*Acta Zoologica Taiwanica 10*(2): 135-144 (1999)

# Abundance and Spatial Variation of *Ommastrephes bartramii* (Mollusca: Cephalopoda) in the Eastern North Pacific Observed from an Exploratory Survey

Chih-Shin Chen[1, 2] and Tai-Sheng Chiu*[1]

[1] Department of Zoology, National Taiwan University, Taipei, Taiwan 10617, ROC
[2] Institute of Fishery Biology, National Taiwan University, Taipei, Taiwan 10617, ROC

**ABSTRACT**

Data collected from an exploratory cruise to the eastern North Pacific were analyzed to describe the abundance and distributional pattern of the neon flying squid, *Ommastrephes bartramii*. In total 15 806 kg of the neon flying squid was caught in a 45-d period, with an average of 351.2 kg $d^{-1}$. The isopleth diagram of catch per unit effort (CPUE) was used as an index of the abundance, and a significant higher abundance was found around 44° N, 164° W. Water mass characteristics was distinctive in the study area. It is apparent that the high abundance of the squid was linked to relatively low water temperature and low salinity. Principal component analysis indicated that water temperature has higher predictive power than salinity to estimate the abundance of neon flying squid. A latitudinal effect on the abundance of squid was confirmed; however no sign of a longitudinal trend was found, i.e., significant high abundance was found patchily. The distribution of neon flying squid in the North Pacific transitional frontal zones is discussed.

**Key words:** *Ommastrephes bartramii*, North Pacific, spatial distribution

## INTRODUCTION

The neon flying squid, *Ommastrephes bartramii*, has been commercially harvested since the early 1970s. It is an important fisheries resource in the North Pacific Ocean (Araya, 1983; Murata, 1990; Murata and Hayase, 1993). During the 1980s, approximately 2.5 $10^5$ t $yr^{-1}$ was harvested by high sea drift-netters from Japan, Korea, and Taiwan (Anon., 1996). The main fishing ground was in the subarctic frontal zone of the central North Pacific Ocean (Gong *et al.*, 1993; Murata and Nakamura, 1998; Yatsu *et al.*, 1998). Squid jiggers have replaced drift-netters since 1993, when drift-net fishing was forbidden by a global moratorium. Currently, the fishing ground utilized by jiggers in the North Pacific is located in the area of 40-42° N and 150 -170° E (Yatsu *et al.*, 1997).

In 1993, three Taiwanese jiggers started fishing in the western North Pacific, and operated a squid jigging industry in the area, with an annual catch of 1.5 $10^4$ t. The fishing ground was located basically in the western North Pacific, i.e., most of it was west of 165° E, but with sparse operation in 165°- E 175° W (Anon., 1998). It is desirable to understand the biological and geographic characteristics of the neon flying squid in the area immediately outside the traditional fishing ground for the purpose of fishery extension and management.

The object of the present study was to examine the population of *Ommastrephes bartramii* in the eastern North Pacific, and to study the relationship between the distribu-

* **Corresponding author.** e-mail: tschiu@ccms.ntu.edu.tw

Table 1. Field data for exploratory survey on neon flying squid in eastern North Pacific, 1997.

| Station | Date | Latitude | Longitude | Operation hours | Catch (Kg) |
|---|---|---|---|---|---|
| 1 | 4-Jul-97 | 45°59' N | 170°00' W | 8.0 | 210 |
| 2 | 5-Jul-97 | 43°59' N | 170°02' W | 10.0 | 56 |
| 3 | 6-Jul-97 | 43°58' N | 166°31' W | 9.5 | 532 |
| 4 | 7-Jul-97 | 44°01' N | 163°48' W | 9.5 | 924 |
| 5 | 8-Jul-97 | 43°59' N | 160°44' W | 10.5 | 980 |
| 6 | 9-Jul-97 | 43°58' N | 157°26' W | 9.5 | 168 |
| 7 | 10-Jul-97 | 43°59' N | 154°01' W | 10.0 | 266 |
| 8 | 11-Jul-97 | 43°48' N | 150°50' W | 11.0 | 924 |
| 9 | 12-Jul-97 | 43°29' N | 150°30' W | 10.5 | 770 |
| 10 | 13-Jul-97 | 41°59' N | 150°00' W | 10.0 | 56 |
| 11 | 14-Jul-97 | 40°58' N | 150°04' W | 10.0 | 280 |
| 12 | 15-Jul-97 | 40°02' N | 150°02' W | 10.0 | 210 |
| 13 | 16-Jul-97 | 38°56' N | 150°02' W | 10.0 | 182 |
| 14 | 17-Jul-97 | 38°00' N | 153°00' W | 10.0 | 70 |
| 15 | 18-Jul-97 | 39°00' N | 153°00' W | 10.5 | 56 |
| 16 | 19-Jul-97 | 40°20' N | 153°14' W | 6.5 | 14 |
| 17 | 20-Jul-97 | 41°15' N | 153°30' W | 11.0 | 84 |
| 18 | 21-Jul-97 | 42°10' N | 153°54' W | 11.0 | 196 |
| 19 | 22-Jul-97 | 42°46' N | 154°33' W | 12.0 | 364 |
| 20 | 23-Jul-97 | 43°00' N | 156°57' W | 11.5 | 644 |
| 21 | 24-Jul-97 | 42°15' N | 158°23' W | 10.5 | 182 |
| 22 | 25-Jul-97 | 41°15' N | 158°57' W | 11.0 | 84 |
| 23 | 26-Jul-97 | 40°05' N | 159°44' W | 12.0 | 70 |
| 24 | 27-Jul-97 | 39°10' N | 160°03' W | 10.5 | 98 |
| 25 | 28-Jul-97 | 39°34' N | 162°29' W | 11.5 | 70 |
| 26 | 29-Jul-97 | 40°41' N | 162°31' W | 11.0 | 84 |
| 27 | 30-Jul-97 | 41°45' N | 162°33' W | 10.0 | 70 |
| 28 | 31-Jul-97 | 42°41' N | 162°44' W | 11.0 | 392 |
| 29 | 1-Aug-97 | 42°56' N | 162°48' W | 11.5 | 154 |
| 30 | 2-Aug-97 | 43°13' N | 163°09' W | 6.5 | 84 |
| 31 | 3-Aug-97 | 44°07' N | 164°15' W | 12.0 | 2,058 |
| 32 | 4-Aug-97 | 44°10' N | 164°18' W | 12.0 | 1,344 |
| 33 | 5-Aug-97 | 44°11' N | 164°21' W | 12.0 | 1,064 |
| 34 | 6-Aug-97 | 44°03' N | 164°47' W | 12.0 | 742 |
| 35 | 7-Aug-97 | 43°11' N | 165°52' W | 11.0 | 322 |
| 36 | 8-Aug-97 | 42°08' N | 165°56' W | 12.0 | 168 |
| 37 | 9-Aug-97 | 42°30' N | 166°29' W | 11.5 | 266 |
| 38 | 10-Aug-97 | 42°53' N | 166°40' W | 12.0 | 140 |
| 39 | 11-Aug-97 | 42°56' N | 166°36' W | 12.0 | 294 |
| 40 | 12-Aug-97 | 42°54' N | 166°26' W | 10.0 | 112 |
| 41 | 13-Aug-97 | 42°01' N | 167°32' W | 12.0 | 140 |
| 42 | 14-Aug-97 | 40°56' N | 168°36' W | 13.0 | 224 |
| 43 | 15-Aug-97 | 40°46' N | 169°44' W | 12.0 | 280 |
| 44 | 16-Aug-97 | 40°27' N | 169°55' W | 12.0 | 266 |
| 45 | 17-Aug-97 | 40°19' N | 169°55' W | 8.5 | 112 |

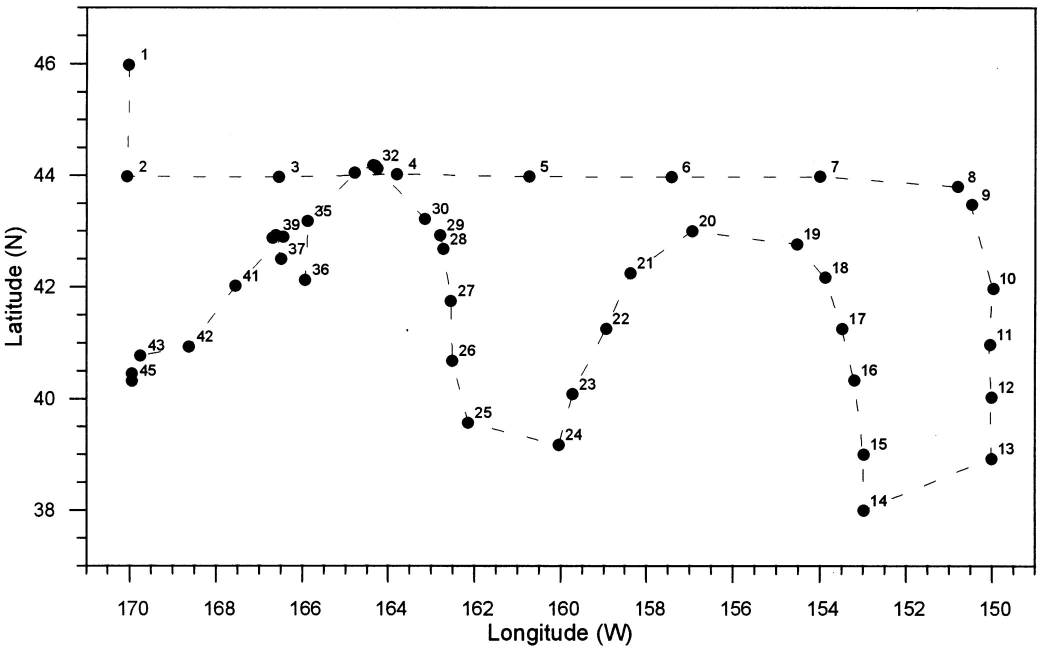


***Figure 1.*** Cruise tracks and sampling stations of the present study in the eastern North Pacific.

tional pattern of the neon flying squid and oceanographic conditions, in an attempt to determine the feasibility of fishing operations in the study area.

## MATERIALS AND METHODS

A 45-d exploratory survey of the neon flying squid was conducted on board a chartered commercial fishing vessel, the *Shyong-chuen No.1*, in the area of 38-46° N and 150-170° W during July-August 1997. The survey area was determined in advance; however the course and stations of the cruise were flexible to adjust to the daily catches (Fig. 1). The vessel had 33 crews and was equipped with 44 jigging machines. Neon flying squids were caught mainly by hand-jig, although some of the jigging machines were used for comparison. The poor catch by jigging machines indicated that some adjustment of the machines was necessary, and their data were separated from those collected by hand-jigs in this study. Our trial operation was conducted by 16 trained fishermen, each holding a jig. A target depth ranging from 150 to 200 m was set by all fishermen. A contest was set up to promote competition of individual fishing effort. Basic information on the jigging operation is shown in Table 1. Normally, the fishing lights were turned on at dusk (1700-1800 h) and off at dawn (0500-0600 h). Hours of operation varied from 6 to 12 h due to cruising between stations and searching for better fishing sites. The daily fishing intensity was estimated to be 10.68 ± 1.39 h. The relative abundance among fishing sites was evaluated by catch per operating hour (kg $h^{-1}$). The spatial distribution of the neon flying squid was analyzed by the software PC Arc/Info (Environmental Systems Research Institute) and graphed with ArcView. The station data were combined to a grid cell with a spatial resolution of 1 × 1 degree.

Sea temperature and salinity profiles were recorded at each station with a conductivity-temperature-depth (CTD) sensor (SBE19 Seacat Profiler, Sea-Bird Electronics), with 200 m of wire paid out at the beginning of each jigging operation. The maximum depth recorded

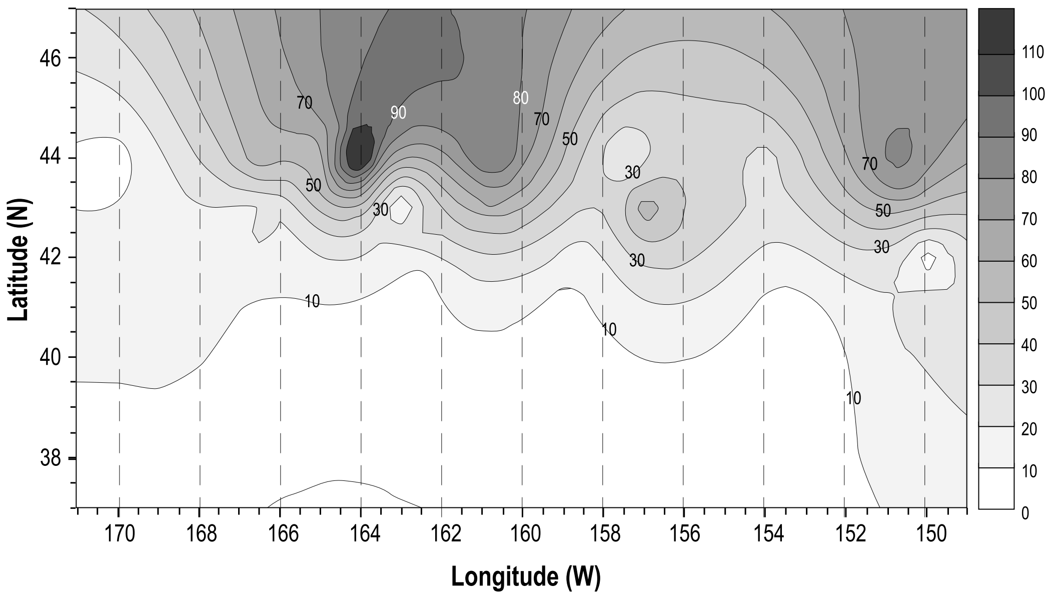


*Figure 2.* Isopleth diagram of CPUE showing the geographic distribution of *Ommastrephes bartramii.*

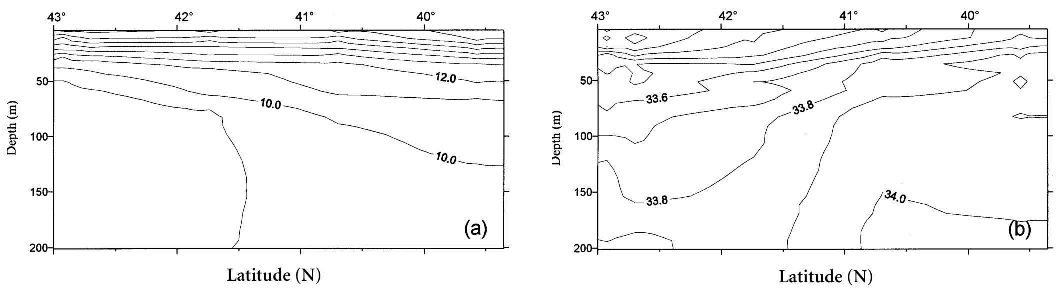


*Figure 3.* Latitude-depth structure of (a) temperature by 1 °C, and (b) salinity by 0.1 ppt increments, along a transect from 39°34'N, 162°29'W to 42°56'N, 162°48'W.

by the CTD sensor at each station varied, due to fluctuating of oceanographic conditions. The recorded temperature and salinity data were uploaded to a personal computer, and converted to ASCII-type data. Five continuous daily samples from stations along 162°30'W, conducted from 28 July to 1 August, were selected for examination of the vertical structure of the temperature and salinity of the water column.

## RESULTS

### 1. Distribution of neon flying squid

A total of 15 806 kg of neon flying squid was caught in the 45-d period, ranging from 14 to 2058 kg $d^{-1}$ with an average of 351.2 kg $d^{-1}$ (Table 1). The highest catch occurred at 44°07'N, 164°15'W on 3 August; while the lowest was at 40°20'N, 153°14'W on 19 July. The average catch per unit effort (CPUE) was 31.9 kg $h^{-1}$, with a range of between 2.2 and 171.5 kg $h^{-1}$. The isopleth diagram of CPUE, which might possibly serve as an index of the abundance of

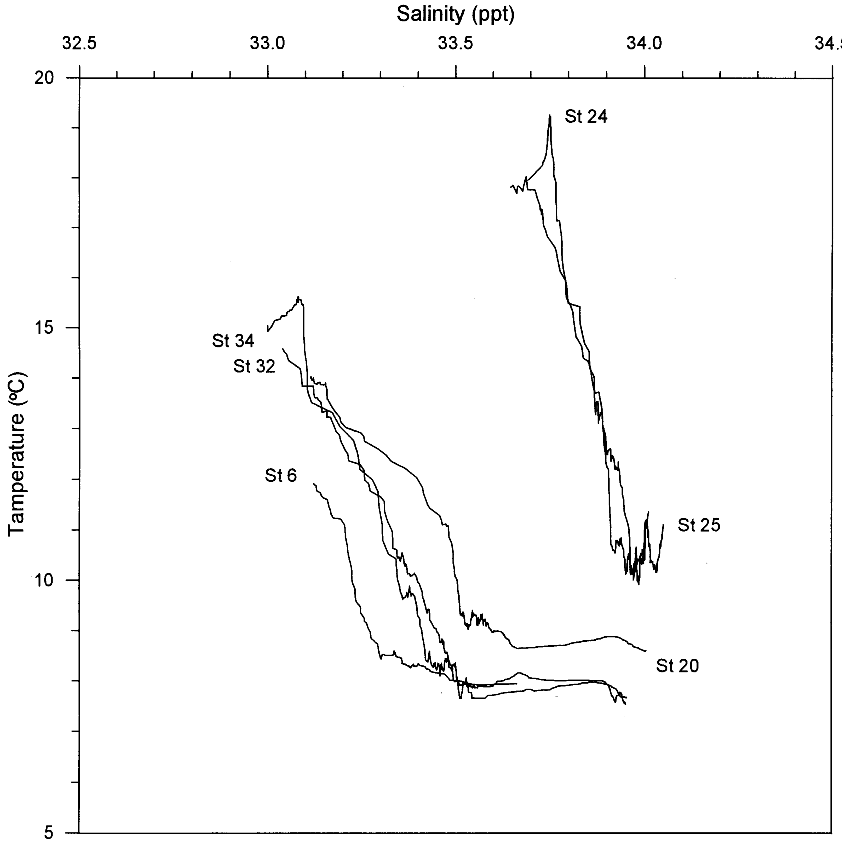


***Figure 4.*** Temperature-salinity (TS) diagrams of water masses at stations 6, 20, 24, 25, 32, and 34.

*Ommastrephes bartramii* in the eastern North Pacific is shown in Fig. 2. A significantly higher abundance was found at about 44° N, 164° W. An apparent latitudinal gradient was shown between 160° and 170° W northward, however the gradient was not seen in the area between 153° and 159° W, where sparse neon flying squid were found around 44° N.

**2. Oceanographic features**

Latitude-depth structures of temperature and salinity along the transect line composed of stations 25-29 are illustrated in Fig. 3. Temperature data indicated that surface temperature ranged 17.2 -19.0 °C, and the temperature at the approximate photic bottom (170-200 m) were estimated to be 8.5 to 10 °C. The salinity was measured as 33.1-33.6 ppt at the surface, and 33.8-34.1 ppt in the subsurface layer (170-200 m). The water was well stratified in the upper 50 m, in which a steep thermocline was also exhibited. However, the 9 °C isotherm deepened sharply in the water south of 41°30'N, indicating the presence of a homogeneous subsurface water mass (Fig. 3a). A salinity gradient was also observed in the upper 50 m. A sharp increase in depth of the 33.9 ppt isohaline was present in waters to the east of 40°30'N (Fig. 3b).

In order to examine the relationship between the abundance of squid to oceanographic conditions, temperature-salinity (TS) diagrams of the water mass from the highest (Sts. 32 and 34) and lowest catches (Sts. 24 and 25) were plotted (Fig. 4). Additional plots from Sts. 6 and 20 are also shown to character-

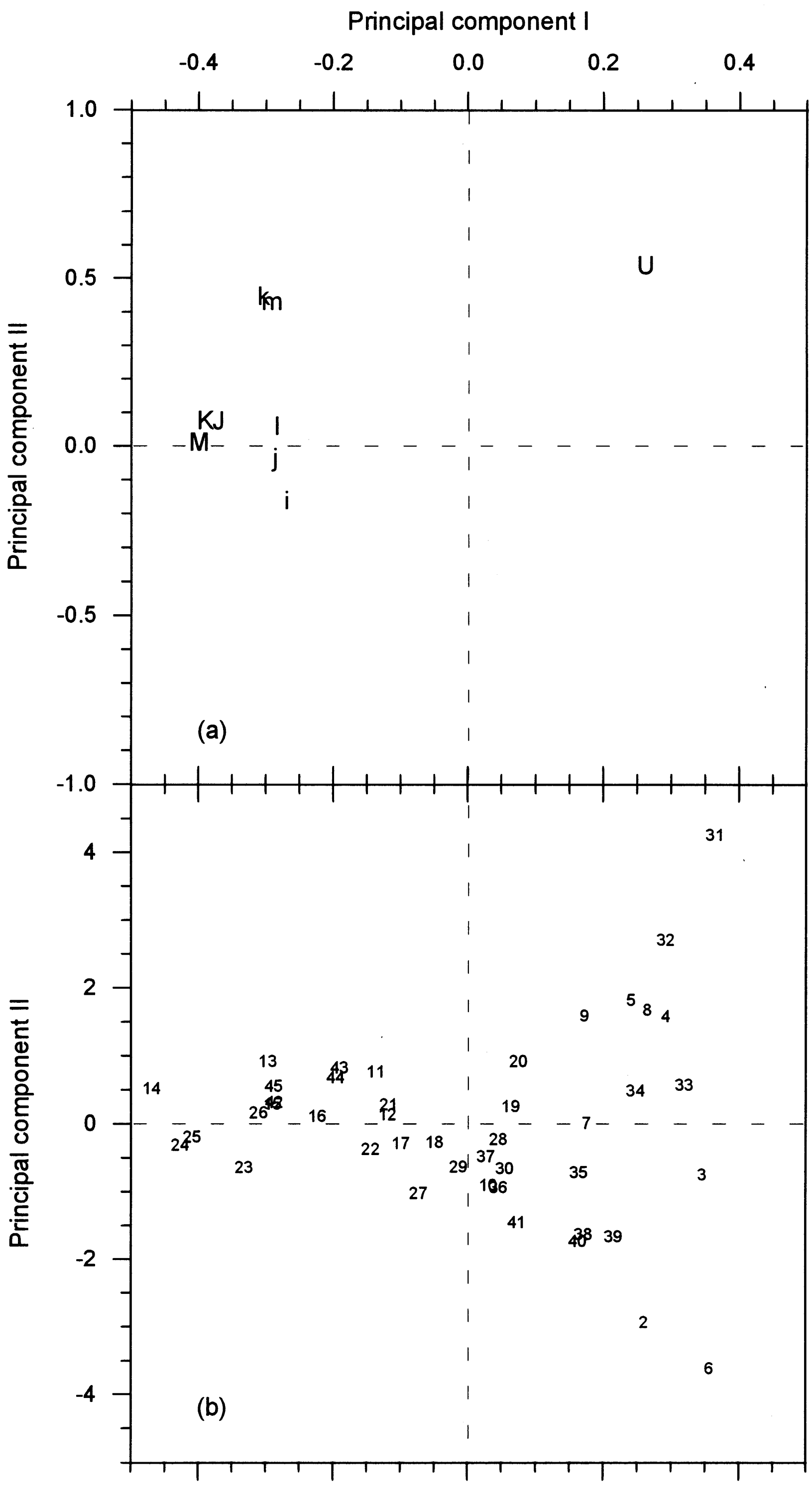


*Figure 5.* Component loading and scatter plots of principal axes 1 and 2 abstracted from the squid abundance index and water variables; U-CPUE; I, J, K, and M for water temperature; and i, j, k, and m for salinity, measured at surface, 100, 150, and 180 m, respectively.

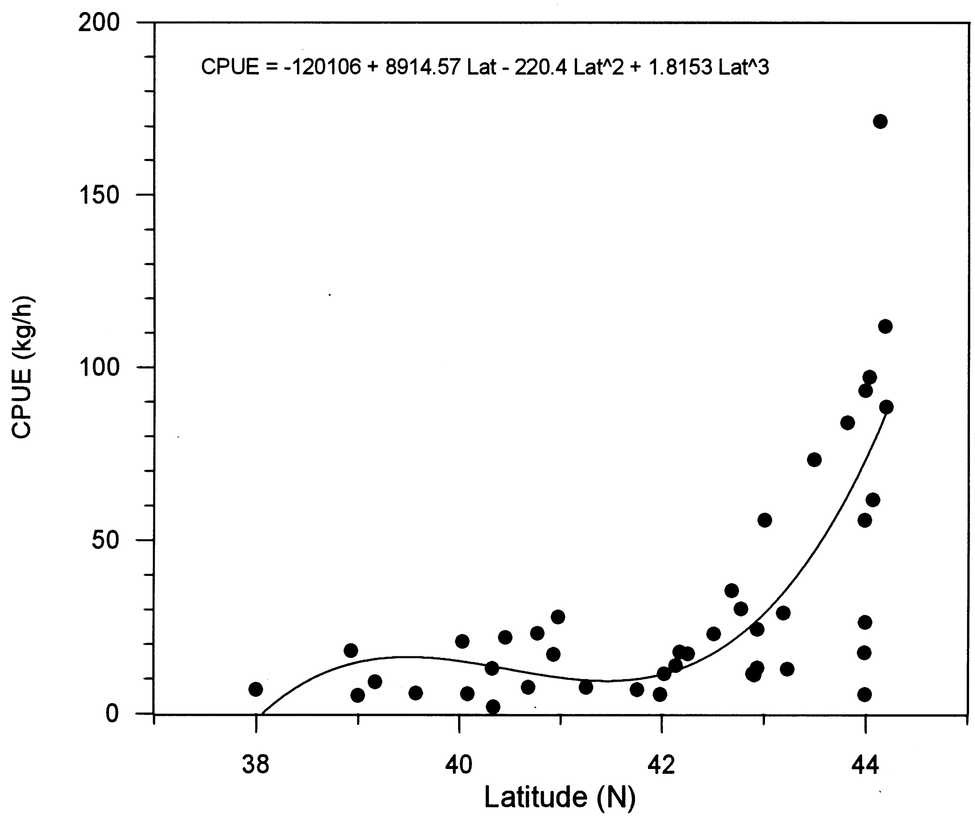


*Figure 6.* Empirical formula obtained from multiple regression analysis on the latitudinal trend of the abundance of *Ommastrephes bartramii.*

ize the scattered minor isopleth centers found around 44° N, 157° W (see Fig. 2). It is apparent that a high abundance of squid is linked to relative low water temperature and low salinity, although the TS diagrams of Sts. 32 and 34 are situated between those of Sts. 6 and 20.

### 3. Relationship between CPUE and oceanographic parameters

We used principal component analysis to reduce the number of oceanographic variables (temperature and salinity measured at the surface, 100, 150, and 180 m, respectively) related to the variation of squid abundance. The analysis exhibited a significant trend of variation as shown by the first two principal axes, through which 74.5% of variation was explained. Component loading indicated that all measured variables were negatively related to CPUE (U) as considered from the first principal component (Fig. 5a). Overall, loading from temperature variables (as shown in capital letters) was more significant than that of salinity (as shown in lowercase letters), while that of subsurface temperature was greater than that of surface temperature. Scatter plots of station data for the first two principal components indicate that high abundance of squid occurring within an optimal temperature ranged was fine-tuned by subsurface water with lower salinity (ref. Sts 31 and 32, Fig. 5b).

### 4. Spatial predictive model

The latitudinal effect on abundance of neon flying squid was confirmed by analysis of variance categorized by 1-degree strata (Fig. 6, $P < 0.001$). The latitudinal gradient could be depicted by a polynominal power function:

CPUE = −120106 + 8914.57 Lat − 220.4 $Lat^2$ + 1.8153 $Lat^3$. The longitudinal effect on the abundance of squid also exhibited a significant effect ($P = 0.0131$). Four longitudinal sections 164-165°'W, 161°'W, 157°'W, and 151°'W, respectively, were found to be above the overall average, while a systematic trend was not confirmed.

## DISCUSSION

The distribution pattern of *Ommastrephes bartramii* in the eastern North Pacific was patchy during the period of July-August 1997, and highly aggregated to the north of 43°'N (Fig. 2). Stations west of 160°'W had a higher CPUE than those east of 160°'W. Based on the catch data from drift net fishery, Murata and Nakamura (1998) found that the fishing ground generally shifted northward and eastward towards colder waters in June-September, and then southward and westward towards warmer waters after October. Subsequently, an ecological strategy of *O. bartramii* was proposed: sub-adults migrate northwards toward the sub-arctic frontal zone for feeding, and mature individuals migrate southwards to subtropical waters for spawning (Murata and Nakamura, 1998). During the period of July-August in the present study, *O. bartramii* appeared to move northward to colder waters in the course of feeding migration.

Two basic marine domains are recognized in the North Pacific, and the transition zone is situated in the middle where temperature and salinity increase southward (Roden, 1970; Favorite *et al.*, 1976). A boundary zone, the sub-arctic frontal zone, between the sub-arctic domain and transition zone, extends from about 40°'N to 43°'N (Roden, 1977, 1991). The southern limit of the sub-arctic frontal zone was best described by the 33.8 ‰ isohaline at the surface layer, and also by the rapid increase in the depth of the 9 °C and 10 °C isotherms (Roden, 1991). However, temperature, salinity, and density fronts do not always coexist (Roden, 1991). In the present study, in the region along 163°30W, the 33.8 ‰ isohaline may outcrop further south of 39°30'N, while a sharp deepening of the 9°'C isotherm was observed near 41°30'N. The southern boundary of the sub-arctic frontal zone was at, or south of, 41°'N. Most of our sampling stations were located within the sub-arctic frontal zone, which presumably was populated by neon flying squid.

The catch of neon flying squid in our exploratory regions was apparently low as compared to that produced by commercial fishing boat in the western North Pacific. High CPUEs were located in the northern region of the sub-arctic frontal zone. Yatsu and Watanabe (1996) proposed that squid are expected to aggregate near the northern transition during their feeding migration when the sea surface temperature (SST) gradient is strong. In our study, the SST gradient was weak between 390 and 43°'N, and the squid were sparse.

The highest CPUE occurred on 3 August at 44°07'N, 164°15'W (St. 31), characterized by medium surface temperature but low subsurface temperature (at 150-180 m) (Fig. 5). The lowest CPUE occurred on 19 July at 40°20'N, 153°14'W (St. 16), characterized by higher temperature through the entire water column. Subsurface (150-180 m) temperature is a more effective predictor of squid catch (Fig. 5), although a high consensus was also found between surface and subsurface measurements. An empirical latitudinal trend parallel to and perhaps also ascribed to water temperature was found in this study. In general, our findings fit well with the existing migratory model, however a more detailed survey and analytical model are desired.

## ACKNOWLEDGMENTS

The authors wish to thank Dr. C. T. Shih for his insightful comments on a preliminary version of this paper. We thank the crews of the *Shyong-chuen No.1* squid-jigging vessel for their assistance in collecting samples during this exploratory survey. Thanks are also extended to Ms. K. Z. Chang of the Economic Fish Laboratory (EFL) Department of Zoology, and Mr. J. S. Lan of the Institute of Fishery Biology, National Taiwan Univ. for help with data preparation. Comments from two anonymous reviewers are also highly appreciated. This study was partially supported by the Fishery Administration, Council of Agriculture, Executive Yuan, Republic of China.

## REFERENCES

Anonymous (1996) *FAO yearbook of Fishery Statistics Capture Production*. Vol. 82. FAO, Rome.

Anonymous (1998) *Annual catch statistics of Taiwan deep-sea squid fishery*. Overseas Fisheries Development Council of the Republic of China, Taipei. 60 pp.

Araya, H. (1983) Fishery, biology and stock assessment of *Ommastrephes bartramii* in the North Pacific Ocean. Mem. Natl. Mus. Victoria 44: 269-283.

Favorite, F., A. J. Dodimead and K. Nasu (1976) Oceanography of the subarctic Pacific region, 1960-1971. Bull. Intl. N. Pac. Fish. Comm. 33: 1-187.

Gong, Y., Y. S. Kim and S. J. Hwang (1993) Outline of the Korean squid driftnet fishery in the North Pacific. Bull. Intl. N. Pac. Fish. Comm. 53: 45-69.

Murata, M. (1990) Oceanic resources of squids. Mar. Behav. Physiol. 18: 1971.

Murata, M and S. Hayase (1993) Life history and biological information on flying squid (*Ommastrephes bartramii*) in the north Pacific Ocean. Bull. Intl. N. Pac. Fish. Comm. 53: 147-182.

Murata, M. and Y. Nakamura (1998) Seasonal migration and diel vertical migration of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific. In *Contributed papers to International Symposium on Large Pelagic Squid*. T. Okutani, ed. Japan Marine Fishery Resources Research Center, Tokyo, pp. 13-30.

Roden, G. I. (1970) Aspects of the mid-Pacific transition zone. J. Geophys. Res. 75: 1097-1109.

Roden, G. I. (1977) Oceanic subarctic fronts of the central North Pacific: structure of and response to atmospheric forcing. J. Phys. Oceanogr. 7: 761-778.

Roden, G. I. (1991) Subarctic-subtropical transition zone of the North Pacific: large-scale aspects and mesoscale structure. NOAA Tech. Rep. US Dept. Commerce 105: 1-38.

Yatsu, A. and T. Watanabe (1996) Interannual variability in neon flying squid abundance and oceanographic condition in the Central North Pacific in 1982-92. Bull. Natl. Inst. Far Seas 33:123-138.

Yatsu, A., S. Midorikawa, T. Shimada and Y. Uozumi (1997) Age and growth of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific Ocean. Fish. Res. 29: 257-270.

Yatsu, A., N. Mochioka, K. Morishita, and H. Toh (1998) Strontium/calcium ratios in statoliths of the neon flying squid, *Ommastrephes bartrami* (Cephlalopoda), in the North Pacific Ocean. Mar. Biol. 131: 275 282.

(Received Mar. 6, 2000; Accepted April 9, 2000)

# 東北太平洋海域赤魷的資源量與空間分布變化：一次探測研究的觀察

陳志炘[1,2]・丘臺生[1]

[1] 國立臺灣大學動物學研究所・[2] 國立臺灣大學漁業生物試驗所

**摘　要**

為瞭解赤魷（*Ommastrephes bartramii*）在東北太平洋水域赤魷的資源量與分布型態，我們在1997年7月4日至8月17日間，於39° - 44° N，150° - 170° W水域進行探測研究。在連續45天的探測作業，總漁獲量為15,806公斤，平均每日漁獲量351.2公斤。以單位努力漁獲量（CPUE, kg $h^{-1}$）為資源豐度的指標，由CPUE等值分布圖發現，較高的資源豐度出現在44°'N，164°'W附近。探測水域的水團具有相當不同的水文性質；而且高資源豐度的出現，顯然與相對較低的海水溫度與鹽度有關連。由主成份分析結果指出：對預測赤魷資源豐度的高低而言，海水溫度比鹽度有較高的預測效力。 以經緯度一度方格為單位，在空間分布上，赤魷有明顯的南北（緯度）傾斜現象；在東西向（經度）的分布上，雖有方格間的顯著效應，但無明顯傾斜之趨勢；換言之，後者呈現堆狀不規則分布。最後，依相關文獻，我們也討論了分布在北太平洋過渡區、鋒面帶附近的赤魷隨季節洄游的情形。

**關鍵字：**赤魷、北太平洋、空間分布。