Scientia Marina 74(4)
December 2010, 687-695, Barcelona (Spain)
ISSN: 0214-8358
doi: 10.3989/scimar.2010.74n4687

Fishery biology of the jumbo flying squid *Dosidicus gigas* off the Exclusive Economic Zone of Chilean waters

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SUMMARY: The jumbo flying squid *Dosidicus gigas* is widely distributed in the eastern Pacific Ocean and supports an important fishery. Although many studies have been carried out on the biology of this species, limited biological information is available in the waters outside the Exclusive Economic Zone of Chile (EEZ) (20°S-41°S and 74°30′W-84°W). Three surveys were conducted in this area by the Chinese squid jigging vessels during the period from April 2006 to May 2008. The majority of the catch in the survey was from the two areas defined by 37°30′-41°S and 78°30′-80°W and by 25°-30°S and 76°-77°30′W. The sex ratio (M: F) of the catch was 1: 2.48. The mean mantle length (ML) was 376 mm for males with a range of 257-721 mm and 388.7 mm for females with a range of 236-837 mm. Two distinguished size classes, medium- and large-sized groups, were identified in this study with the medium-sized group (350-450 mm ML) consisting of 89% of the total catch. The sizes at first sexual maturity were 638 mm ML for females and 565 mm ML for males. This study suggests that all the individuals examined were hatched from March 2007 to February 2008, indicating that *D. gigas* might spawn all year around with a peak spawning time from November 2007 to January 2008. Most of the stomachs analyzed had food remains. The preys included three major groups: fish (mainly lanternfish), cephalopods and crustaceans, but *D. gigas* was the dominant species in the stomach contents, showing strong evidence of cannibalism. The information obtained from this study improves our understanding of the fishery biology of *D. gigas* off Chile.

Keywords: *Dosidicus gigas*, fishery biology, Chile.

RESUMEN: Biología pesquera de la pota gigante *Dosidicus gigas* en aguas exteriores a la Zona Económica Exclusiva de Chile. – La pota gigante *Dosidicus gigas* está ampliamente distribuida en el océano Pacífico oriental y soporta una pesquería importante. Aunque se han realizado muchos estudios sobre la biología de esta especie, la información existente para aguas externas a la Zona Económica Exclusiva (ZEE) de Chile (20ºS-41ºS y 74º30′W-84ºW) es muy limitada. Los barcos poteros chinos realizaron tres campañas en esta área entre abril de 2006 y mayo de 2008. La mayoría de las capturas en esas campañas proceden de dos áreas definidas por las coordenadas 37º31′S-41ºS 78º30′W-80ºW y 25ºS-30ºS 76ºW-77º30′W, respectivamente. La relación sexual (M:H) en las capturas fue de 1:2.48. La longitud media del manto (LM) fue de 376 mm para los machos con un rango que varió entre 257 y 721 mm, y de 388.7 mm para las hembras (236-837 mm). Se diferenciaron dos clases de tamaño: un grupo medio, cuya LM varió entre 350 y 450 mm representando un 89% de la captura total, y un grupo grande. La talla de primera maduración sexual fue de 638 mm para las hembras y de 565 mm para los machos. Este trabajo sugiere que todos los individuos examinados habían nacido entre marzo de 2007 y febrero de 2008, lo cual indica que *D. gigas* puede frezar durante todo el año, habiendo existido un pico de puesta desde noviembre de 2007 hasta enero de 2008. La mayoría de los estómagos analizados contenían restos. Las presas incluyen tres grandes grupos de organismos: peces (principalmente mictófidos), cefalópodos y crustáceos. Sin embargo, *D. gigas* fue la presa dominate en los contenidos estomacales, lo cual es una evidencia del fuerte canibalismo existente en esta especie. La información que se deriva de este trabajo mejora nuestro conocimiento sobre la biología de *D. gigas* frente a Chile.

Palabras clave: *Dosidicus gigas*, biología pesquera, Chile.

INTRODUCTION

The jumbo flying squid (*Dosidicus gigas* d'Orbigny, 1835) is widely distributed in the eastern Pacific Ocean from California (37°N) to southern Chile (47°S), and the maximum longitudinal distribution is reached eastwards up to 125°W at the equator (Nesis, 1983; Nigmatullin *et al*., 2001). The highest concentrations in the southern and northern hemispheres have been observed off the Peruvian coast and the Gulf of California, respectively (Wang and Chen, 2005; Keyl *et al*., 2008). *D. gigas* supports one of the most important cephalopod fisheries in the eastern Pacific Ocean. The *D. gigas* landings are mainly from Peru, Mexico and Chile, and reached 291-435 thousand t, 53-66 thousand t, and 122-297 thousand t, respectively, from 2005 to 2007. The squid jigging fleet from China, Japan and South Korea also targeted *D. gigas* stock with a total annual landing of 55-122 thousand t from 2005 to 2007 (http://www.fao.org/fishery/statistics/global-capture-production/query/en).

Many studies have been carried out on the fisheries biology of *D. gigas* in the Gulf of California and off the Peruvian coast (Nigmatullin *et al*., 2001; Chen *et al*., 2008). These studies suggest that the population structure is complicated, consisting of three groups with a different mantle length (ML) at maturity. These three groups include a small group with an ML at maturity of 130-260 mm and 140-340 mm for males and females, respectively, which are predominantly present in the equatorial area; a medium-sized group with an ML at maturity of 240-420 mm and 280-600 mm for males and females, respectively, which occur over the whole species range; and a large size group with an ML at maturity of >400-500 mm and >550-650 mm for males and females, respectively, which occur in the northern and southern peripheries of the range (Nesis, 1983; Nigmatullin *et al*., 2001).

Zúñiga *et al*. (2008) postulated the existence of two reproductive cycles for *D. gigas* based on the regular pattern of periodicity in the monthly catch of *D. gigas* along the Chilean coast during the period from 2002 to 2005. The life spans of all three groups are about 1 year, but the largest individuals of the large group can probably live for 2 years (Nigmatullin *et al*., 2001; Hu *et al*., 2009).

Statolith ageing studies generally confirmed high growth rates of *D. gigas*, which could attain large sizes in less than 1 year. A mature female of 720 mm ML had an increment of 345 mm in its statoliths (Arkhipkin, 1989), a 770 mm ML male and a 860 mm ML female had an increment of 52 mm and 338 mm, respectively (Masuda *et al*., 1998; Argüelles *et al*., 2001).

Wormuth (1970) also showed large geographical variations in size composition for *D. gigas*. Individuals larger than 400 mm ML are rarely found to the north of the equator, while to the south they can reach a size of more than 1000 mm ML. Off the Chilean coasts, Garcia-Tello (1965) found *D. gigas* of up to 930 mm ML. In the high sea (5-16°S and 79-90°W) off Peru from June to August, the ML of catch ranged from 203 to 805 mm and the dominant ML was between 240 and 480 mm, accounting for 80% of the total catch (Ye, 2002).

Spawning takes place throughout the year, but with a distinct peak in spring and summer in the southern hemisphere (October-January; Tafur *et al*., 2001). *D. gigas* are monocyclic and have the highest potential fecundity of all the cephalopods, up to 32 million oocytes (Nigmatullin, 1999). In the Gulf of California, the large female *D. gigas* mature at 750 mm ML and males mature at two sizes, 530 mm and 670 mm ML. A medium-sized mature group is identified: 400 mm ML for females and 330 mm ML for males (Markaida and Sosa-Nishizaki, 2003). In the open waters off Peru, the male *D. gigas* are found to mature at younger ages than the females. Argüelles *et al*. (2008) also examined changes in the size-at-maturity of female *D. gigas* off the Peruvian coast during the period from1989 to 2004. The initial size at sexual maturity was estimated to be 374 mm ML for females and 228 mm ML for males (Ye and Chen, 2007).

D. gigas is an active predator (Nesis, 1983; Wang and Chen, 2005). The common prey species include copepods, hyperiid amphipods, euphausiids, pelagic shrimps and red crabs (*Pleuroncodes planipes*), heteropod molluscs, squid, pelagic octopods and various finfishes (Ehrhard *et al*., 1983; Bazanov, 1987; Nigmatullin *et al*., 2001; Markaida, 2006). The most common finfish preys are epipelagic lanternfish, and squid prey species are ommastrephids, including *D. gigas* (Nigmatullin *et al*., 2001).

In Chilean waters, *D. gigas* are highly abundant and support one of the most important fisheries in recent years (Rocha, 1997; Zúñiga *et al*., 2008). Rocha and Vega (2003) reported that *D. gigas* were landed year-round, mainly concentrated in waters off central Chile. Ibáñez and Cubillos (2007) described the spatial and seasonal changes in the size structure and reproductive activity of *D. gigas* in the central-southern area off Chile (34-40°S). Little information is, however, available on the fishery biology of *D. gigas* in the waters outside the Exclusive Economic Zone (EEZ) of Chile (south of 20ºS).

This study evaluates the fishery biology of *D. gigas* based on data collected in the three scientific surveys for *D. gigas* undertaken by the Chinese squid jigger vessels from 2006 to 2008 in waters outside the EEZ of Chile. We present information on the spatial distribution of catch, population structure, maturity, age and feeding, which is critical in our understanding of the life history and population dynamics of *D. gigas* off Chile. The study fills a knowledge gap in fishery biology of *D. gigas* in an area not covered in previous studies.

MATERIALS AND METHODS

The surveys were conducted by the three Chinese squid jiggers New Century No 52, Xin Jieli No 8 and Zhe Yunyu No 807 (Table 1). The survey area is de-

Table 1. – The key parameters of the three squid jigging vessels used in this study.

Key vessel parameters	*New Century* No 52	*Xin Jieli* No 8	*Zhe Yunyu* No 807
Total length	64.00 m	60.85 m	54.3 m
Gross register tonnage	1336 t	1168 t	432 t
Number of squid jigging machines	46	47	38
Power of fishing lights	160×2KW	120×2KW	130×1KW

Table 2. – Summary of the survey areas and sample collection of *Dosidicus gigas* between April 2006 and May 2008.

Survey date	Vessel	Survey area	Planned station	Fishing station	Number of samples	Range of mantle length (mm)
Apr.-Jul. 2006	*New Century* No 52; *Xin Jieli* No 8	26°S-30°S and 76°W-78°W; 37°30′S-41°00′S and 78°30′W-84°W	95	101	1013	236-549
Nov. 2006-Jan. 2007 and May-Jul. 2007	*New Century* No 52; *Xin Jieli* No 8	22°-30°30′S and 75°30′-78°W; 37°30′S-41°00′S and 78°30′-82°W	124	130	430	287-702
Jan.-Mar. and May 2008	*New Century* No 52; *Zhe Yunyu* No 807	20°-24°30′S and 74°30′-82°W	120	121	635	270-837

scribed in Table 2. Fishing stations were pre-selected and defined by 30’×30’ longitude and latitude before the survey (Fig. 1). The final fishing positions were defined as the actual sites where *D. gigas* were caught. Samples were randomly taken from the catch and 2078 specimens of both sexes were measured in ML to the nearest 1 mm and in weight to the nearest 10 g. Specimens were sexed and their maturation stages were defined on a scale I-V (Lipinski, 1979). The number of specimens analyzed per station varied depending on the total catch at the station. Fishing position, water temperature and salinity of different water depths from surface to 300 m, number of jig lines in uses (8 jiggers per line), fishing depth, time at the beginning and end of each deployment and total catch were recorded.

Statoliths were dissected for *D. gigas* in the field and stored in 90% alcohol for age and growth analysis. There were 133 specimens in total for statolith samples with their ML values ranging from 288 to 575 mm. The ageing method followed that described by Arkhipkin (1991). An image analysis system (WT-Tiger 3000) was used for counting rings on both sides of statoliths. For each of these squid, the hatching date was estimated from its age and the date when the squid was caught.

Mantle lengths of the specimens used for diet analysis ranged from 156 to 610 mm. Major preys in the stomach contents were identified based on undissolved tissues in the stomach. The degree of stomach fullness was recorded on the following scales (Chen *et al.*, 2007): 0, stomach is empty; 1, there is little content; 2, stomach is less than half full; 3, stomach is more than half full; and 4, stomach is full.

The whole body weight-ML relationship and somatic body weight-ML relationship (i.e. excluding offal of squid) were quantified using the equation $W = aML^b$, where W is the whole body weight or somatic body weight. Log transformation was applied to the equation and parameters *a* and *b* were estimated using the linear least squares method (Ricker, 1975).

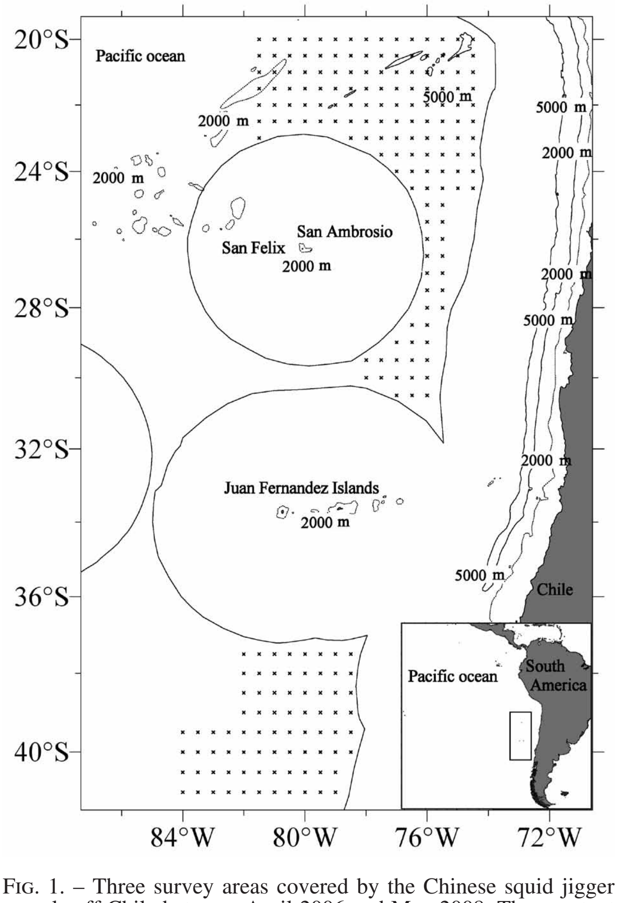

Fig. 1. – Three survey areas covered by the Chinese squid jigger vessels off Chile between April 2006 and May 2008. The constant line and asterisks represent the Exclusive Economic Zone and planned survey stations, respectively.

All sampled male and female individuals were examined for their maturation respectively, and data were used to determine the ML at which 50% of squid were mature which refers to ‘size at first maturity’ or ‘$ML_{50\%}$’. Changes in the proportion of mature squid

TABLE 3. – Temperature (T) and salinity (S) of different water depths in the fishing grounds of *Dosidicus gigas* off Chile.

Areas	Month	Surface layer		50 m depth		100 m depth		200 m depth	
		T	S	T	S	T	S	T	S
37°30'-41°S and 78°30'-80°W	December to January	14	33.91-34.15	13.5-14	33.92-33.95	12-13.5	33.59-33.93	9	33.98-34.16
	May to July	14-15.5	33.58-34.23	13.5-14.5	33.14-34.29	10-12	33.82-34.11	8.5-9.5	33.95-34.18
25°-30°S and 76°-77°30'W	April to May	17.5-19							
	June	17.5-21	34.17-34.71	17-19	34.26-34.79	13-15	33.97-34.28	10-11.5	34.17-34.65

with ML were fitted to a logistic equation described below using the least squares method:

$$P_i = \frac{1}{1+e^{-(c+dML_i)}}$$

where P_i is the proportion of mature individuals in length class ML_i, c and d are the two parameters to be estimated in the regression analysis, and $ML_{50\%}=c/d$.

RESULTS

Catch data, relationship between fishing ground and environmental variables

The daily catch ranged from 0.1 to 32.0 t/d composed entirely of *D. gigas*. The total catch was 2745 t during the three surveys, and the average daily catch reached 4.94 t/d. The number of fishing days when the daily catch was lower than 2 t/d only consisted of 13.59% of the total fishing days, and the number of days when daily catch was more than 5 t/d consisted of 68.6% of the total fishing days. During the three surveys, the catch mainly came from the two areas defined, respectively, by 37°30′-41°S and 78°30′-80°W, and by 25°-30°S and 76°-77°30′W (Fig. 2). High density of *D. gigas* was found in the above two areas with different environmental conditions (Table 3). On the fishing ground of 37°30′-41°S and 78°30′-80°W, the temperatures for different depths (0 m, 50 m and 200 m) were 14-15.5°C, 13.5-14.5°C and 8.5-9.5°C, respectively, from December to January and May to July (Table 3). On the fishing ground of 25°-30°S and 76°-77°30′W, the temperatures for different depths (0 m, 50 m and 200 m) were 17.5-21°C, 17-19°C and 10-11.5°C, respectively, in April, May and June (Table 3). The salinity of different water layers in the fishing grounds is also summarized in Table 3.

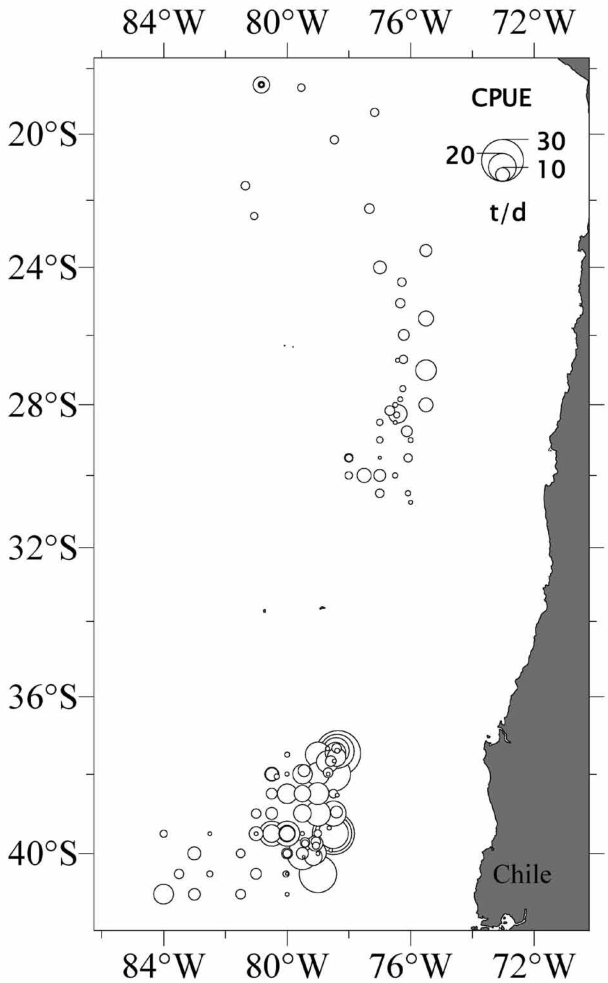

FIG. 2. – Spatial distribution of daily catch of *D. gigas* in the 0.5°×0.5° latitude and longitude off Chile between April 2006 and May 2008.

Population structure

In total 1481 female and 597 male *D. gigas* were randomly sampled and examined. The sex ratios (M:F) for the catch were 1:2.48, 1:2.77 and 1:2.36 for the three surveys, respectively (P<0.05). The mean ML was 376.0 mm for sampled males (ranging from 257 to 721 mm) and 388.7 mm for sampled females (ranging from 236 to 837 mm). The mean body weight was 1617 g for males (ranging from 570 to 10940 g) and 1887 g for females (ranging from 350 to 20400 g). There was a clear mode from 300 to 450 mm ML for males and females, accounting for 89.1% and 89.3% of the total catch, respectively (Fig. 3a). There was also a clear mode for the whole body weight (BW) from 1000 to 2000 g for males and females, accounting for 60.0% and 65.1% of the total samples, respectively (Fig. 3b). A less significant mode was observed at 600-700 mm ML and 9000-11500 g BW for females (Fig. 3a and 3b).

The spatial distributions of size for *D. gigas* by two-degree longitude and two-degree latitude were analyzed. The spatial distribution in squid size and dominant ML group had greater variability along the latitude (P<0.05) than that along the longitude (P>0.05). Between 20°S and 30°S, the average ML

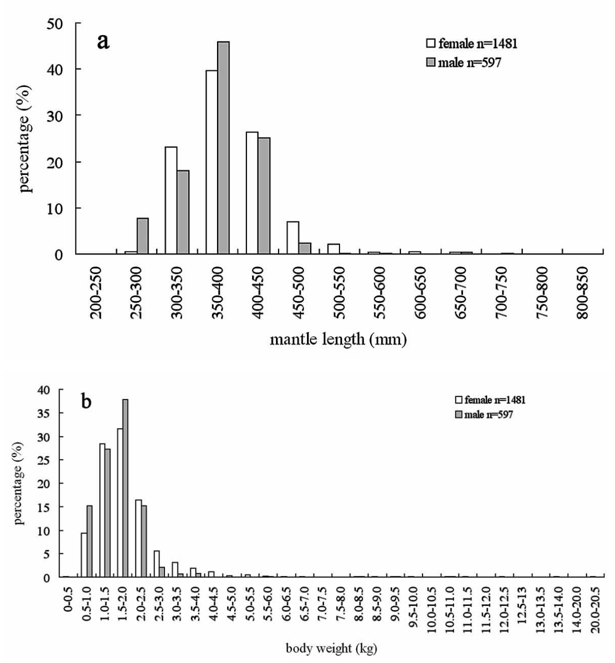

FIG. 3. – Mantle length (a) and body weight (b) compositions of female and male *D. gigas* during the three surveys off Chile between April 2006 and May 2008.

and BW ranged from 375.1 mm to 442.7 mm and from 1580g to 3190 g, and the larger size of *D. gigas* (439.1-442.7 mm ML) was distributed in the waters from 24°S to 30°S. Between 37°S and 41°S, the average ML and BW ranged from 365.2 mm to 390.7 mm and from 1560 to 1640 g. However, based on the spatial distribution for longitude between 77°W and 85°W, the average ML and BW were between 365.4 mm and 392.8 mm and ranged from 1580 to 1960 g. In the area of 81°W to 83°W, the size of *D. gigas* varied greatly with their ML and BW, ranging from 273 to 837 mm and from 640 to 2040 g, respectively. There was no such spatial pattern in size distribution along the longitudinal direction.

Mantle length–body weight and mantle length-somatic body weight relationships

The ML (cm)–BW (g) relationships (Fig. 4a) were estimated as:

$BW=0.0592ML^{2.8036}$ (r=0.98, n=597) for males, and
$BW=0.01476ML^{3.1446}$ (r=0.97, n=1481) for females

The ML (cm)–somatic body weight (SBW, g) relationships (Fig. 4b) were estimated as:

$SBW=0.03808ML^{2.8777}$ (r=0.98, n=597) for males, and
$SBW=0.01988ML^{3.1258}$ (r=0.97, n=1481) for females

There was a significant difference in the BW-ML and SBW-ML relationships between the sexes (P<0.05, ANCOVA).

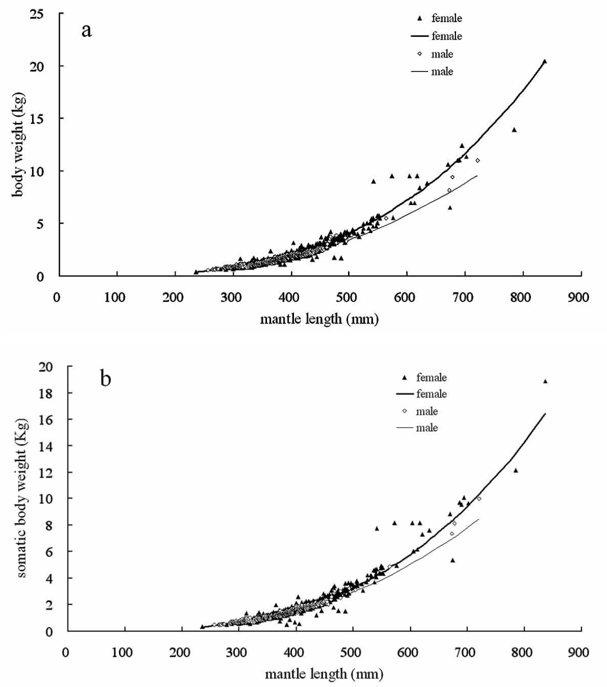

FIG. 4. – Relationships between body weight (a), somatic body weight (b) versus mantle length for female and male *D. gigas* off Chile.

Maturity

Maturation status was similar between the sexes (Table 4), with 88.4% of males in the preparatory stage (I), 4.0% in the maturing stage (III) and 2.7% in the mature stage (IV). For females, 96.1% were immature (stages I and II) and only 3.9% were in the maturing and mature stages (III and IV; Table 4). There were no post-spawning squids (V; Table 4).

There were monthly variations in sexual maturity for both female and male squids (Table 4). From January to March, nearly 100% of males and females were in the immature stage (I), while in May and September 81.3% and 72.1% of females, and 77.8% and 82.8% of males, respectively, were in the immature stage (I) (Table 4).

The relative frequency distribution for length classes of mature individuals for females and males are described as:

males: $P_i = \dfrac{1}{1+e^{-(-12.222+0.019148 l_i)}}$ $(R^2 = 0.9564)$

females: $P_i = \dfrac{1}{1+e^{-(-6.67935+0.011817 l_i)}}$ $(R^2 = 0.6018)$

The sizes at first sexual maturity were estimated as 638 mm ML for females and 565 mm ML for males.

Age composition

The sample of *D. gigas* (288-517 mm ML and 637-4164 g BW) collected from January to June 2008

TABLE 4. – Monthly composition of sexual maturity for *Dosidicus gigas* off Chile between April 2006 and May 2008.

Sex	Month	Number of samples	Stage of sexual maturity (%)				
			Immature		Maturing	Mature	Post-reproduction
			I	II	III	IV	V
Female	Jan.	122	99.2	0.0	0.0	0.8	0.0
	Feb.	149	83.9	10.7	5.4	0.0	0.0
	Mar.	45	100.0	0.0	0.0	0.0	0.0
	May	416	81.3	18.7	0.0	0.0	0.0
	Jun.	116	88.8	6.0	5.2	0.0	0.0
	Sep.	68	72.1	20.6	1.5	5.9	0.0
	Nov.	34	91.2	2.9	2.9	2.9	0.0
	Dec.	47	93.6	0.0	2.1	4.3	0.0
	Overall	997	88.7	7.4	2.1	1.8	0.0
Male	Jan.	13	100.0	0.0	0.0	0.0	0.0
	Feb.	39	94.9	0.0	5.1	0.0	0.0
	Mar.	15	100.0	0.0	0.0	0.0	0.0
	May	189	77.8	12.2	8.5	1.6	0.0
	Jun.	64	87.5	1.6	9.4	1.6	0.0
	Sep.	29	82.8	6.9	3.4	6.9	0.0
	Nov.	11	81.8	18.2	0.0	0.0	0.0
	Dec.	17	82.4	0.0	5.9	11.8	0.0
	Overall	377	88.4	4.9	4.0	2.7	0.0

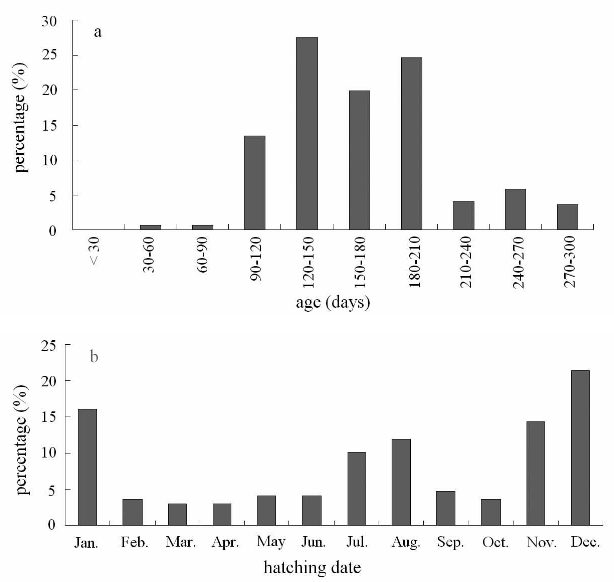

FIG. 5. – Compositions of age (a) and hatching date (b) of *D. gigas* off Chile.

had ages ranging from 88 to 299 d according to the analysis of statolith increment (Fig. 5a). All the specimens hatched from March to December 2007 and from January to February 2008 (Fig. 5b), with the majority (50.9%) of hatching occurring from November 2007 to January 2008. The oldest *D. gigas* in the sample grew to the size of 517 mm ML and weighed 4163 g.

Diets

Most of the stomachs analyzed had food remains, and on average 20.9% were empty (Fig. 6). The stomach contents included three major prey groups: fish, cephalopods and crustaceans, representing 57%, 36% and 7% of the stomach contents by weight, respectively. All the prey remains in the stomach contents were identified as lanternfish and *D. gigas*, and nearly 50%

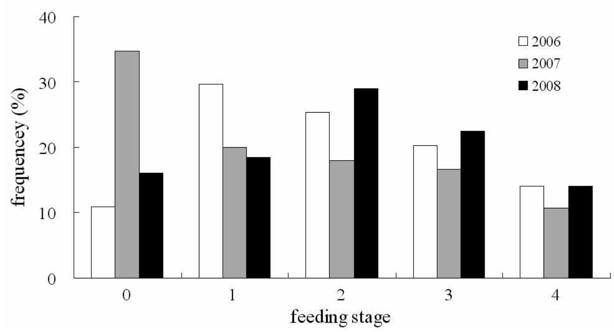

FIG. 6. – Frequencies of different feeding stages of *D. gigas* off Chile.

of the stomachs showed the evidence of cannibalism. However, cannibalism was much greater for the squids caught in the light field near the survey vessel, and the fish, Chilean jack mackerel (*Trachurus murphyi*) was often attacked by large-sized *D. gigas* around the squid jigging vessels in the southern waters (38°-41°S).

About 67% of the stomachs were less than half full, and the fullness of stages 1 and 2 consisted of 20.9% and 25.1% of the total samples (Fig. 6), respectively.

DISCUSSION

D. gigas were found to be widely present in the survey area, but the majority of catch was located in the areas defined by 37-40°S and 78°30′-81°W and by 23°30′-28°S and 75°30′-78°W. This is consistent with previous studies (Ibáñez and Cubillos, 2007). The distribution of *D. gigas* is considered to be closely related to sea surface temperature (SST). This study suggests that the favourable SST for *D. gigas* ranges from 17.5 to 21°C on the northern fishing ground (20°-30°S) and from 14 to 16°C on the southern fishing ground (37-41°S). This is consistent with the results obtained for other areas included in previous studies. For example, the high concentration of *D. gigas* took place in Peruvian waters with SST between 17 and 22ºC (Waluda *et al*., 2006). Thus, the result of this study supports the hypothesis that SST is critical in influencing the spatial distributon of *D. gigas* (Anderson and Rodhouse, 2001; Nigmatullin *et al*., 2001).

The recent catch of *D. gigas* along the Chilean coast between 2002 and 2005 has been reported to increase (Zúñiga *et al*., 2008), which is consistent with the report in the waters of 40-45°S and 100-75°W by the Chinese large mid-water trawler targeting jack mackerel (*Trachurus murphyi*) and the Chinese squid jigging survey from 2006 to 2008. This may suggest that there is a local population of *D. gigas* in Chilean waters (Zúñiga *et al*., 2008). More studies, however, need to be done to examine the influence of SST on the spatial distribution and migration of *D. gigas* and the possible existence of a local population in the waters off Chile.

The intraspecific structure of *D. gigas* tends to be complicated (Nigmatullin *et al*., 2001), and there has been no consensus on population structure. The ML composition of catch is often considered as an indicator of population structure. The dominant group observed in the survey was squid of 350-450 mm ML for males and 350-450 mm ML for females. In the oceanic waters off central-southern Chile, mature medium-sized squids were found in the austral winter (July-September), mature medium-sized and large-sized squids in the austral spring (October-December), and small immature and mature medium-sized squids in the austral summer (January-February) (Ibáñez and Cubillos, 2007). The size of our sample ranged from 236 to 837 mm ML, probably covering the possible size range of this species. Ibáñez and Cubillos (2007) postulated that the spatial and temporal changes in size structure of *D. gigas* off central-southern Chile were probably due to the existence of a migratory strategy of the species in the study area. Based on the hatching-date distribution from the collected sample, we concluded that there were at least two spawning groups, a summer group (hatching from June to August) and a winter group (hatching from December to February of the next year) (Fig. 5b). This result is consistent with that reported in some studies (González and Chong, 2006; Zúñiga *et al*., 2008), it contradicts the results reported by Nigmatullin *et al*. (2001). Lack of evidence in this study for the presence of the small-size group described in Nigmatullin *et al*. (2001) might result from the low catchability of small squid by the large jiggers used in this study.

Of the sample collected in three surveys, there were more females than males and the averaged sex ratio (M:F) was 1: 2.48. In the survey, the big squid jigger with three lines of 1.6 mm diameter was used. As a result, the small individuals of *D. gigas*, mostly males, might have less likelihood of being caught than the large individuals. Thus, the observed skewed sex ratio may result from the selectivity of fishing gear. In Peruvian waters, Tafur *et al*. (2001) reported that females were always more than males during the study period, and the averaged sex ratio (M:F) was 1: 2.85, comparable with that of this study.

This study found that *D. gigas* males matured at smaller sizes than females, which is normally described as a characteristic of cephalopods in general (González and Guerra, 1996). The range of sizes for mature males and females in this study is different from that found in the oceanic waters off Peru (Nesis, 1983) and in Peruvian waters (Tafur *et al*., 2001).

The sample of *D. gigas* (288-517 mm ML and 637-4164 g BW) collected from January to June 2008 had ages ranging from 88 to 299 d according to the increment of statoliths (Fig. 5a). The oldest squid in the sample grew to the size of 517 mm ML and weighed 4163 g. Ages of *D. gagis* have been studied using two different methods: cohort analysis using length-frequency distributions (Ehrhardt *et al*., 1983) and ageing analysis using statolith gladii techniques (Arkhipkin and Murzov, 1987; Masuda *et al*., 1998; Argüelles *et al*., 2001). *D. gagis* is confirmed to grow fast, reaching 700-750 mm ML by the end of age 1 (Ehrhardt *et al*., 1983). The longevity of all three groups of *D. gigas* is about 1 year, but some huge specimens (>750 mm ML) of the large group could live for up to 1.5-2 years (Nigmatullin *et al*., 2001; Wang and Chen, 2005).

We found that all the individuals examined were hatched from March 2007 to February 2008. Therefore, *D. gigas* were likely to spawn all year around, and the peak spawning time in the study areas was from November 2007 to January 2008. There is a distinct peak in spawning during spring and summer in the southern hemisphere (Nigmatullin *et al*., 2001; Taipe *et al*., 2001), and a secondary peak from July to August (Tafur and Rabi, 1997; Tafur *et al*., 2001).

The parameters of the length-weight relationships were different from those found by Chong *et al*. (2005) for central-northern Chile in 1993 and by Ibáñez and Cubillos (2007) for central-southern Chile from 2003 to 2004. The average weight of females was heavier than that of males at a given ML, and the difference increased in specimens larger than 450 mm ML.

D. gigas is and opportunistic predator whose feeding spectrum differs between sizes and regions (Wang and Chen, 2005). The stomachs contained fish, cephalopods and crustaceans, mainly lanternfish and *D. gigas*. More than 50% of the stomachs had evidence of cannibalism for *D. gigas*. Nigmatullin *et al*. (2001) found that the feeding spectrum of *D. gigas* changed with their sizes, from macroplanktonic invertebrates and fish fry (in juveniles) to fish and squid (in adults). Near-surface lanternfish completely predominate among fish preys, and *D. gigas* are predominant among squid preys. Diets also varied spatially, mainly determined by food availability in the ecosystem. For example, the diets were dominated by mesopelagic fishes such as *Benthosema panamense*, *Triphoturus mexicanus*, and *Vinciguerria lucetia* in the Gulf of California and adjacent waters (Markaida and Sosa-Nishizaki., 2003), which is different from teh findings of this study.

In this study, we obtained results on some key aspects of the fisheries biology of *D. gigas* off Chile. The information obtained is critical to improving our understanding of the spatial variability of key biological processes for a species with such a wide distribution. To further improve our understanding of the fisheries biology of *D. gigas* off Chile, we need to conduct a comparative study to quantify differences in fisheries biology between this squid population and squid populations inhabiting Peruvian waters, Californian waters and Chilean coastal waters. Key environmental variables influencing the biological processes should be identified and quantified.

ACKNOWLEDGEMENTS

The support for the three scientific surveys made by *New Century* No 52, *Xin Jieli* No 8 and *Zhe Yunyu* No 807 is gratefully acknowledged. This work was funded by the National Nature Science Foundation (NSFC40876090), the "Shu Guang" project (08GG14) of the Shanghai Municipal Education Commission, the Specialized Research Fund for the Doctoral Programme of Higher Education (20093104110002) and the Shanghai Leading Academic Discipline Project (Project S30702). Y. Chen's involvement in the project was supported by the Shanghai Dongfeng Scholar Programme.

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Scient. ed.: A. Guerra.
Received October 1, 2009. Accepted February 2, 2010.
Published online July 6. 2010.