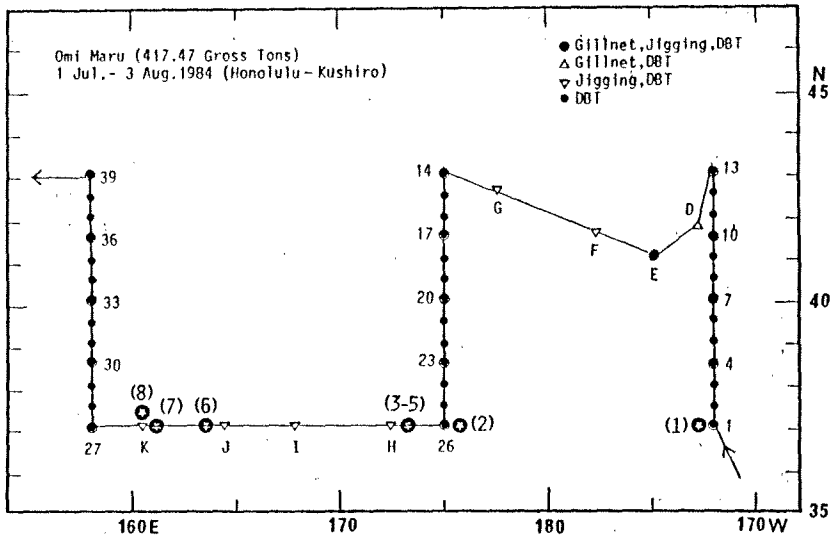

Fig. 1. Track chart of the R/V *Omi-Maru* during July and August in 1984, and the locations (stars) where flying behaviors of neon flying squid were observed. Numerals and alphabets denote No. of Stations, while numerals (1–8) in parentheses are the same as Obs. No. in **Table 1.**

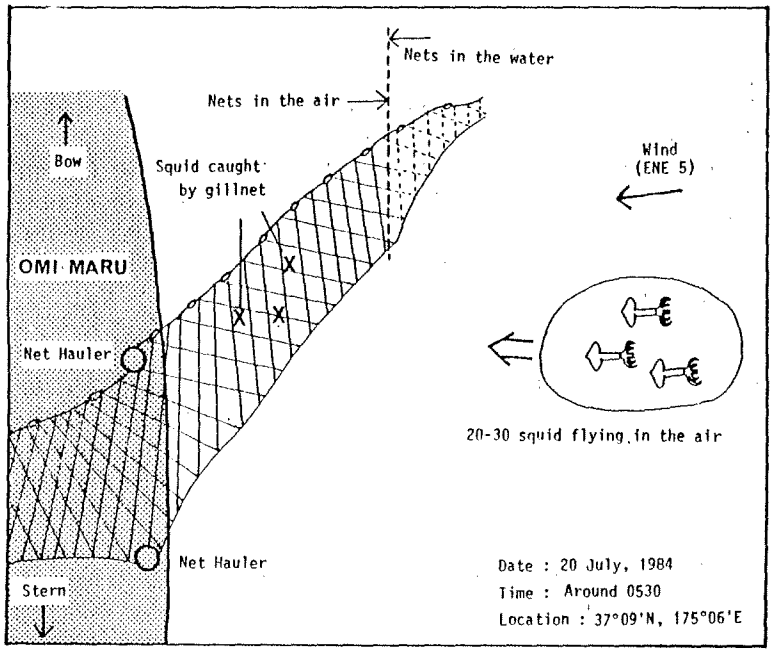

Fig. 2. A schematic diagram showing the flying behavior of squid observed on 20 July, 1984 (See No. 2 in Table 1).

the ventral surface of the mantle and the arms appeared whitish in color. The flight, similar to the previous one, occurred immediately after the sea surface had been sharply whipped by the floatline of the gillnet. At this station, the surface temperature was 17.4°C, the salinity, 33.94‰, winds E-NE'ly at Beaufort 5, and the weather was cloudy.

(3) Observation 3–5 (Nos. 3–5 in Table 1)

At around 1630 on July 20, while the vessel was underway at lat. 37°01'N, long. 173°06'E, approximately 40 common dolphins *Delphinus delphis* were sighted at a distance of about 3.6 km. The dolphins then began moving toward the

vessel and in about 10 minutes, were swimming alongside. Ahead of them and in their path, three separate flights of squid schools were observed. The first was at 1633 when 200–300 squids took flight; the second at 1638 when there were around 50 squids, and the third occurred soon thereafter, when roughly between 10 and 20 squids were seen flying. In each case, the flight was in the same general direction as the path of the dolphins. At Station H (lat. 37°01′N, long. 172°30′E) closest to these observed flights, the surface temperature was 21.0°C, salinity, 34.66‰, and winds, E-NE'ly at Beaufort 4; and the weather was cloudy.

(4) Observation 6 (No. 6 in Table 1)

While underway during the morning of July 23 (0700–1100), at lat. 37°00′N, long. 162–163°E, roughly between 30–50 of squids were observed in flight. At the station closest to this observed flight (Station J at lat. 37°00′N, long. 164°18′E), the surface temperature was 21.7°C. salinity, 34.63‰, and winds SE'ly at Beaufort 3. The area was covered by sea fog.

(5) Observation 7 (No. 7 in Table 1)

While underway at 1810 on July 23, at lat. 37°00′N, long. 160°32′E, 14 dolphins appeared near the vessel. Soon thereafter, roughly between 200 and 300 of squids were observed in flight. At the station nearest to this observed flight (Station K at lat. 37°00′N, long. 160°20′E), the surface temperature was 24.0°C, the salinity 34.45‰, and the weather was calm, and clear.

(6) Observation 8 (No. 8 in Table 1)

At around 2100 on July 23, while squid jigging was being operated at Station K at lat. 37°00′N, long. 160°20′E, about 100 squids became airborne about 20 m from the vessel. They flew in the direction of the vessel at a height of 1–2 m above sea surface and reentered the water close to the vessel. During the flight, the shape and coloration of the squid resembled the squid in the Observation 2 above. The size of these squids coincided with neon flying squid that were caught by jigging (range in dorsal mantle length: 13–18 cm; modal length, 14 cm). The flight began immediately after a large squid jig (20 cm long stainless steel hook used in hand jigging) was cast into the water. At this station, the surface temperature, salinity, *etc.* were as described above for the Observation 7.

Squid Catches in the Vicinity of Observed Flights

At the survey stations in the vicinity of the observed flights (near lat. 37°N), neon flying squid and luminous flying squid *Eucleoteuthis luminosa* were only two species taken. The catches totalled 2,318 neon flying squid and 615 luminous flying squid (Table 2).

Neon flying squid were caught in large numbers at all stations, and greatly outnumbered luminous flying squid at all but Stations I and J. Although relatively large numbers of lumious flying squid were caught at Stations H, I and J, between long. 164° and 172°E (102 to 331 squid per station), few were caught at the other stations (1 to 37 squid per station).

The height of gillnet (5–7 m) and the hook depths of jigging gear (0–30 m) used, are thought to represent the possible depths at which squid may be caught by these two fishing gears.

Size Composition of Neon Flying Squid

The dorsal mantle length compositions of neon flying squid taken at the locations where squids were observed flying, or at the stations nearest to flight observations, are shown in Fig. 3.

Although a fairly wide size range (15–49 cm) was seen in the squid taken at Station 1, 83% of the

Table 2. Catch records of squids by gillnets or jiggers at the locations around lat. 37°N on board the R/V *Omi-Maru* in 1984. Date and locations are those at onset of squid jigging

St	Date	Location	Number of squid caught			
			O. bartrami		*E. luminosa*	
			Gillnets	Jiggers	Gillnets	Jiggers
1	6 July	37°00′N, 172°00′W	344	282	0	4
26	19 July	37°00′N, 175°00′E	145	6	0	1
H	20 July	37°01′N, 172°30′E	—	640	—	136
I	21 July	37°01′N, 168°40′E	—	58	—	102
J	23 July	37°00′N, 164°18′E	—	285	—	331
K	23 July	37°00′N, 160°20′E	—	160	—	4
27	24 July	37°00′N, 158°00′E	106	292	0	37

catch fell within narrow range of 16–18 cm. The modal length was 17–18 cm. At Station 26 and Station H, 80% and 90%, respectively, of the catches were squids in the 17–19 cm size range; the modal length was 18 cm in both cases. At Station J, 95% of the catch were between 16 and 18 cm; the modal length was 17 cm. Similarly, at Station K, the size range was 13–18 cm; the modal length was 14 cm.

On the other hand, luminous flying squid taken at 3 locations between long. 164° and 172°E, ranged in dorsal mantle lengths from 11 to 18 cm with modal lengths from 14 to 16 cm.

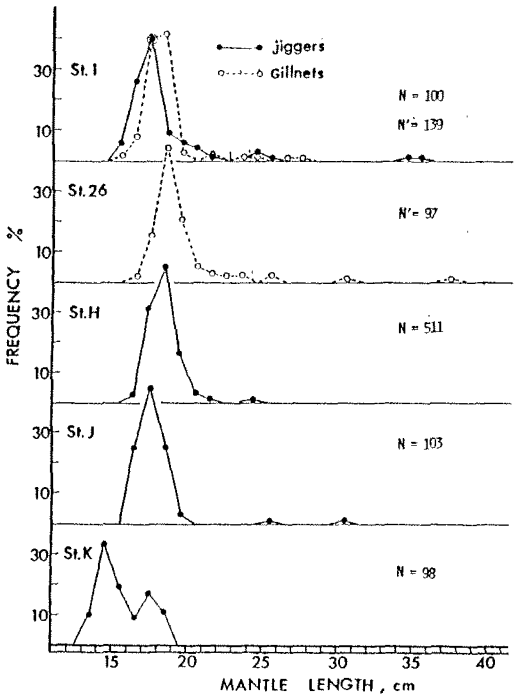

Fig. 3. Dorsal mantle length compositions of neon flying squid caught by gillnets or by jiggers at the locations where squid were observed in flight, or at the stations nearest to flight observations in July of 1984. N and N′ denote numbers of squid measured from the catches by jiggers and by gillnets, respectively.

Oceanographic Conditions

According to the distributional chart of surface temperature for the second 10-day period in July 1984[9] (Fig. 4), all of the observed squid flights occurred where there was a prominent northward projection of the 21–24°C surface isotherms.

The surface temperatures and salinities at the locations of the observed flights, or at the stations nearest to the observed flights, are referred to Table 1, and the temperatures at the 100-m depth ranged from 10 to 13°C.

According to the chart of vertical temperature distributions along long. 158°E, 175°E, and 172°W,[10] (Fig. 5), warm waters with temperatures higher than 10°C generally reached depths more than 100 m in the area between lat. 37° and 40°N. However, between lat. 41° and 43°N, the warm waters occurred at even shallower under 50 m, except in the vicinity of lat. 42°N along long. 175°E. Judging from the vertical temperature distributions, as well as the distribution of surface salinities, it appears that lat. 37°–40°N, 40°–41°N, and 42°–43°N in the survey area, correspond respectively to the subtropical region, subarctic boundary, and subarctic region.[10]

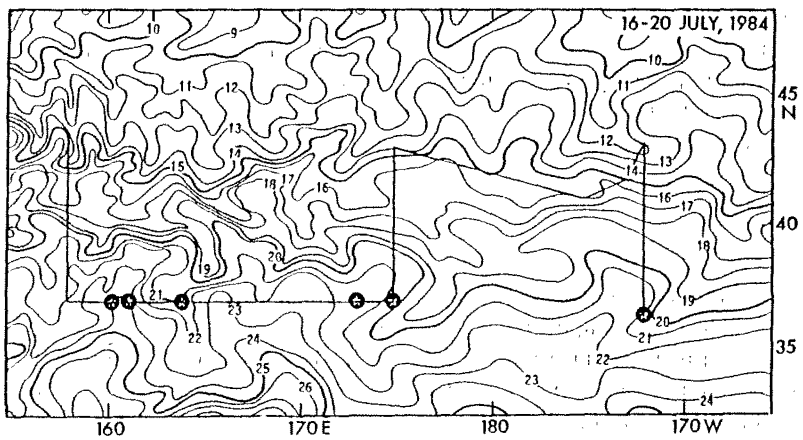

Fig. 4. Horizontal distribution of surface water temperature (°C) in the middle of July in 1984 (from data of Japan Fish. Infor. Ser. Cent.[9]). Stars denote the locations where flying behaviors of squid were observed.

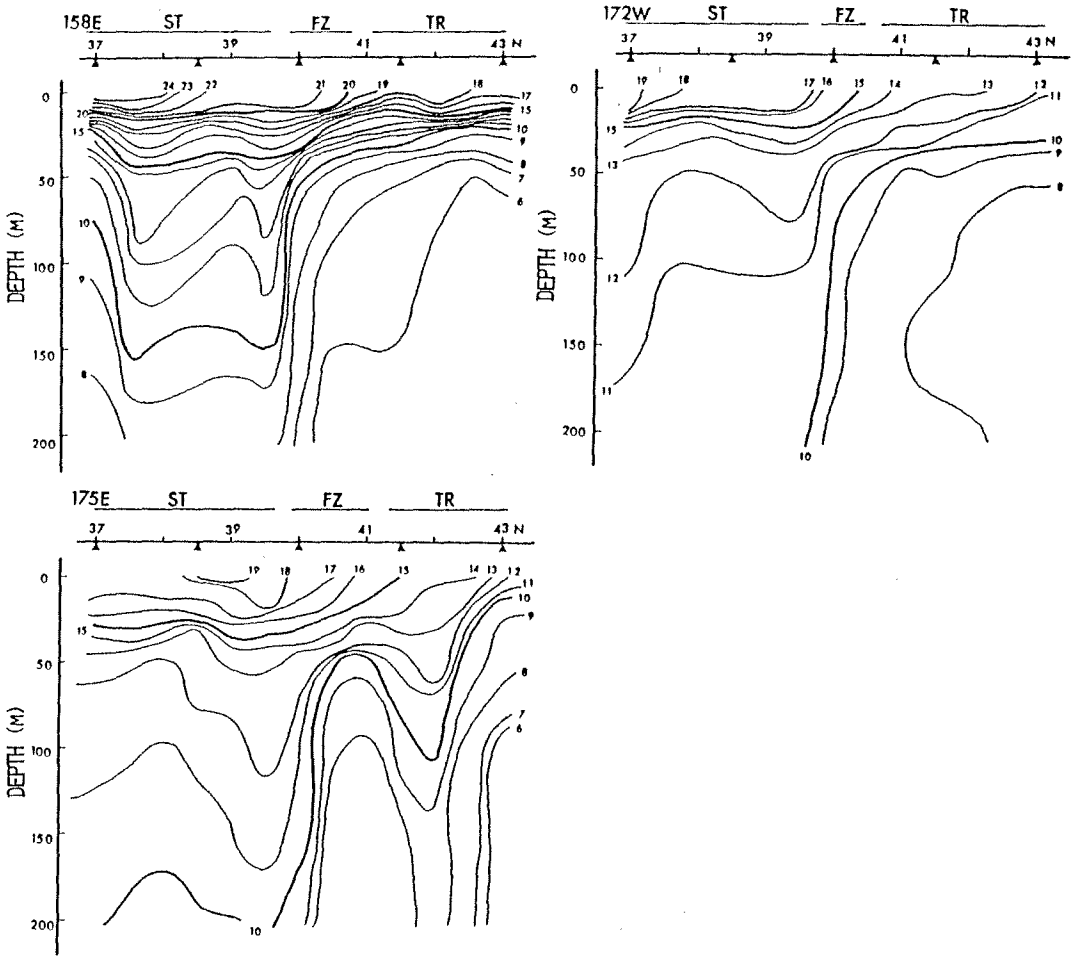

Fig. 5. Vertical distributions of temperature (°C) along the long. 158°E, 175°E and 175°W in July of 1984 (Murata *et al.*[10]).
ST: Subtropical zone, FZ: Subarctic boundary, TR: Transitional zone

From the above, it is believed that all of the observed squid flights took place within the waters of the subtropical region, where the surface temperatures ranged from 17 to 24°C, surface salinities from 33.9 to 34.7‰, and where the temperatures at the 100-m depth ranged from 10 to 13°C.

Discussion

All of the squids observed in flight were beleived to be neon flying squid for the following reasons: 1) squid jigging and gillnet fishing in the immediate vicinity of the observed flights yielded large numbers of neon flying squid of about the same size as the squid seen in flight; and 2) of the approximately 20–30 squids seen in flight at lat. 37°N, long. 175°E (No. 2 in Table 1), 3 were caught in the gillnet that was being retrieved, and were identified to be neon flying squid.

Judging from the report by Kubodera and Yoshida,[8] the dorsal mantle length composition of neon flying squid caught by gillnet was regarded as reflecting that of the actual squid population at this location (Fig. 3).

The gillnet catches in the survey area showed that neon flying squid were very widely distributed between lat. 37°N and 42°N.[10] Moreover, the catches revealed that they were most densely distributed near the subarctic boundary near lat. 40°N. The catches also showed a distinct tendency for larger squid to be distributed farther to the north.[10] Namely, at lat. 37°N, the squid ranged from 14 to 19 cm in dorsal mantle length with modal lengths of 14, 17 and 18 cm; at lat. 38°30′N, from 17 to 27 cm with modal lengths of 18 and 21 cm; at lat. 40°N, from 20 to 25 cm with modal

lengths of 20 and 24 cm; while those caught farthest to the north at lat. 41°30'N ranged from 27 to 42 cm with modal lengths of 27, 38 and 41 cm.

The flying behavior of neon flying squid was limited to the southernmost portion of the survey area, and no flight was observed in the more northerly areas in spite of the denser distribution of squids. The reason for this may be closely related to the size of squid existed. According to the relationship between dorsal mantle length and body weight of neon flying squid,[11] body weight of most of the squid taken in the area near the observed flights is calculated to be from 57 to 216 g with mantle length of 13.0–19.9 cm. The body weight of neon flying squid increases very rapidly with the growth in mantle length, as seen the following data: at a length of 15.5 cm, weight is 98 g; at 20.5 cm, 237 g; at 25.5 cm, 471 g; and at 30.5 cm, 826 g.

From the photographs of purpleback flying squid in flight in the Indian Ocean, Azuma[5] reported that the flight was not the trajectory-type flight exhibited by dolphins, but was rather gliding-type flight like flying fish. Azuma conjectured that the primary lift would be provided by the spread arms of the squid, as well as by an instant membrane that was formed by a mucus.

The form of neon flying squid in flight, as described earlier, closely resmbled that[5] of purpleback flying squid. It is therefore understood that both neon flying squid and purpleback flying squid show similar gliding-type flight behavior. A thin membrane, referred to as the protective membrane, is well developed on a pair of the third arms of neon flying squid.[12] This membrane is thought to play an important role in flight. However, judging from the structure of the body parts, there seems to be relatively little lifting power during flight. For this reason, it is assumed that the flying behavior of neon flying squid is very closely related to the body weight. Although no report on the relationship between flying behavior and body weight is available, Arata[1] reported that a squid (neon flying squid, or webbed flying squid) with a dorsal mantle length of 15.2 cm flew a distance of 12–15 m at a height of 1.8–2.4 m above the sea surface.

In spite of the fact that neon flying squid is one of the commercially important species of the northern North Pacific, no observation has been reported previously on its flight behavior.* The reason may be that the commercial fisheries are exploiting squid that are much larger than those that undertake these flights. In squid jigging and gillnet fisheries, monthly averages of mantle lengths of neon flying squid taken ranged from 22 to 32 cm during August-October (Data of Aomori Prefectural Fisheries Experimental Station) and from 35 to 42 cm during June-November (Data of Hokkaido Regional Fisheries Research Laboratory), respectively.

The observed flights occurred both by day and by night. Moreover, there seems to be no special relationship between those flights and wind direction, wind force, or weather conditions. The squid became airborne when dolphins existed in the neighborhood (Nos. 3, 4, 5 and 7 in Table 1), when the gillnet floatline sharply slapped against the surface of the sea (Nos. 1 and 2 in Table 1), or when a large squid jigging hook was cast into the water (No. 8 in Table 1). Since the flights occurred habitually following a disturbance of the sea surface, it seems that such the behavior may be a form of fright reaction for escaping from danger. Akimushkin[2] as well as Clarke[3] conjectured that the squid made a flight when they were suddenly frightened, or when they were trying to escape from their enemies.

From the above, it is believed that neon flying squid has a flying behavior to escape from their frights and enemies such as dolphins, marlins and so on. As Azuma[5] has postulated, the flights are considered to be gliding-type flights. The initial leap and burst of speed is thought to be supplied by the jet propulsion when a jet of water is shot out of the funnel. However, the flight behavior of neon flying squid seems to be limited to the smaller individuals whose dorsal mantle length is less than about 18 cm, and whose body weight is under about 170 g. Larger individuals are thought to be too heavy to fly. Furthermore, this flying behavior suggests that the smaller ones of neon flying squid lives mainly near the surface of the sea by day and night.

Acknowledgements

I wish to thank Dr. T. Otsu in Honolulu, and Dr. T. Sato, Hokkaido Regional Fisheries Research Laboratory, Kushiro, for reading the manuscript with suggestions for its improvement. Many

* When the author interviewed the fishermen engaged in the neon flying squid fisheries, they had no available information on the flight of neon flying squid.

thanks are also due to Mr. H. Yamawaki for taking charge of a sighting survey in this cruise, and the crew of the R/V *Omi-Maru* for their all-out help in carrying out this survey.

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