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The Ecological Aspects of Neon Flying Squid *Ommastrephes bartrami* in Summer off the West Coast of the US*1

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The results of a fishing survey on neon flying squid off Oregon and Washington states during August of 1990 are itemized as follows: 1) Most of the squids captured were females whose *DML* ranged from 25 to 60 cm, 2) the relative growth equation of the female neon flying squid is $W = 0.026L^{3.04}$, 3) good fishing ground was located in a warm water front and near an upwelled cold water area, whereas the water temperature ranged from 12.8 to 19.4°C at the surface and from 7.5 to 8.3°C at a abundant depth of 120 m, 4) the angling depth ranged from 50 to 150 m while most of the squids were caught at 120 m. At depths ranging from 10 to 60 m, thermocline was found, so this may be a considerable reason why neon flying squid could not break through this layer, and 5) the catch is greatly influenced by the duration of moonshine (*H*) during the night time. Big catches are found at drastically varying values of *H*.

In recent years, many studies on both the biological and ecological aspects of neon flying squid *Ommastrephes bartrami* (Lesueur) have been made in the northwestern part of the Pacific ocean.[1,2] In the northeastern part of Pacific ocean, preliminary studies on this species have been conducted off the west coast of the US and Canada since 1979.[3-7] All of these exploration were carried out with drifting gillnets, and only few of them have provided information on its environment and behaviour. Since the neon flying squid is an oceanic one, distributed worldwide in the subtropical and temperate zone,[8] it is necessary to investigate neon flying squid in a wider area to understand fully such behaviour as scholl, groups distribution, and migration.

In August 1990 a joint research survey with the US National Marine Fisheries Service was carried out within the exclusive economic zone (EEZ) of Oregon and Washington States. The objectives of this survey were 1) to investigate the distribution of neon flying squid and its relative density by area, depth, water temperature and other environmental factors such as lunar phase, based on a comparison of catches and 2) to collect some biological information on neon flying squid including sex ratio, size composition, length-weight relationship, sexual maturity, and stomach contents.

Materials and Methods

Fishing surveys were carried out from August 1st through 28th 1990 within the US EEZ between 12 and 200 nautical miles off Oregon and Washington by the Japanese squid-jigging vessel, Fuki-maru No. 63. The survey area was stratified into three subareas with 2-degree latitude intervals, as subarea *A*, *B*, and *C* between 42 to 44, 44 to 46, and 46 to 48°N lat., respectively. The location of nightly fishing stations (Fig. 1) was sampled according to the features of bottom topography and sea surface temperature (*SST*).

A total of 118 jig-lines were used in each nightly operation, consisting of 108 lines by machines and the other 10 by handline. To observe angling depth, the main line had graduated markings in metres.

The average light intensity near the sea surface (I_0), measured in lux, was used to estimate light intensity at a desired depth (I_z), from the following formula:

$$I_z = I_0 \exp(-kz) \qquad (1)$$

where k is the attenuation coefficient (m^{-1}).

Water temperature was measured at the hull depth by thermometer with accurate position data from a Global Positioning System during sailing and drifting. During the day, sea colour

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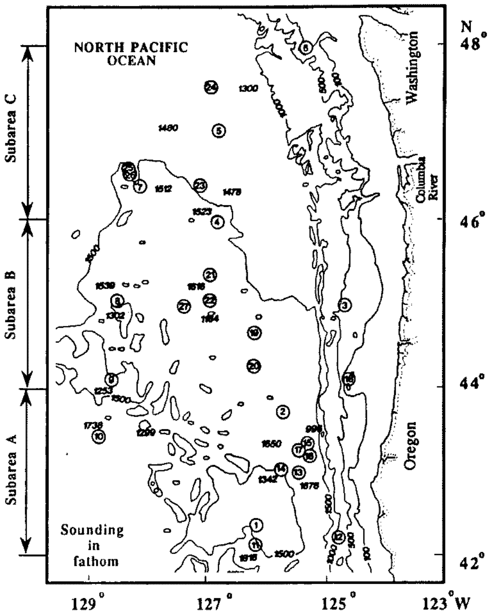

Fig. 1. The geographical distribution of fishing stations, from 1 to 27, off Oregon and Washington states in August 1990. *A*, *B*, and *C* represent subareas which were located between 42 and 48°N lat. (— isobath in fathoms).

and secchi dish measurement were noted whenever sea conditions such as wind and waves were observed. In addition, water temperature according to depth was also recorded by a Digital Bathythermometer each time fishing operation was carried out.

Fishing operations were carried out from sunset until the twilight of the following morning. Unit weight of the squid captured in kg and dorsal mantle length (*DML*) in cm were noted. The maturity stage of neon flying squid was determined from the ratio of nidamental gland length (*NGL*) to *DML* as defined by Durward *et al.*[9]

The stomach contents of sampled squids were observed by visual examination on board and a few samples were collected.

Fishing operations were recorded in terms of line-hours estimated by multiplying the total number of lines used by the duration of fishing in hours.

Results and Discussion

Biological Characteristics

A total weight of about 5t of neon flying squid was caught; the daily catch ranged from 0 to 1137 kg. The distribution of catch according to weight in each station is shown in Fig. 2a. The amount of capture increased relative to the increase in the depth of water up to about 3000 m (see Fig. 2b). The minimum depth where squids were caught was about 600 m. Considering the fishing ground of this species in the northwestern part of the Pacific ocean, they were caught where the depth of water was deeper than 3000 m, and their fishing ground was found where the water depth was about 5000 m.[10,11] Figure 3 shows the angling depth of neon flying squid ranging from 50 to 150 m; a dense concentration of squid was found at 120 m. At this point, the influence of the current on the jig-line was not considered.

The sex ratio of neon flying squid showed a significant disparity, with females dominating,

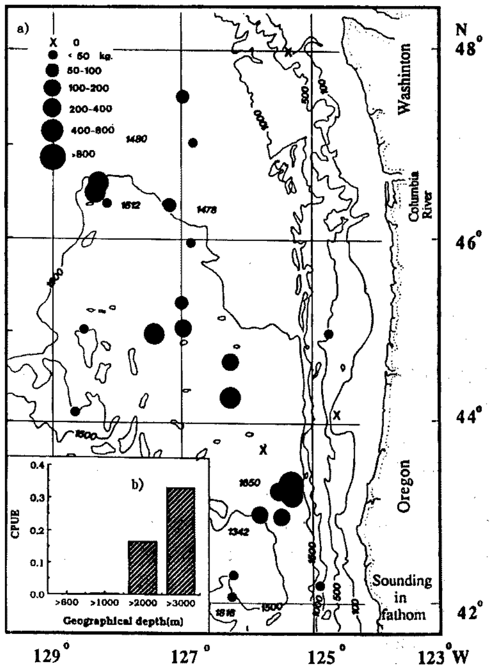

Fig. 2. a) Distribution of *Ommastrephes bartrami* (by weight in kg per night) off Oregon and Washington states in August 1990. (— isobath in fathoms). **b)** Correlation between catch in *CPUE* (number of catch per fishing effort) and geographical depth in meters.

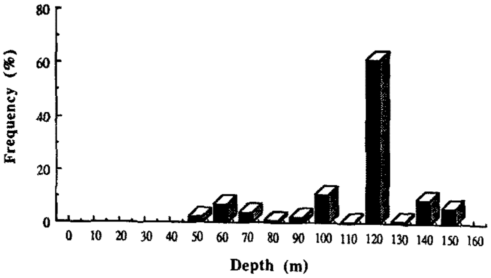

Fig. 3. Relationship between the frequency of catch in percentage and angling depth in meters.

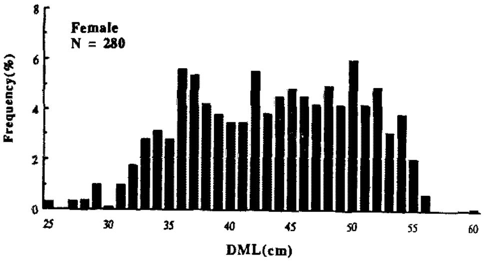

Fig. 4. The *DML* frequency (%) distribution of female neon flying squid off Oregon and Washington states in August 1990.

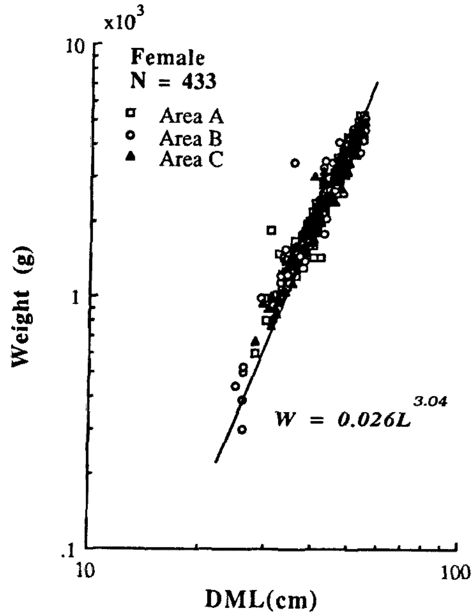

Fig. 5. *Relationship between DML (cm) and weight (g) of female neon flying squid off Oregon and Washington states in August 1990.*

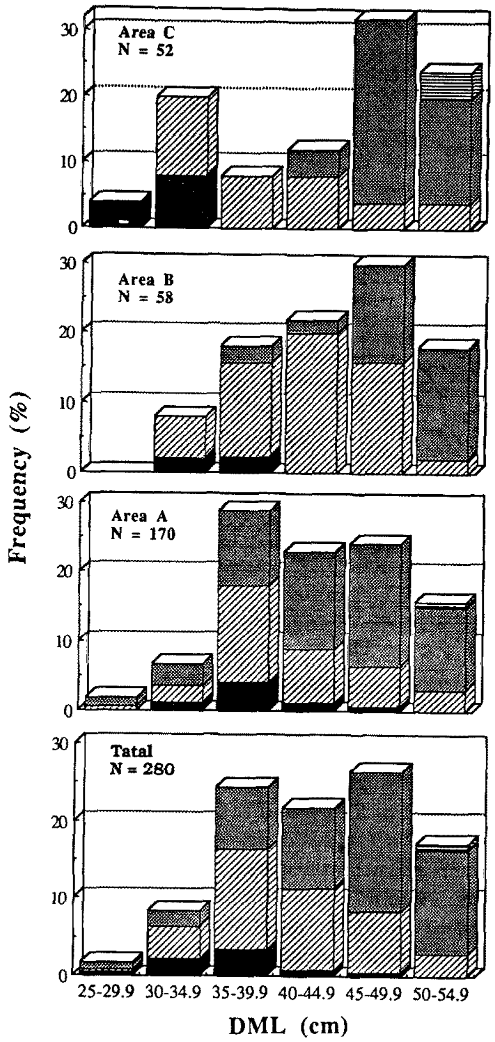

Fig. 6. The maturity stages of female neon flying squid by *DML* in each subarea off Oregon and Washington states in August 1990. The maturity stages are determined from the ratio of the *NGL* to *DML* as defined by Durward *et al.* (1979).

- ■ Stage 1; *NGL/DML* less than 0.09.
- ▨ Stage 2; *NGL/DML* range from 0.091 to 0.125.
- ▩ Stage 3; *NGL/DML* range from 0.126 to 0.200.
- ▤ Stage 4; *NGL/DML* range from 0.201 to 0.350.

while only 2.4% (11 individuals) were males which were found offshore in subareas *B* and *C*. The same results have been reported in Canadian waters by Shaw and Jameison.[7] This characteristic is probably the same as that of squid in the northwestern part of the Pacific ocean, in which the males separated from the females and migrated ahead to the breeding area.[11]

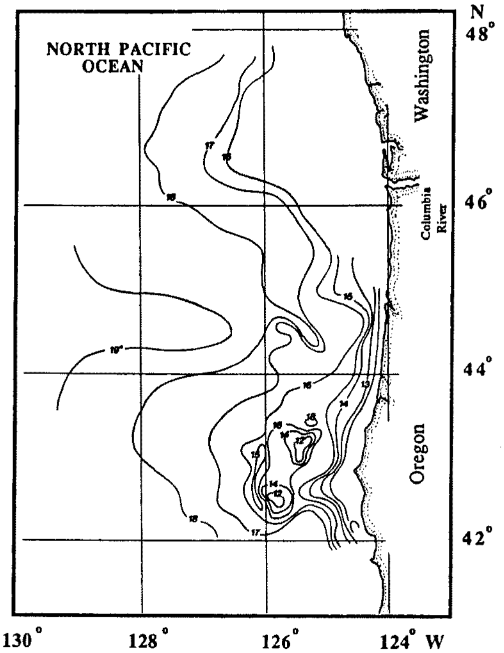

Fig. 7. Distribution of sea surface temperature (°C) during surveys in August 1990.

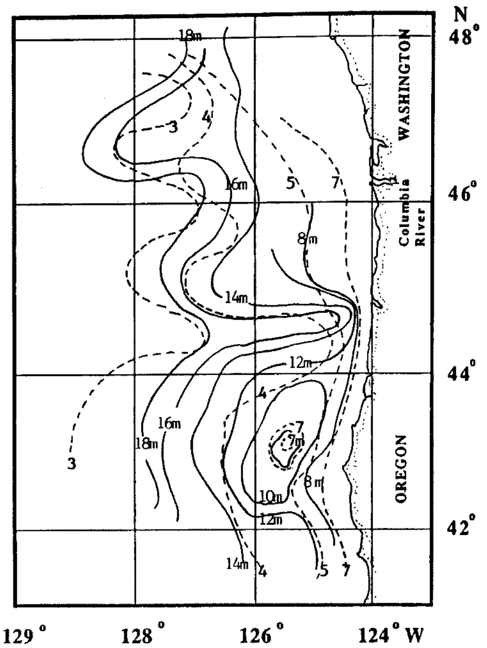

Fig. 8. Distribution of water transparency (m) and colour of sea in August 1990. The solid line and dotted line represent transparency in meters and the colour of sea, respectively.

Neon flying squid had a body weight ranging from 600 to 5300 g and a *DML* ranging from 25 to 60 cm. The squid size was rather large when compared with the same species which ranged from 19 to 40 cm in summer in the northwestern part of the Pacific ocean,[2] indicating that squids over 50 cm in size were found in the survey area.

The population structure of the dominant female squid was complex with at least two modes evident of 36 and 50 cm *DML* (Fig. 4). The male squid had a mode of 35 cm *DML* which ranged from 30 to 39 cm. These results indicate that female squid are larger than males, while most squids over 40 cm in size are female.

Figure 5 shows the relation between *DML* (L) in cm and weight (W) in g of female neon flying squid. The relative growth equation was as follows:

$$W=0.026L^{3.04}$$

where the relation coefficient was 0.975. Compared to that of squid in the northwestern part of the Pacific ocean,[12] the 3.04 value of this formula was rather small.

As shown in Fig. 6 the maturity stages of squid ranged from stage *1* to *4*, and approximately 55% of them showed maturity stage *3*. A few squid, over 50 cm in *DML*, had reached maturity stage *4*. In addition, their maturity stage was increased by an increase in *DML*. In subarea *C*, squids of over 45 cm in *DML* were found to be of maturity stage *3*. However, no indication of copulation was found on them at all. For these reasons, it seemed that the neon flying squid may have a northward migration similar to that of squid in the northwestern part of the Pacific ocean.

The stomach contents of 9 female neon flying squids, 30–37 cm in *DML*, were determined with the cooperation of Dr. Okutani. It was found that they feed not only on fish, but also on crustacean larva and some cephalopods which were classified as nail squid. Most of the contents of the stomach comprised nail squid.

Fishing Ground Environment

Figures 7 and 8 exhibit the distribution of water temperature (°C) near the sea surface, and the water transparency and colour of the sea, respectively. The water temperature in the nearshore area was low and warm water appeared far from the shore. As shown in Fig. 7, there was a significant cold water mass in subarea *A*

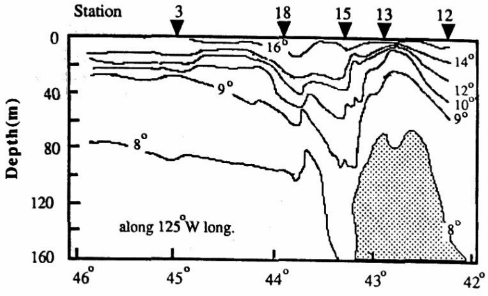

Fig. 9. Vertical distribution of the water temperature (°C) along 125°W long. in subareas **A** and **B**.

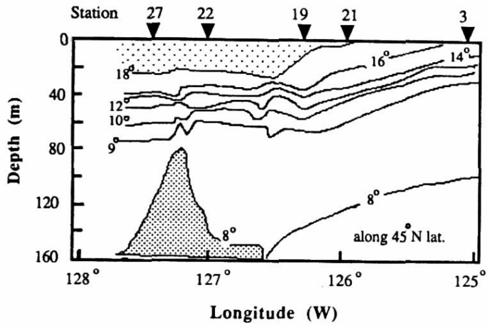

Fig. 10. Vertical distribution of water temperature (°C) along 45°N lat. in subarea **B**.

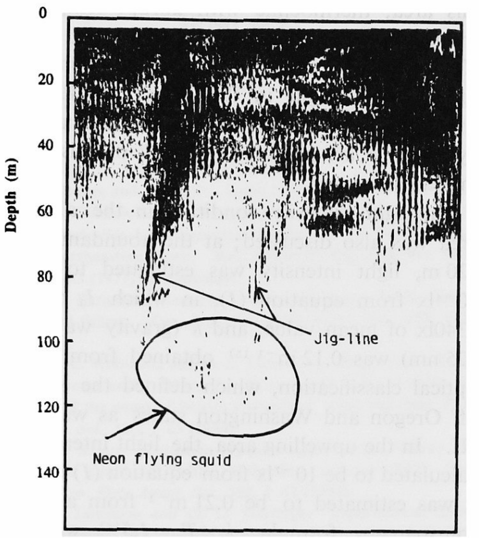

Fig. 11. Echo traces of a school of neon flying squid, deep scattering layer (*DSL*), and jig-line on recording paper from St. **26**.

where the colour index was *7* and water transparency was low at about 7 m. Figure 9 shows the vertical distribution of temperature along 125°W long. where the thermocline ranged from 10 to 30 m and cold water of 10°C rose to near the surface. In summer, a large quantity of turbid water from the Columbia River flows into sea. It is distributed southward by the California current[13] and appears on the surface by upwelling.[14] Under such circumstances it is expected that the cold water rising to the surface is the upwelling phenomenon.

In the upwelling area St. *13*, during lighting operation, many schools of small and large fish such as blue shark and Pacific white-sided dolphin were observed around the vessel. Moreover, the echotraces of large schools of fish appeared on the fish-finder; some pacific promfet and mackerel were also caught by jig. However this phenomenon was not seen in the other areas. This seemed to confirm that there is a richness of fish in the upwelling area. Judging from the results of squid captured in subarea *A*, the good fishing areas were located in St. *15*, *16*, and *17* beside the upwelled cold water of the 8°C contour line with the water temperature ranging from 12.8 to 16.1°C at the surface and 7.5 to 8.3°C at 120 m.

In subarea *B*, the clear warm water with an 18°C contour line discharged onto the shore as shown in Figs. 7, 8, and 10. Figure 10 shows the vertical distribution of water temperature in which the warm water front with thermocline ranged from 20 to 60 m while the upwelled cold water of also 8°C appeared. The good fishing areas were located in St. *22* and St. *27* beside the upwelled cold water where *SST* ranged from 18.3 to 19.4°C. And at 120 m, water temperature ranged from 7.9 to 8.1°C. In the northwestern part of the Pacific ocean, neon flying squid were mainly found along the warm water front where the water temperature ranged from 15 to 20°C,[1] and 12 to 18°C.[11] The temperature of the abundant area in subarea *B* was fully taken into account in these results.

Angling Depth

Squid were caught within a depth of 50 to 150 m while the abundant depth was found at 120 m, as shown in Fig. 3. Figure 11 shows the echotrace of a school of squid at 100 to 120 m in St. *26*. The number of squid in this school was estimated at 30. Some of them were also caught and identified as neon flying squid. In this area, thermocline with abrupt temperature changes ranging from 5 to 11°C (Fig. 9 and 10) was found at a depth of 10 to 60 m. No squid were caught in this layer. Under these circumstances, it can be understood that neon flying squid are not able to break or exist in the thermocline layer.

The light intensity condition in the abundant area was also discussed; at the abundant depth, 120 m, light intensity was estimated to be 4×10^{-4}lx from equation (*1*), in which I_0 was the 7340lx of mean value, and k (gravity wavelength 525 nm) was 0.12 m^{-1}[15] obtained from Jerlov's optical classification, which defined the sea area off Oregon and Washington states as water type III. In the upwelling area, the light intensity was calculated to be 10^{-7}lx from equation (*1*) in which k was estimated to be 0.21 m^{-1} from a relative transparency formula, $k\times T_w=1.5$[16] where T_w is the secchi disc measurement value equivalent to 7 m. Neon flying squid in the waters off Ogasawara Island*3 were observed in the daytime at the depth layer ranging from 400 to 800 m. Thus the light intensity at 400, 600, and 800 m was computed to be 4.1×10^{-5}, 8.4×10^{-10}, and 1.7×10^{-14}lx, respectively, from an equation (*1*) in which I_0 was estimated to be 10^5lx and k was 0.054 m^{-1} for water type *IB*.[15] From the aforementioned, even in an upwelling area at 120 m deep, it was considered that the light intensity was sufficiently large and squid vision functioned effectively.

Lunar Effects

In spite of the sufficient depth with virtually the same sea conditions, the number of the catch differed according to date. This was thought to be caused by the lunar effect. Firstly the degree of fullness of the moon (*P*) was studied, this being determined as *1* for the full moon, *0* for the new moon, with gradations in between according to the phases of the moon. In this respect, the weather conditions were not considered. From Fig. 12, the relationship between *P* and *CPUE* differed according to the period of the moon's phase; the maximum and minimum *CPUEs* in period II were probably opposite to those of *CPUEs* in period III. These are likely to show that the P may not be directly related to or have an influence on the catch.

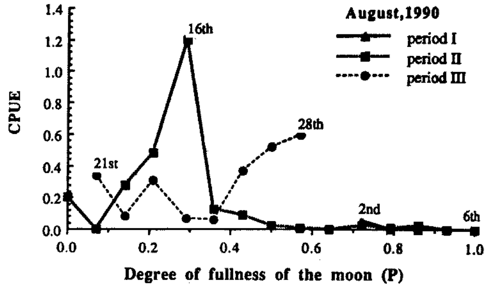

Fig. 12. Relationship between the degree of fullness of the moon (*P*) and catch in *CPUE*. The *P* was assumed into three fishing periods; symbols ▲, ■, and ● represent period I from the beginning on the 2nd through the 5th, period II from full moon to new moon toward the lebt on the *P* scale, and period III from the day after the new moon on the 21st through the 28th of August 1990, respectively.

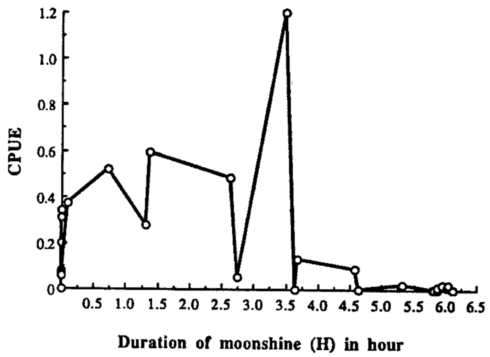

Fig. 13. Relationship between the duration of moonshine (*H*) in hours and catch in *CPUE*.

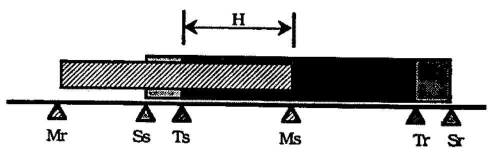

Fig. 14. Schematic diagram of duration of moonshine (*H*).
Mr: Time of moonrise.
Ms: Time of moonset.
Ss: Time of sunset.
Sr: Time of sunrise.
Ts: Ending of twilight (after Ss).
Tr: Beginning of twilight (before Sr).
H: Duration of moonshine during night time.
Period of twilight.
Period of night time.
Period of moonshine.

*3 Y. Nakamura: Oral presentation at the spring meeting of Japan. Soc. Sci. Fish. in Tokyo, April 1991, p. 193.

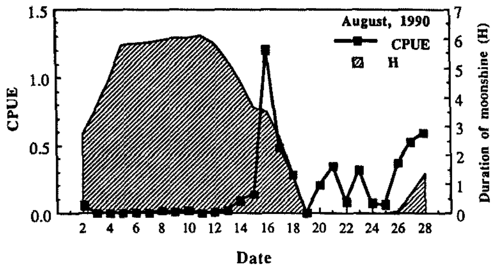

Fig. 15. The correlation between the H and catch in CPUE in August 1990.

Secondly, the relationship between *CPUE* and the duration of moonshine (H) in hour was studied (Fig. 13). The H was determined as shown in Fig. 14. From Fig. 13 the *CPUE* seemed to alternate with H; when H was at its maximum value 6.12 h, *CPUE* dropped to 0, after a which decline of H occurred together with an increase in *CPUE*. However, when H equalled 0 h, *CPUE* was not at its maximum value.

Thus, the correlation between H and *CPUE* by day were discussed (Fig. 15), indicating that the *CPUE* was low on moonless nights ($H=0$ h) compared with that of both sides, whereas the H varied drastically. It is a remarkable feature, in these circumstances, that the catch is greatly influenced by H.

Other data from 1983 off Sanriku in the northwestern part of the Pacific Ocean*4 was reanalyzed on the route of the H and catch in *CPUE*, this showing a similar phenomenon to the aforementioned.

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