Forecasting the stock size of the autumn cohort of Japanese common squid (*Todarodes pacificus*) based on the abundance of trawl-caught juveniles

Predicción del tamaño de la población de la cohorte de otoño del calamar común japonés (*Todarodes pacificus*), basado en la abundancia de juveniles capturados con redes de arrastre

Hideaki Kidokoro[1], Takafumi Shikata[2] and Shinsuke Kitagawa[3]

[1]Japan Sea National Fisheries Research Institute, Fisheries Research Agency. 1-5939-22, Suido-cho, Chuo-ku, Niigata, Niigata, 951-8121. Japan
[2]Ishikawa Prefecture Fisheries Research Center. 3-7 Ushitsushinminato, Notomachi, Ishikawa, 927-0435. Japan
[3]Toyama Prefecture Fisheries Research Institute. 364 Takatsuka, Namerikawa, Toyama, 936-8536. Japan
e-mail: kidokoro@fra.affrc.go.jp

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ABSTRACT

The distribution of juveniles of Japanese common squid (*Todarodes pacificus*) autumn cohort and its relation to oceanographic conditions were analyzed to see if they can be used to accurately forecast the stock size. Research cruises was conducted using a total of 5 research vessels during 2001-2010 in April in the southern Sea of Japan. Juveniles were caught in 267 of 331 tows of a trawl net at approximately 0-10 m depth, and the numbers caught in each tow ranged from 0 to 1087. Samples were divided into the autumn and winter cohorts based on the dorsal mantle length (DML). The autumn cohort was abundant (40 inds / tow) where the sea surface temperature ranged from 10 to 11 °C and less abundant in warmer water. This cohort was more abundant in offshore areas, while the winter cohort was more abundant near shore. The mean catch of the autumn cohort was used as an index of the annual abundance of juveniles. This index and the stock size were significantly correlated. These results suggest that the stock size of the *T. pacificus* autumn cohort can be forecasted before the fishing season based on the abundance of juveniles, but this relationship is highly uncertain due to observational errors.

Key words: Ommastrephidae, predicting stock size, stock management.

RESUMEN

Se analizó la distribución de los juveniles de la cohorte de otoño del calamar japonés (*Todarodes pacificus*) y su relación con las condiciones oceanográficas para ver si podrán ser utilizados para predecir con exactitud el tamaño de la población. Los cruceros de investigación se realizaron en abril durante 2001-2010 en cinco barcos al sur del Mar de Japón. Los juveniles se capturaron con una red de arrastre en 267 de 331 arrastres, a una profundidad aproximada de 0 a 10 m, variando el número de organismos capturados en cada arrastre de 0 a 1,087. Las muestras se dividieron en las cohortes de otoño e invierno sobre la base de la Longitud de Manto Dorsal (DML). La cohorte de otoño fue abundante (40 inds / arrastre) cuando la temperatura superficial del mar (SST) fue de 10 a 11 °C y menos abundante en aguas más cálidas. Esta cohorte fue más abundante en zonas de alta mar, mientras que la de invierno fue más abundante cerca de la costa. La captura media de la cohorte de otoño se utilizó como un índice de la abundancia anual de juveniles. Este índice y el tamaño de la población se correlacionaron significativamente. Estos resultados sugieren que el tamaño de la población de la cohorte de otoño de *T. pacificus* pueden preverse antes de la temporada de pesca basada en la abundancia de los juveniles, pero esta relación es bastante incierta debido a errores de observación.

Palabras clave: Manejo de recursos, Ommastrephidae, predicción tamaño poblacional,

INTRODUCTION

The Japanese common squid, *Todarodes pacificus* (Steenstrup 1880), is distributed in the northwest Pacific, including the Sea of Japan, and spawns year round with a peak in autumn and winter (Kasahara, 1978; Okutani, 1983). Its distribution area and migration pattern vary with the hatching season, so the population is usually divided into two main cohorts based on the hatching season, i.e., autumn and winter (Araya, 1967; Kasahara, 1978; Okutani, 1983; Kidokoro *et al.*, 2003). The autumn cohort occurs mainly in the Sea of Japan, while the winter cohort is distributed mainly in the Pacific Ocean (Araya, 1967; Kasahara, 1978; Okutani, 1983; Kidokoro *et al.*, 2003).

T. pacificus is the most commercially important cephalopod in Japan and South Korea. It is caught mainly by jigging and trawls, and annual landings by the Japanese and South Korean fisheries in recent years have been about 500,000 t (Kidokoro *et al.*, 2012). Although some Japanese fisheries have been regulated through licensing systems, the Japanese Fisheries Agency has adopted a total allowable catch (TAC) system as an additional stock management method since 1998. The annual TAC is usually set based on an allowable biological catch (ABC), which is recommended by researchers at the national fisheries research institutes. The annual ABC is currently calculated using a limit reference point *e.g.* *F*med or *F*msy (Caddy & Mahon, 1995) from a stock size predicted for the next fishing year. If the actual stock size is smaller than the predicted stock size, there is a risk of overfishing the stock. One way to reduce this risk is to estimate the stock size just before the fishing season based on the abundance of pre-recruits (juveniles), and then revise the ABC and/or TAC accordingly. However

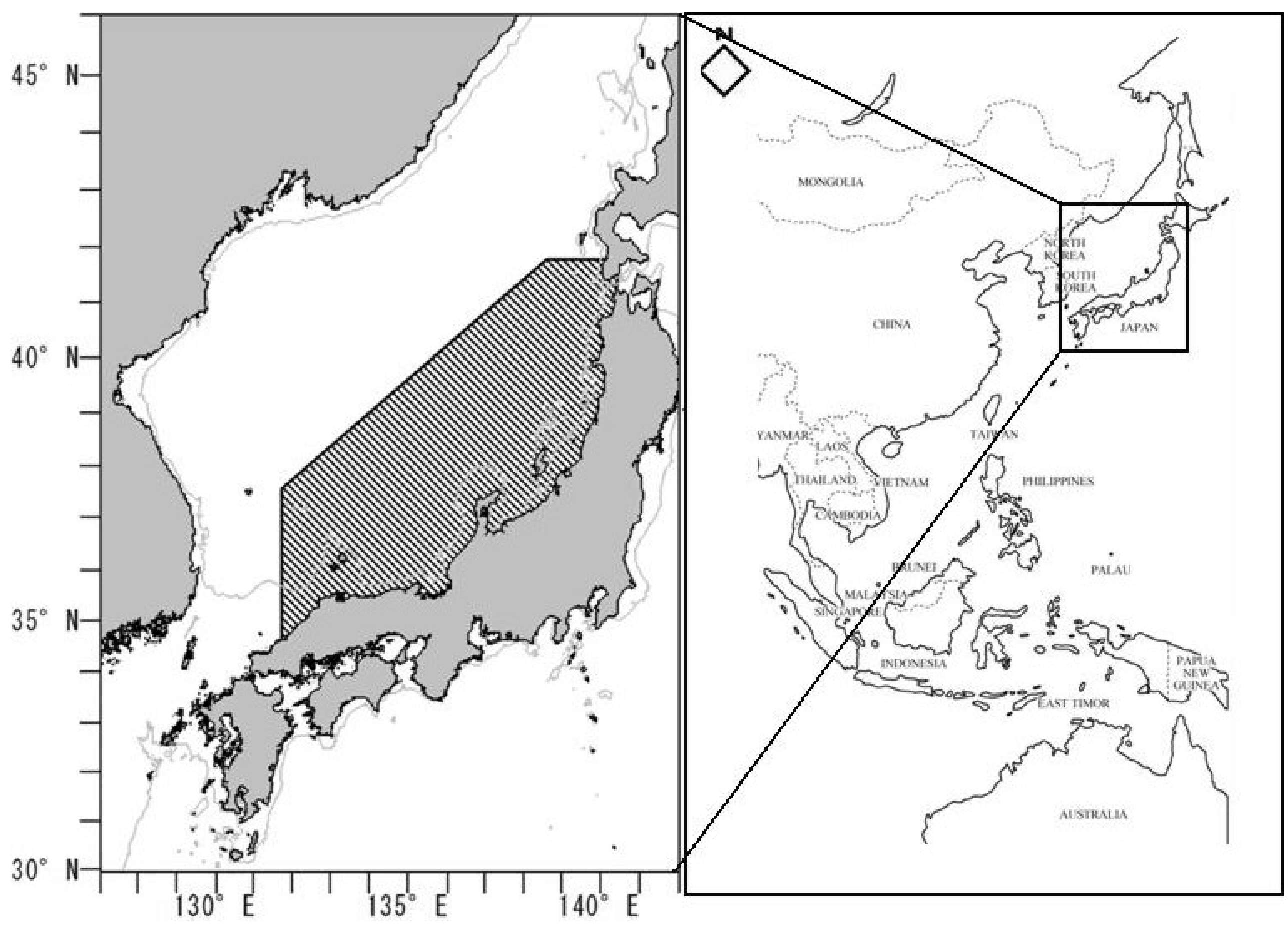

Figure 1. Map of survey area. Surveys were conducted in the southern part of the Sea of Japan (shown by areas with oblique lines).

the ecology of the juveniles remains poorly known (Murata, 1983; Kidokoro *et al*., 1999; Kawabata *et al*., 2006).

To improve stock management for *T. pacificus* using the TAC system, it is considered essential to predict the stock size just before fishing season based on the abundance of juveniles. In this study, juveniles were collected to examine their distribution and its relation to oceanographic conditions. Based on these result we examined a method to forecast the stock size of the *T. pacificus* autumn cohort based on juvenile abundance just before the fishing season.

MATERIALS AND METHODS

Mid-surface water trawl nets survey. Research cruises to collect *T. pacificus* juveniles were conducted using a total of five research vessels during 2001-2010 in April in the southern Sea of Japan (Fig. 1). Juveniles were caught by a trawl with a mouth diameter of 10-12 m and cod end mesh size of 7 mm (Fig. 2) towed at approximately 0-10 m depth at about 30 experimental stations. The nets were equipped with kites at the mouth (Fig. 2) and usually operated with otter boards.

Each tow lasted 30 minutes at night (20:00-04:00), and water temperatures and salinities were measured using a CTD just before or after the tow. *T. pacificus* were sorted immediately from catches on the deck after each tow, counted, and measured dorsal mantle length (DML).

Division of samples into two cohorts. Samples were divided into the autumn and winter cohorts based on the DML. *T. pacificus* takes about 4 months to grow to 50 mm DML (Kidokoro *et al*., 1999), so *T. pacificus* larger than 50 mm DML size presumably hatched before December of the previous year (i.e., members of the autumn cohort), and those less than 50 mm DML presumably hatched after January in the same year (i.e., members of the winter cohort).

Distribution of juveniles. The catch numbers of juveniles were mapped by cohort each year to examine their horizontal distribution. To compare the distribution to oceanographic conditions, the mean of catch numbers by cohort were calculated at 1 °C SST intervals. The mantle length compositions and the mean of catch numbers for the SST intervals were calculated by pooling using all data obtained during 2001-2010.

Comparison of juvenile abundance and estimated stock size. Stock assessment reports during 2001-2010 from the Japanese Fisheries Agency (Kidokoro *et al*., 2012) were used to estimate the stock size of autumn cohort. These estimates were based on experimental jigging surveys in June-July of each year (Kidokoro *et al*., 2003; Kidokoro *et al*., 2012). The estimated stock size was 2,000,000 tons around 2000 and declined to about 1,500,000 tons around 2010 (Table 1).

The mean numbers of the autumn cohort in the trawl surveys were used as an index of the annual abundance of juveniles, which was used as explanatory variables to predict the stock size of the autumn cohort. These data were fit to a simple linear model ($Y = ax+b$) by the least-square method, and the significance was tested based on the null hypothesis ($a=0$).

RESULTS

Distribution patterns of *T. pacificus* juveniles. *T. pacificus* juveniles (DML range: 8 to 205 mm) were caught in 267 of the 331 tows (Fig. 3), and the number caught in each tow ranged from 0 to 1087. The catch mode was less than 50 inds. / tow, but in some tows, several hundred individuals were caught (Fig. 4). The autumn cohort tended to be more abundant in offshore areas, while the winter cohort was abundant near shore (Fig. 5).

The SST ranged from 3 to 16 °C in the survey area, but juveniles were caught only above 7 °C (Fig. 3, 6). The mean catch increased with SST up to 10 °C and reached about 50-70 inds. / tow where the SST ranged 10 to 16 °C (Fig. 6). The autumn cohort was abundant (40 inds. / tow) at 10-11 °C SST, and less abundant in warmer water (Fig. 6). On the other hand, the winter cohort was abundant above 13 °C (Fig. 6).

Predicting stock size based on juvenile abundance. The annual mean catch number of autumn-cohort juveniles per tow varied widely (Fig. 7). The number was about 40 inds. / tow in 2001 and 2002, declined to about 10 inds. / tow in 2004 and 2005, increased to about 20 inds. / tow in 2008, and was very low (2 inds. / tow) in 2010. For the winter cohort, the number was about 20 inds. / tow during 2000 and 2005, was very low (2 inds. / tow) in 2006, and increased to 60 inds. / tow in 2009. The annual trend in the number caught differed between the cohorts.

The stock size and the mean catch of autumn cohort juveniles was significantly correlated ($a = 19.8 \times 10^3$, $p < 0.05$) (Fig. 8). When the data were fit to a simple linear model, the y-intercept was high and significant ($b = 1004 \times 10^3$, $p < 0.001$).

DISCUSSION

The spawning area of *Todarodes pacificus* shifts seasonally (Araya, 1967; Shojima, 1972; Okutani, 1983). It located mainly in the southwestern part of the Sea of Japan and the northern East China Sea in autumn (Goto, 2002), and shifts to the middle and southern East China Sea in winter (Araya, 1967; Okutani, 1983; Sakurai *et al*., 2000). Egg masses and hatchlings spawned in autumn are conveyed by the offshore and inshore branches of Tsushima Current from the spawning grounds to the Sea of Japan (Araya, 1967; Okutani, 1983; Goto, 2002). On the other hand, those spawned in winter are conveyed by the Kuroshio to the Pacific side (Watanabe, 1965; Bower *et al*., 1999) or inshore areas in the Sea of Ja-

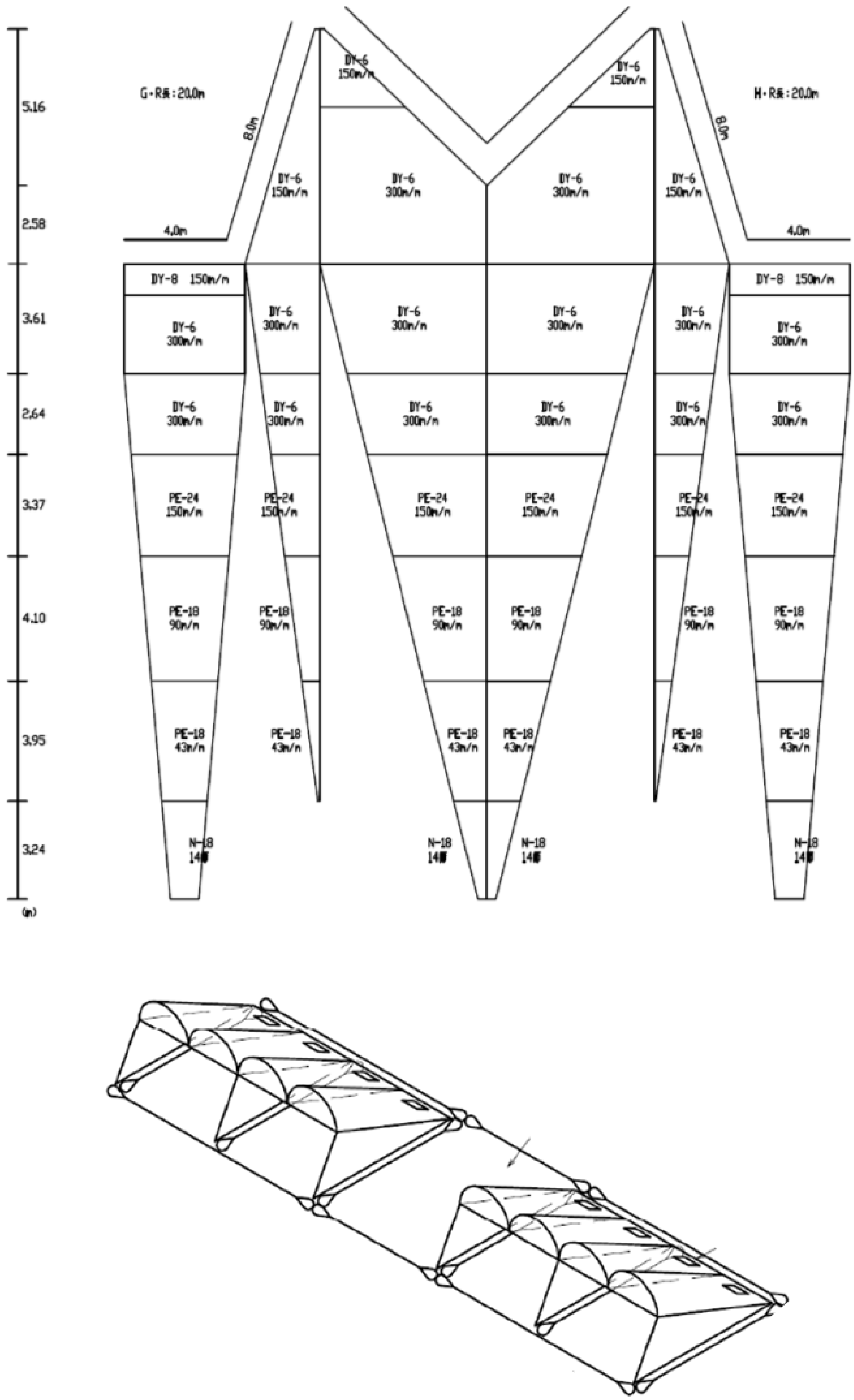

Figure 2. A trawl net used in the present survey. Upper figure is the design of the trawl net and lower figure is the over view of the kite.

Table 1. Estimated stock size of *Todarodes pacificus* autumn cohort from Kidokoro *et al*. (2012).

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
(X 1000 t)	1765	2039	1374	982	1322	1286	910	1714	1485	1188

pan by the inshore branch of the Tsushima Current (Araya, 1967; Okutani, 1983). We found that autumn-cohort juveniles tended to be dominant in the offshore area, and the winter cohort juveniles were dominant in the coastal area (Fig. 5). This difference was presumably due to differences in the current systems that flowed from the spawning grounds.

Cephalopod stocks generally do not show a clear relationship between spawning stock size and subsequent recruitment due to their high recruitment variability (Pierce & Guerra, 1994; Basson *et al*., 1996; Uozumi, 1998). As a result, predicting recruitment is difficult. In the present study, stock size and the annual average number of juveniles in the autumn cohort were significantly correlated (Fig. 8). This suggests that it might be possible to accurately forecast the stock size of the autumn cohort before the fishing season begins, which would allow the ABC and / or TAC to be revised accordingly before fishing season, if needed.

However, the y-intercept for data fit to a linear model was quite value. Based on this model, if no juveniles are caught by trawl surveys, the predicted stock size of the autumn cohort is

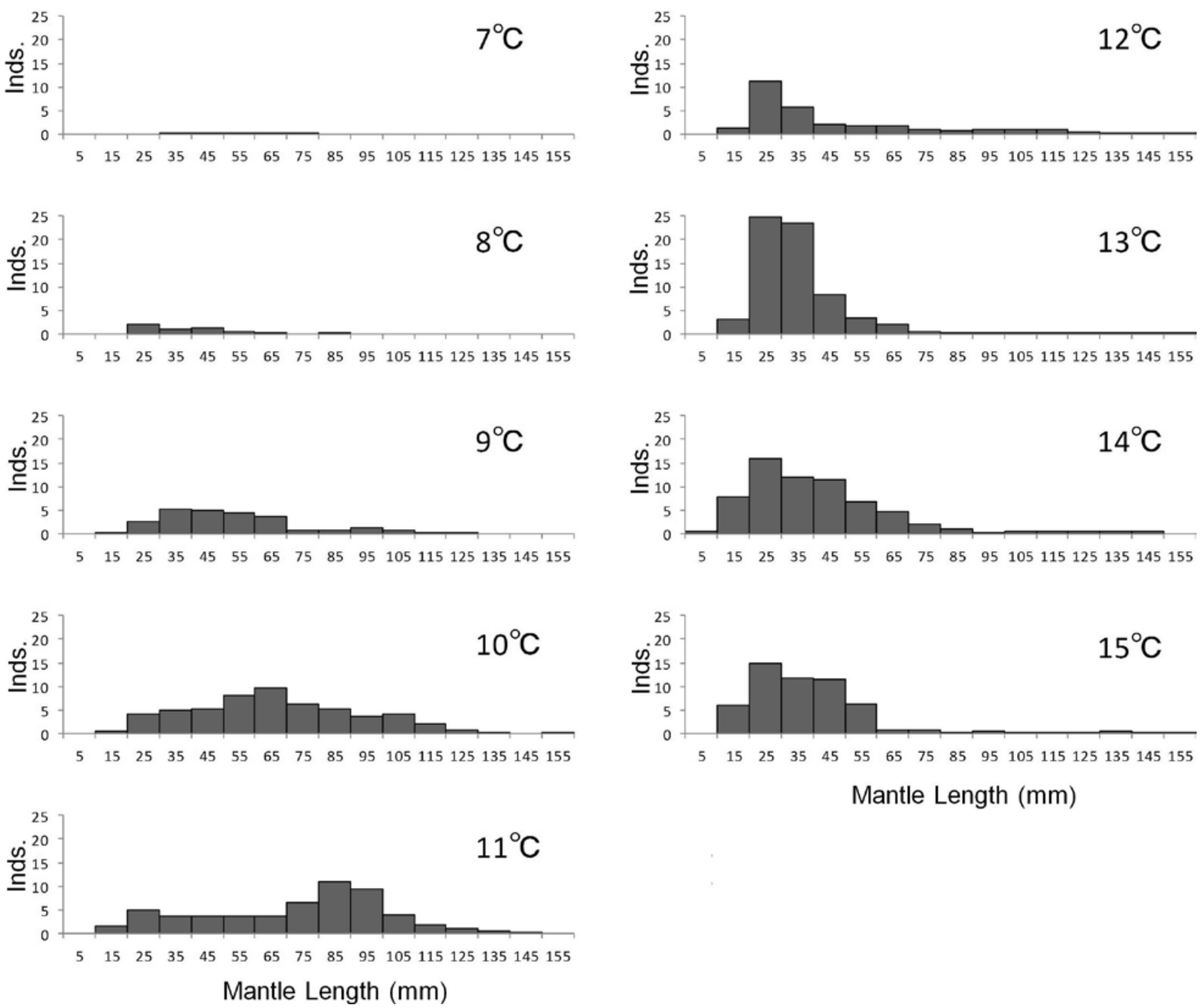

Figure 3. Dorsal mantle length (DML) compositions of juvenile *Todarodes pacificus* in sea surface temperature.

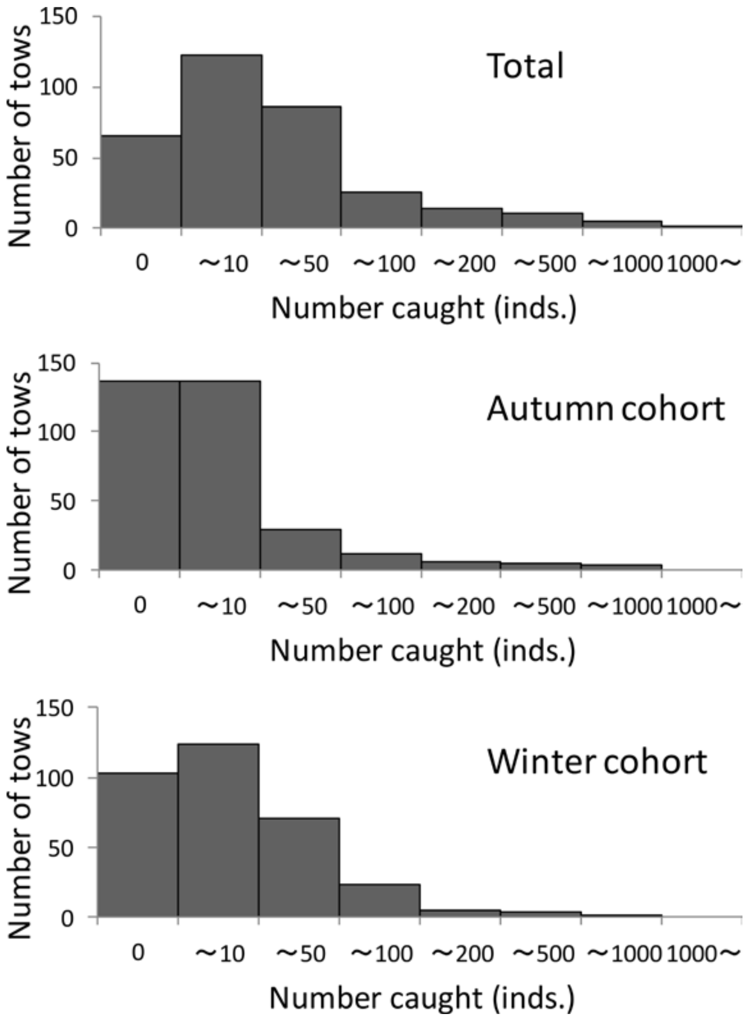

Figure 4. Squid frequency distribution caught by the trawl nets.

about one million tons. Basically, observation errors in explanatory variables will be biased towards a lower slope and higher intercept (Krebs, 1999). The high y-intercept obtained in this study was considered to be due to observation errors in the trawl surveys, though the relationship between juvenile abundance and stock size is probably nonlinear. There were some stations where hundreds of individuals were caught (Figs. 4-5) each year, which contributed a large part of the mean number caught. This huge variation in catch number per tow can lead to large observation errors.

Basically, increasing the number of stations and using larger sampling gear are effective ways to reduce observation errors, but these modifications usually increase costs. Instead of these modifications, survey plans can be modified to more effectively consider the distribution pattern of juveniles obtained in this study (horizontal distribution pattern, relationship between density and SST in cohorts), which is expected to reduce observation errors. Based on the distribution pattern of juveniles shown in this study, we believe that we can collect juveniles of the autumn cohort more efficiently by surveying offshore areas in the Sea of Japan particularly where the SST is 10-11 °C. Modification of survey plans based on the ecological traits of the juveniles is expected to reduce observation errors and to estimate the abundance of juvenile squid more precisely, which will contribute to more accurate and efficient management of this stock.

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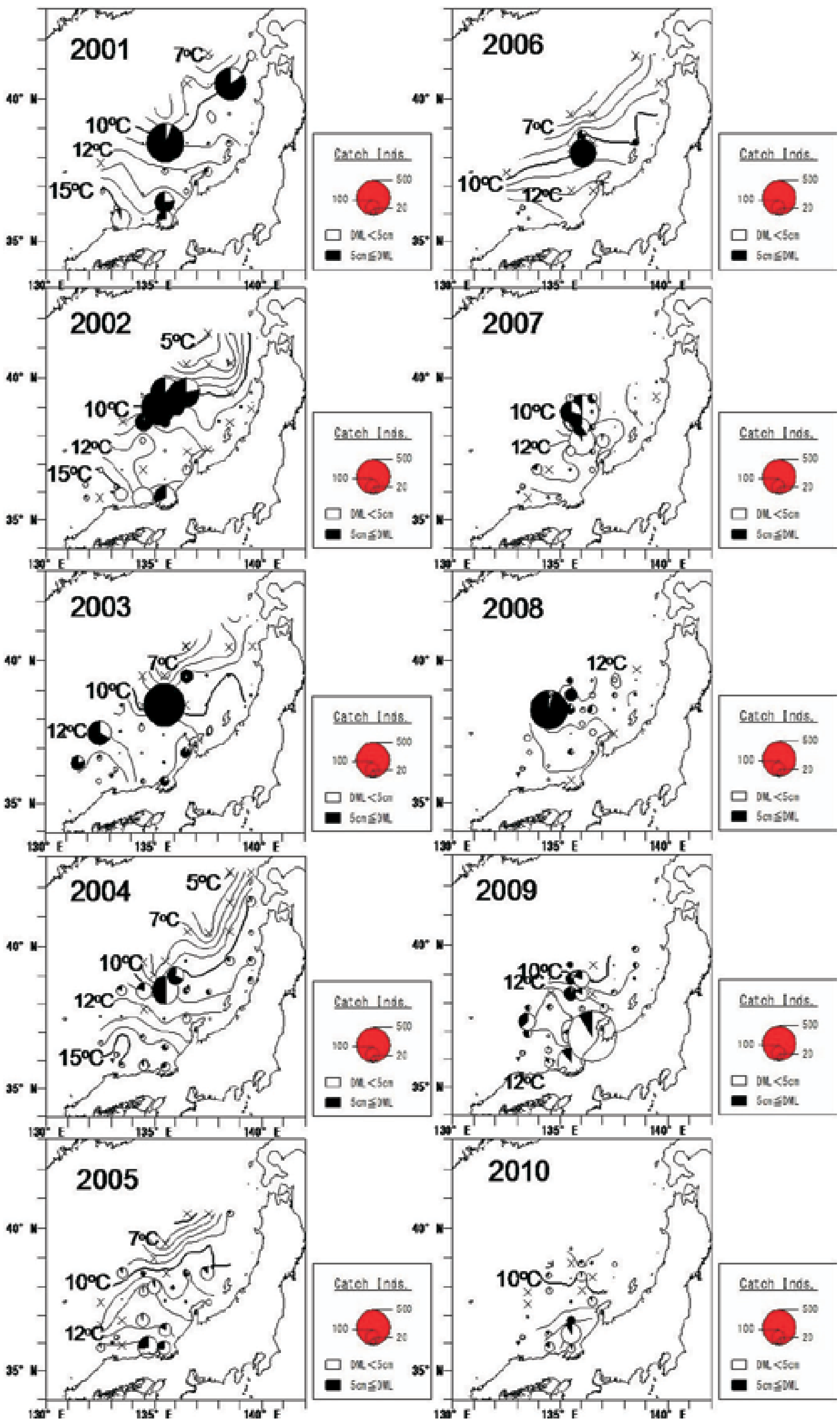

Figure 5. Site of stations and number caught of juvenile *Todarodes pacificus* at the stations shown with the special distribution of SST. The area of circles show the number of juveniles caught. The number of juveniles of autumn cohort (DML upper than 50mm) was shown in the area of black color. Stations that *T. pacificus* were not caught were shown by crosses.

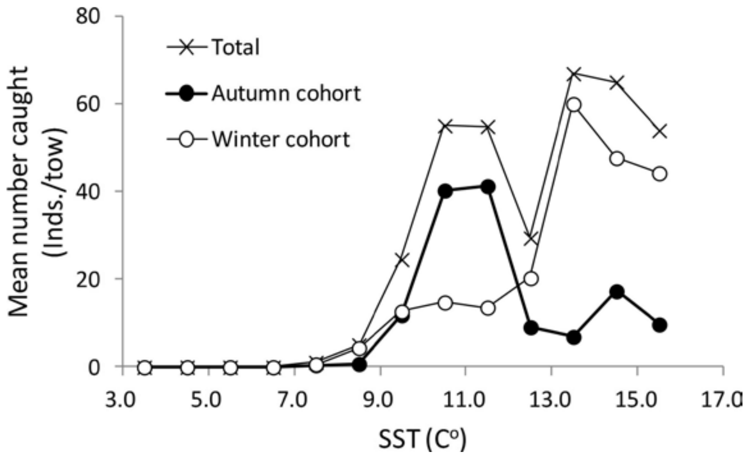

Figure 6. Changes in the mean number caught in SST. Cross shows the number caught of all size class, closed circle shows those of autumn cohort and open circle chows those of winter cohort.

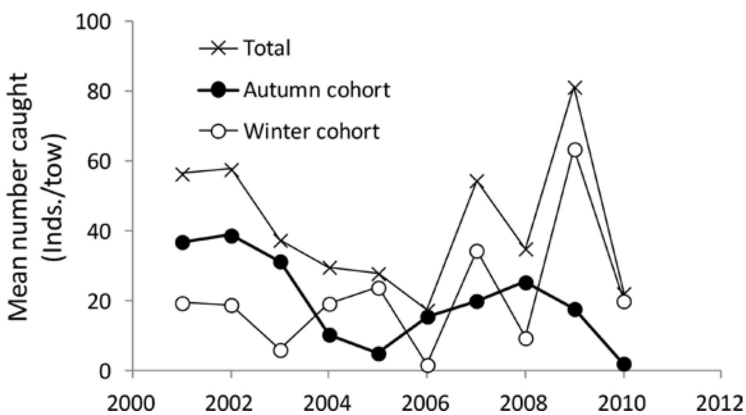

Figure 7. Annual changes in the mean number caught juveniles.

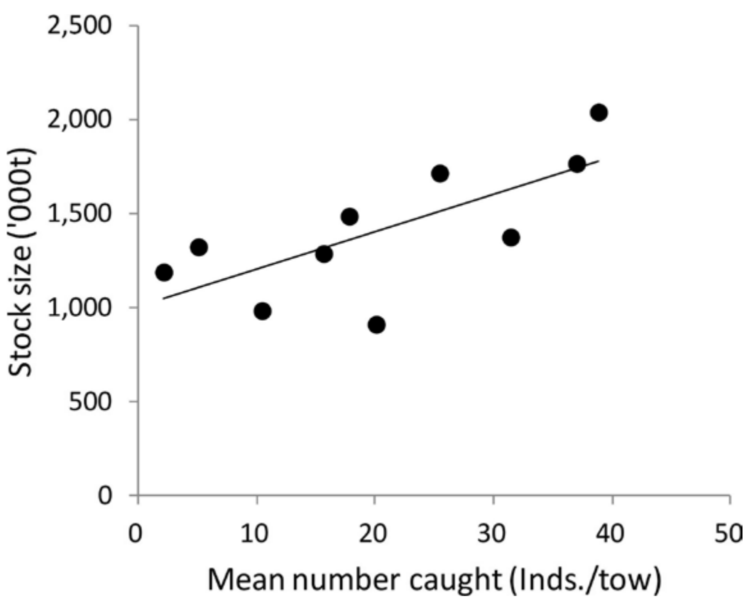

Figure 8. Relationships between the stock size and annual mean number caught juveniles for *Todarodes pacificus* autumn cohort. There was significant positive relationship (p<0.05).

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