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Hydroacoustic survey of the jumbo squid *Dosidicus gigas* in the Gulf of California during March and September-October 2010

Prospección hidroacústica del calamar gigante *Dosidicus gigas* en el Golfo de California durante marzo y septiembre-octubre de 2010

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ABSTRACT

The horizontal and vertical distribution and the dorsal mantle length (DML) of the jumbo squid (*Dosidicus gigas*) were investigated in the Gulf of California (26-33 °N) during March and September-October 2010 using a Simrad EY-60 echo-sounder (120 kHz split beam transducer) and jig sampling. During March jumbo squids were captured and echo-detected off Santa Rosalía and around and south of the Grandes Islas region, in regions where satellite sea surface temperatures ranged between 16.5 and 18 °C. Jumbo squid were also abundant south of Guaymas Basin and along the east coast with SST ranged between 17.5 and 19 °C. During September-October jumbo squids were echo detected and captured at the west coast of the gulf at regions with SST below the mean of the survey area (< 30.5 °C). Jumbo squid distribution and DML estimated using hydroacoustic methods and measured from captured squids followed the previously known seasonal migrations and temporal DML frequency distribution reported in the Gulf, in the Grandes Islas region and east coast of the Gulf during the spring and in the east coast during late summer. Hydroacoustic data showed no evident daily vertical migrations during the two sampling seasons.

Key words: *Dosidicus gigas*, Gulf of California, hydroacoustic survey.

RESUMEN

Se estudió la distribución horizontal y vertical y la estructura de longitud del manto (LM) del calamar gigante (*Dosidicus gigas*) recolectados en el Golfo de California (26 °-33 °N) durante marzo y septiembre-octubre del 2010, mediante una prospección acústica (ecosonda Simrad EY-60; 120 kHz de frecuencia, de haz dividido) y captura de calamares con poteras. Durante marzo, los calamares fueron eco detectados y capturados con poteras en la zona de las Grandes Islas, donde la temperatura superficial (TSM) detectada por satélite, registró un intervalo entre 16.5 y 18 °C. Los calamares fueron abundantes además al sur de la Cuenca de Guaymas y a lo largo de la costa este del golfo, en aguas con TSM entre 17.5 y 19 °C. Durante septiembre-octubre los calamares fueron eco detectados y capturados a lo largo de la costa oeste del golfo, en regiones con TSM por debajo de la media del área muestreada (<30.5 °C). La distribución horizontal y las estimaciones de LM realizadas con métodos de hidroacústica y capturados con poteras, concuerdan con los modelos de migración estacional y de distribución de frecuencias de LM previamente reportados en el golfo: principalmente distribuidos en las Grandes Islas y costa este del golfo en primavera, y en la costa este durante el final del verano. Los datos hidroacústicos no mostraron evidencia de migración vertical diaria en ninguna de las dos épocas del año estudiadas.

Palabras clave: *Dosidicus gigas*, Golfo de California, prospección hidroacústica.

INTRODUCTION

The jumbo squid (*Dosidicus gigas* D'Orbigny, 1835*)* is a key predator species in the pelagic marine ecosystem, a significant prey for top predators, and an economically significant fishery resource (Olson & Young, 2007). Since mid 1990´s this species has expanded it distribution toward higher latitudes along the eastern Pacific as north as California, Oregon, and Alaska. The underlying reasons why this species expanded it distribution range are so far not well understood, but it is likely that multiple factors are involved *i.e.* efficiently exploitation of ecological niches or removal of top predators (Zeidberg & Robison, 2007).

As a part of a fishery management, the biology and estimated biomass of the jumbo squid in the Gulf of California has been studied using exploratory surveys and squid landing captured with standard jigging method (Nevárez-Martínez *et al*., 2000; Morales-Bojórquez *et al*., 2001; Martínez-Aguilar *et al*., 2004; Velázquez-Abunader *et al*., 2010). However, migrations and movements of this species may influence the estimations of capture-per-unit-effort (Martínez-Aguilar *et al*., 2004). Indeed, this ommastrephid squid is highly mobile with exceptional swimming capacities (Markaida *et al*., 2005), able to tolerate drastic changes in seawater temperature (up to 15 °C range) and swim from oxygenated near surface waters to the upper boundary of the oxygen minimum layer in a single dive (Gilly *et al*., 2006). Moreover, the geographical distribution of *D. gigas* varies seasonally in the Gulf of California (Markaida *et al*., 2005) likely related with ephemeral productive zones or suitable spawning areas (Yatsu *et al*., 1999).

Several fish stocks in the world are managed using information obtained from hydroacoustic surveys to estimate their annual population biomass. The use of hydroacoustic techniques allow the detection of target species in large volumes of water in relatively short time, and estimate abundance in areas and seasons where the fishing fleet does not operate (Simmonds & MacLennan, 2005). In Mexico, hydroacoustic surveys has been used to study the behaviour and distribution of several small pelagic fish species, including anchovies (*Engraulis mordax* Girard, 1854), Pacific sardines (*Sardinops sagax* Jenyns, 1842), pelagic crustaceans, like the red crabs (*Pleuroncodes planipes* Stimpson, 1860), several krill species (mostly *Nyctiphanes simplex* Hansen, 1911 and *Nematoscelis difficilis* Hansen, 1911) and the shape and density of plankton and nekton aggregations (deep scattering layers) (Robinson *et al*., 2007; Robinson & Gómez-Gutiérrez, 1998; Robinson & Gómez-Aguirre, 2004; Gómez-Gutiérrez & Robinson, 2006; Villalobos *et al*., 2009). However, few studies have used acoustic methods to study jumbo squid in the Gulf of California. Benoit-Bird *et al*. (2008) studied the target strength of jumbo squids *D. gigas*, using an anchorage boat providing valuable equations relating dorsal mantle length and target strength using multi frequencies. Gallo-Reynoso *et al*. (2009) did a non-quantitative study using the Furuno dual 50-200 kHz echosounder to study the predator-prey relationship in terms of vertical distribution between the sperm whale (*Physeter macrocephalus* Linnaeus, 1758) and the jumbo squid in the Guaymas Basin. Later, Benoit-Bird and Gilly (2012) using multi-frequency acoustic measurements and analysis of data visualization detected swimming coordination behaviour of individual jumbo squids in the column water. In the present study, we used hydroacoustic techniques and jigging catches to know the distribution patterns of the jumbo squid in the Gulf of California during spring (March) and late summer (September-October 2010). As far as the authors know this is the first attempt to study distribution of jumbo squid using hydroacoustic survey in an extensive region of the Gulf of California, as previous studies have been done in specific parts of the gulf (Gallo-Reynoso *et al*., 2009; Benoit-Bird *et al*., 2008; Benoit-Bird & Gilly, 2012). Similarly, maps of distribution and abundance of *D. gigas* estimated acoustically have been produced by IFOP (Chile) and IMARPE (Peru) in the Humboldt Current System. The aim of this study was to survey the central and northern part of the Gulf of California to 1) know jumbo squid horizontal and vertical circadian distribution, 2) to compare jumbo squid dorsal mantle length and frequency distribution using conventional jig sampling and using hydroacoustic methods and 3) describe their distribution patterns with sea surface temperature and Chlorophyll-*a* concentrations.

MATERIALS AND METHODS

Two oceanographic cruises on board the R/V El Puma (50 m length) were carried out in March 10-25 and September 17 to October 4, 2010 along the central and northern part of the Gulf of California, Mexico. During March, vessel track day/night pattern was no geographically systematic. We adaptively set hydroacoustic transects according to the information in real time of the location of the jumbo squids provided by cell phone by fishermen from Guaymas and day sampling satellite images of sea surface temperature (SST) and chlorophyll-a (Ch-*a*). The Grandes Islas region, from north of Angel de La Guarda island to San Pedro Mártir island, was hydro-acoustically surveyed during seven consecutive days, the entire survey lasted 18 days. The Grandes Islas region was surveyed during day (7.00 to 19.00 h) and during night (19.01 to 6.59 h) local time. After that, the vessel headed toward the central part of the Gulf covering the east and west coast with three long hydroacoustic transects crossing the gulf. In this latter part, the survey was continuous but the geographic track surveyed during the day was different from the geographic track surveyed during the night. During Sept-Oct we covered the Grandes Islas region and the central Gulf during 18 days. Transects were systematic and we obtained hydroacoustic information sampling along the same ship track during the day and during the night.

Satellite sea surface temperature (SST). SeaWIFS SST data of 1.1 km resolution (http://oceancolor.gsfc.nasa.gov/cgi/browse.pl) recorded during March 15th and September 27th 2010 was selected to cover the hydroacoustic survey area.

Column water environmental conditions. A CDT Sea-Bird SB-09 equipped with a calibrated fluorometer was deployed to characterize temperature and fluorescence (a proxy of chlorophyll-*a* concentration) along the water column. Temperature and Chl-*a* concentration data (from 4 to 200 m depth during both cruises) recorded at the east coast, near Guaymas (27 °47′ N, 110 °57′ W), in the middle part of the gulf (27 °20′ N, 111 °17′ W) and along the west coast, near Santa Rosalia (27 °29′ N, 110 °39′ W) was used to compare regional vertical environmental conditions.

Jumbo squid jigging sampling. Three people fished simultaneously jumbo squids using hand jigs (with 3 to 5 crowns) attached to 150-m hand-held line positioned about 4 m each other located along the starboard of the ship. When we observed small jumbo squids (< 20 cm dorsal mantle length, DML) at surface we used a 2 crowns jig to catch them. Each jumbo squid fishing period was standardized to 15 minutes for all the fishermen. DML and total weight of each captured jumbo squid was measured. Jigging during both oceanographic cruises was done exclusively during night time.

Hydroacoustics sampling. Hydroacoustics surveys were done using a Simrad EY-60, 120 kHz split beam echosounder with a beam-opening angle of 7°. Transmitted power was 500 W. The equipment was interfaced with a GPS Trimble AG160 to provide accurate geographical position and ship speed. The ping rate was set at 3 pings s^{-1} and the pulse duration was 256 μs giving a vertical acoustic resolution of 19.8 cm. Individual echoes criteria definition were minimum echo length = 0.80 m and maximum echo length 1.20 m relative to transmitted pulse. The transducer was attached to the vessel's hull located at 4 m depth and calibrated with a standard copper sphere of 23 mm and nominal target strength of –40.4 dB before each oceanographic cruise following the procedures suggested by the Simrad reference manual (Simrad, 2008).

Identifying the acoustics traces of *D. gigas.* During March in the Grandes Islas region (29 °39′ N, 113 °07′ W, seafloor depth 350 m), 17 jumbo squids (mean DML = 65.1 cm, range = 22.1-80.5 cm, stdev = 9.19 cm) were captured with jigging. Simultaneously, an underwater camera (Deep Power and Light, Multi-SeaCam) equipped with a depth sensor and light was used to validate in real time the different echo traces showed in the echogram. In this site the sea was calm and jumbo squid, sardine schools (*Sardinops sagax*) and other unidentified small pelagic fish species were observed with the underwater camera. Echoes reflected by squids were distinctively identified as continuous lines as the jumbo squids crossed the sound beam. Small pelagic fish echo traces where typically amorphous schools found near the surface recognized from out previous experience (Domínguez-Contreras *et al.*, 2012). There were also no identified echoes located between 25 and 50 m depth. According to the shape and echo strength they probably were zooplankton aggregations (Fig. 1a-b). Echo traces indicate that small pelagic fish schools remained near the surface with no evident vertical movements. However, jumbo squids echo traces distribution indicated vertical movements. We confirmed with the camera that at near surface layers where the echo traces indicated the presence of amorphous schools matched with layers where small pelagic fish were observed. All these observations lasted about three hours (2:00 to 5:00 h).

The echograms recorded during all the hydroacoustic surveys were analysed with the software Sonar-4 (Balk & Lindem, 2011) from 10 to 300 m depth or 10 m above the seafloor over the continental shelf. Echo-integration was done in horizontal segments of 50 pings and in 10-m layer thick depths throughout the water column named here as elementary sampling unit (ESU = 50 pings long and 10-m thick layers). To discriminate echoes reflected by the jumbo squid from the pelagic fish schools and zooplankton aggregations the following criteria were set: First, only single target strength (TS) echoes ranging between –45 and –30 dB were selected for acoustic analysis. This TS range was selected based on the TS-DML correlation provided by Benoit-Bird *et al.* (2008) and likely represents jumbo squids between 14 and 78 cm DML. Second, the minimum number of individual echoes (degree of shoaling or compactness) in the acoustic sample was included in the analysis. ESU with < 25% of echoes recognized as individuals were not included in the analysis (excluding those pelagic animals that tend to form dense schools). We selected this percentage as an empirical value to separate the small pelagic fish and the jumbo squid based on the degree of compactness. There was no statistical procedure in the acoustical analysis echo identification. Using these two empirical criteria we discriminated jumbo squids from the small pelagic fish schools in > 90% of the ESU analysed. Once echograms at verification locations were analysed, the same analysis procedure of 50 pings and 10 m layers along the water column, TS range, and degree of schooling was used to analyse the rest of the echograms recorded along the transects (ship moving) during both cruises. To avoid background noise during standard CTD oceanographic stations (ship not moving and no

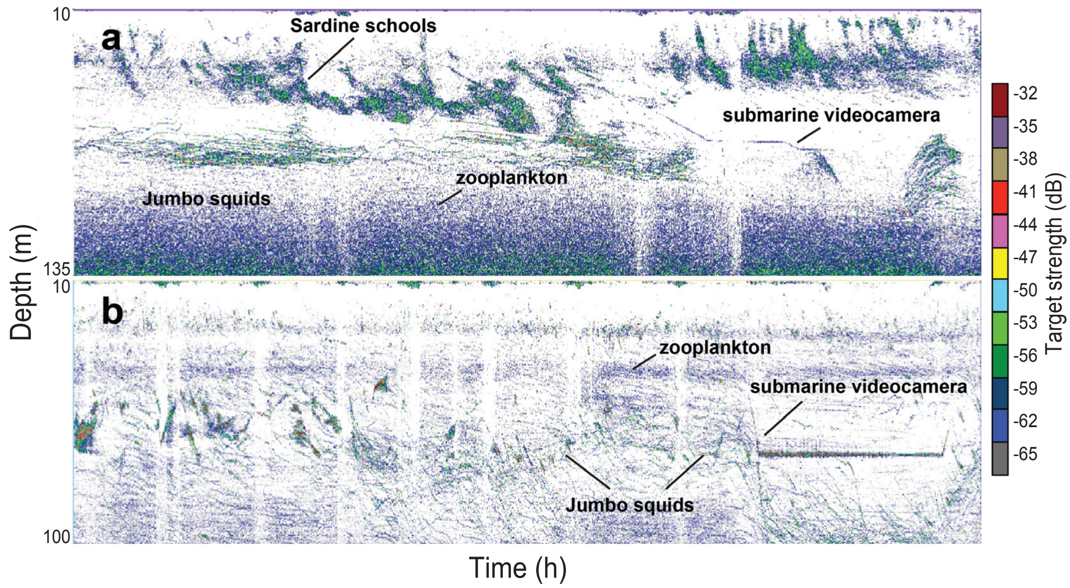

Figure 1a-b. (a) Echogram of echo-traces found during the procedure to identify jumbo squid from other sources in March 2010. The underwater camera revealed that the amorphous, compacted echoes were Pacific sardine and the long, more separated echoes were jumbo squid aggregations. Horizontal axis represents 25 min. Vertical axis is depth (10-140 m). The echogram also shows unidentified echoes, presumably caused by zooplankton aggregations. (b) Echogram of abundant jumbo squid echoes recorded in July 2007. Jigging sampling shows large mature squids (>60 cm mantle length). Horizontal axis represents 30 min. Vertical axis is depth (10-135 m). Both echograms were recorded with amplitude of –65 dB (right-side scale).

jumbo squid were collected), only echograms recorded while the ship was moving (> 4.5 m s^{-1}) were analysed.

RESULTS

During March we surveyed 3,796 km and during Sep-Oct we surveyed 4,227 km. Satellite SST, ship survey track, and location of the stations were jumbo squids were collected with jigging and detected with the echo-sounder are shown in Figure 2a-b.

Satellite sea surface temperature. During March there were three modes of satellite SST; which overall ranged between 15 and 21 °C (Fig. 3a). The coldest sea surface temperature frequency distribution ranged from 16 to 18 C detected in the Grandes Islas region and around San Pedro Mártir Island. The second high frequency SST records ranged from 18.5 to 20 °C. Specifically, the 18 to 19 °C range was detected along Sonora coast and a filament of sea surface water oriented from Guaymas toward the west. The third high frequency SST range, include the warmest temperatures (20.5 °C) detected in the southern part of the study area (Fig. 3a). During Sep-Oct satellite SST was considerably warmer (29 and 33 °C) than during March and with a uni-modal frequency distribution at 31 °C (Fig. 3b). The relatively less warmer SST recorded during Sep-Oct were located along the west coast of the gulf (29-30 °C). The rest of the study area was homogeneously warmer than 31 °C.

Vertical distribution of temperature and chlorophyll-*a*. During March no evident thermocline was observed in any of the three sites and temperature in the first 100 m depth was considerably colder than in Sept-Oct. The depth of maximum chlorophyll-*a* concentration was recorded at 20 m depth at the west coast and at 42 m depth and the central gulf. The maximum chlorophyll-*a* concentration near Guaymas was near the surface (Fig. 4a-c). During Sep-Oct the thermocline was detected at 40 m depth in the central part and near surface at Guaymas. A maximum chlorophyll-*a,* was detected between 35 and 40 m depth in the three areas (Fig. 4d-f).

Hydroacoustic survey. During March, 15,154 segments were analysed and 22,558 segments in Sep-Oct. In March, segments with one or more 10 m depth layers; which fulfilled the two squid identification criteria (positive segments) represented 1.9% (292) of the total echoes detected. During Sep-Oct this proportion was 0.25% (58). The locations of the jumbo squid positive segments for each oceanographic survey are shown in Figure 2a-b. During March jumbo squids were located at the Grandes Islas region and in the south and east of the study area. There were three locations where the jumbo squids were highly aggregated (accounting 57% of all positive acoustic segments). During the second cruise were not detected highly aggregated jumbo squids. Geographical position of the positive segments was associated with the satellite detected SST along the hydroacoustic track. During March, the jumbo squid positive segments were located in regions with satellite SST ranging between 16.5 and 18.0 °C and between 18.5 and 20.0 °C. During Sep-Oct, positive segments were recorded in the

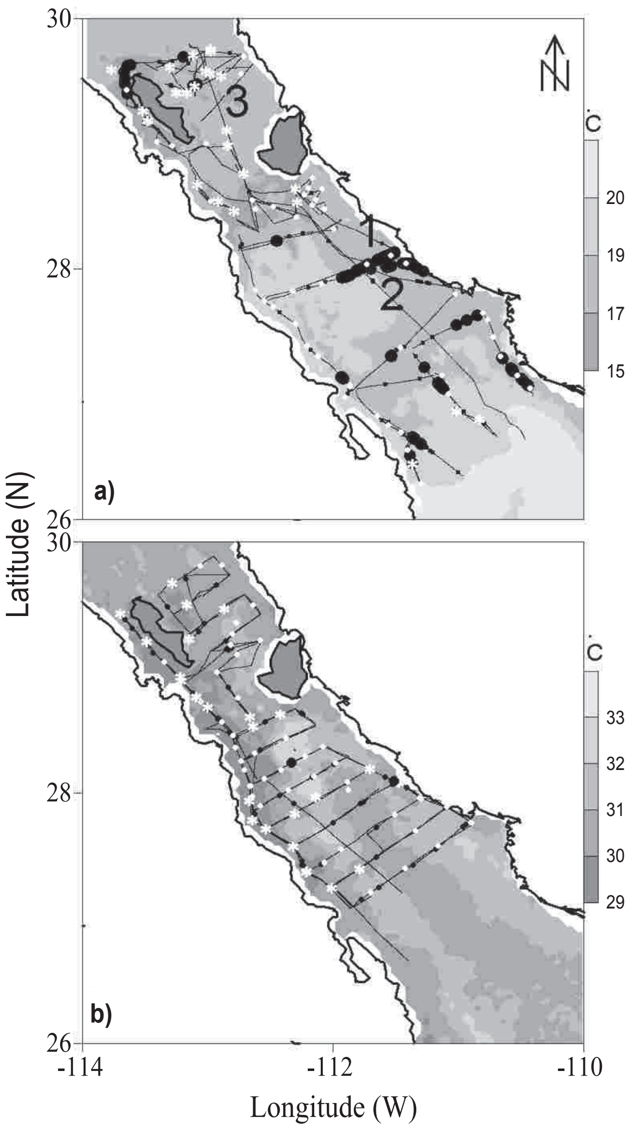

Figure 2a-b. (a) R/V El Puma track (continuous line) during March, 2010. SST recorded by satellite is shown in the background (scale bar at the right). (b) R/V EL Puma track (continuous line) during September-October, 2010. SST recorded by satellite is shown in the background (scale bar at the right). Numbers 1 to 3 in indicate the areas with the highest jumbo squid positive acoustic segments detected during March. Black dots are acoustic segments with jumbo squid detected with the echo-sounder (positive segments). Crosses represent jigging and asterisks represents location where squids were caught.

relatively lower temperature detected in the cruise 30.4 °C (mean overall 30.8 °C, n = 62,111, mean jumbo squid positive segments, n = 52, ANOVA, F = 18.9 p<0.0001) and these squids were echo located along the west coast of the gulf.

Target strength distribution. For target frequency strength distribution only segments and layers which fulfilled the two jumbo squid identification criteria was used. During March, a TS distribution was observed between −39 and −35 dB (Fig. 5a). However, there are not enough data to describe correctly the TS distribution, thus this distribution should be taken with caution. Target strength values > −30 dB were also detected, but in a lower proportion than smaller squids with TS < −40 dB. During Sep-Oct, TS distribution was multi-modal (Fig. 5c). Small TS values < 40 dB were detected frequently. Echoes detected between −30 and −40 dB were also detected and with a peak at −25 dB.

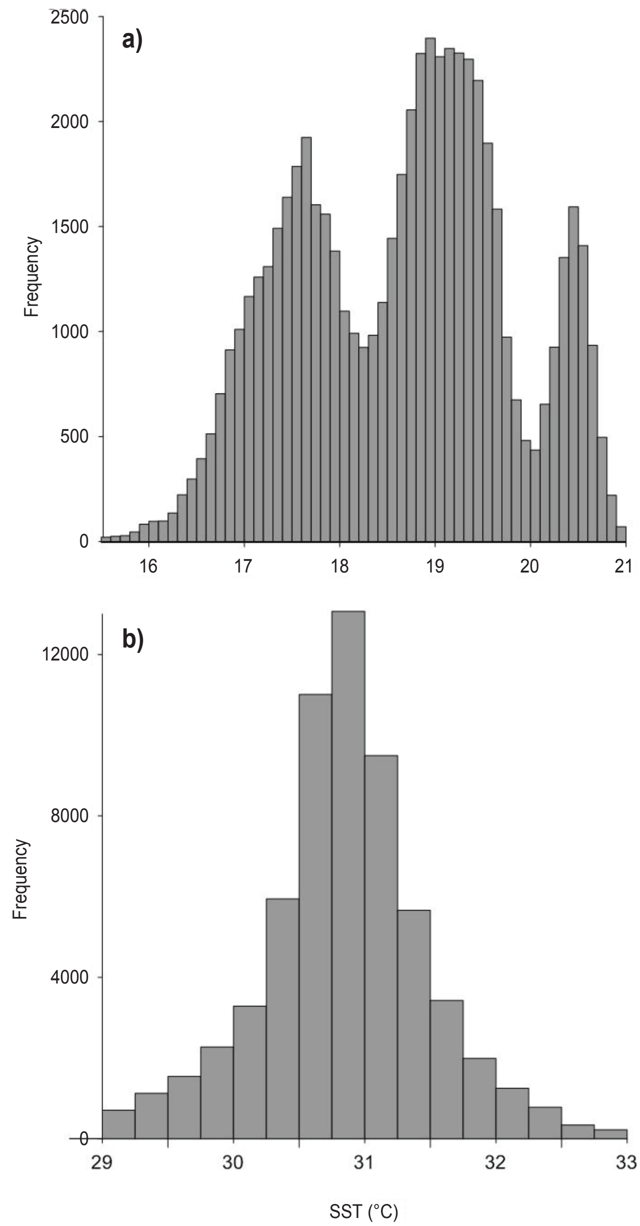

Figure 3a-b. Satellite sea surface temperature frequency distribution recorded in the north and central part of the Gulf of California obtained from the Field-of-view Sensor (SeaWiFS) during (a) March 15 and the (b) September 27, 2010.

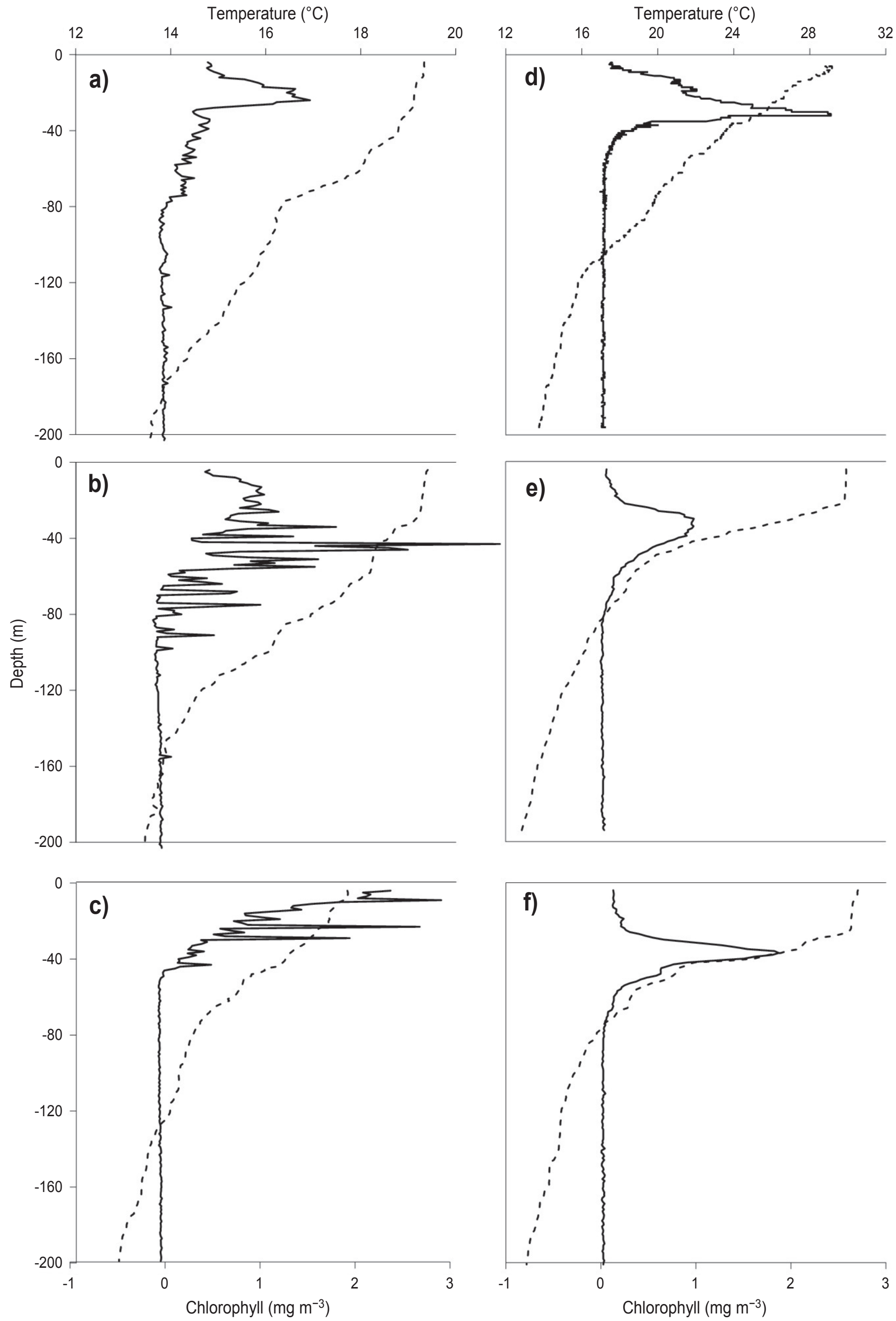

Figure 4a-f. Sea water temperature (dotted line) and chlorophyll-*a* concentration (continuous line) recorded along the water column at the east, centre and west region of the Gulf of California during (a, b, c) March and (d, e, f). Sep-Oct 2010.

The analysis of the TS as a function of the depth showed that overall small *D. gigas* individuals were detected near the surface during both oceanographic surveys (Fig. 6). However, the correlation TS-depth was significant only during Sep-Oct cruise (R^2 50.9, $p < 0.001$) detecting echoes of large individuals at deeper waters (> 200 m depth).

During March, echoes associated to jumbo squids were detected throughout the water column during the circadian cycle. During the day, the jumbo squids were detected from 10 to 150 m depth. During the night, jumbo squid echoes were detected at < 50 m layer (Fig. 7a) During Sep-Oct cruise the jumbo squids were found along the entire sampled column (10-300 m depth) during

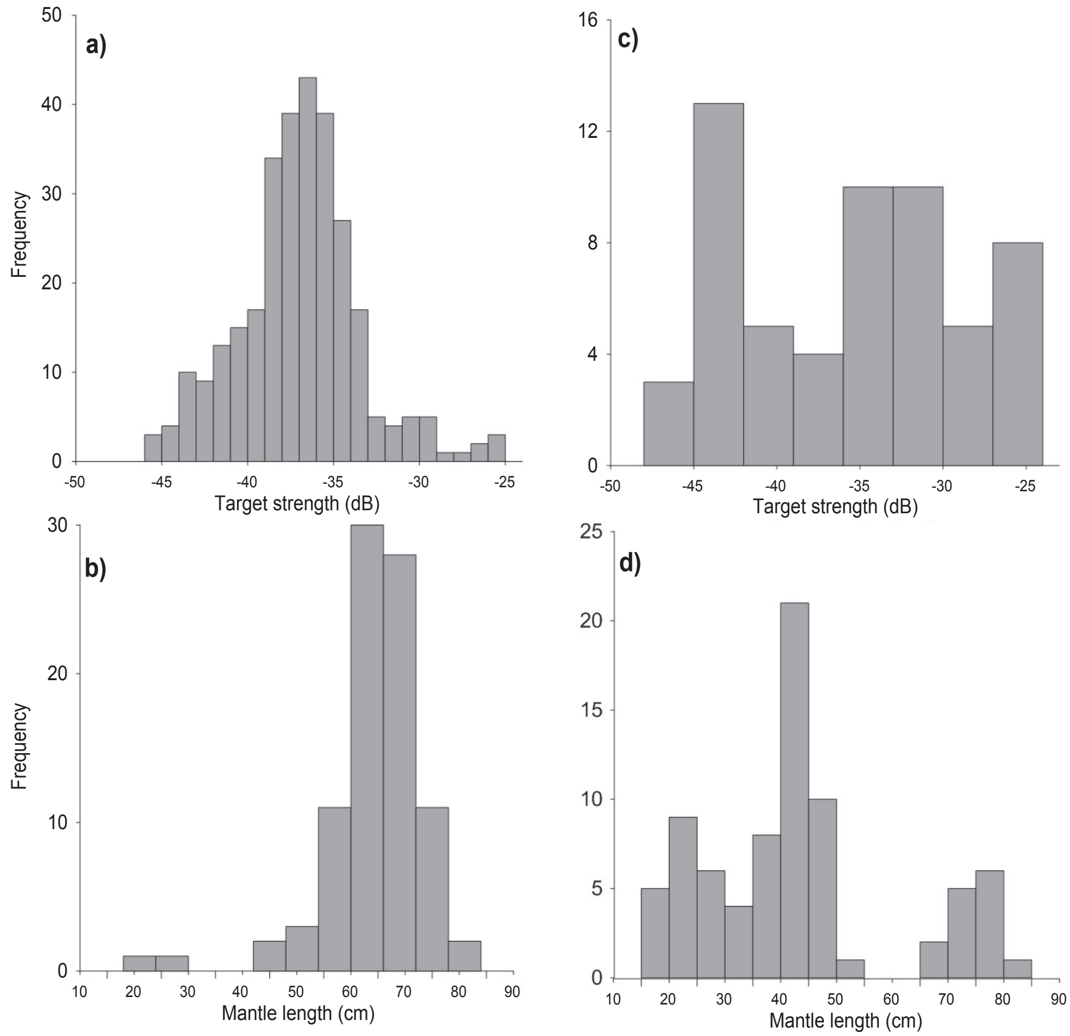

Figure 5a-d. Target strength (TS) frequency distribution of echoes associated with *D. gigas* during (a) March and (c) Sept-Oct 2010 and dorsal mantle length (DML) frequency distribution of *D. gigas* captured by jigging (b) March and (d) Sep-Oct 2010.

day and night without any clear daily vertical migration pattern (Fig. 7b).

Jig sampling. In March jumbo squid fishing was done in 75 distinct locations and only at 23 of them jumbo squids were captured (positive stations) (Fig. 2a, Table 1). During Sep-Oct jigging was done in 100 locations and jumbo squids were captured only in 28 stations (Fig. 2b, Table 1). During March, most of the jumbo squid were captured in the Grandes Islas region and south of this region where the lowest SST were recorded (< 18 °C). Jumbo squids were also caught in three stations located in the southern part of the area of study with satellite SST between 19 and 20 °C (Fig. 2a). During Sep-Oct individuals were caught along the west coast in satellite SST values significantly lower than the mean SST for all the area (mean overall 30.8 °C, n = 62,111, mean positive jigging 30.2 °C, n = 28, ANOVA, F = 105, $p < 0.001$) (Fig. 2b). A comparison of the SST at location with positive jumbo squid jigging and SST at locations with acoustic positive jumbo squid segments showed no significant differences (ANOVA, F= 2.8, $p = 0.093$).

Jumbo squid DML frequency distribution detected during March showed a single distribution mode with a 70 cm DML (Fig. 5b). Some of the squids were young individuals within 20 and 30 cm DML range (Table 1). During Sep-Oct the jumbo squid DML frequency distribution was multi-modal (Fig. 5d). The size groups were small individuals 20 to 30 cm DML, medium sizes 40 to 50 cm DML, and large individuals 65 to 85 cm DML. Pooling all the data the mode was 40 cm (Table 1). During Sep-Oct very large individuals were caught with jigs, but because of their large weight and physical strength they escaped before getting up to ship deck. Small jumbo squid individuals were quite abundant near the sea surface. They were frequently observed from the ship deck during the nigh when jig fishing was done.

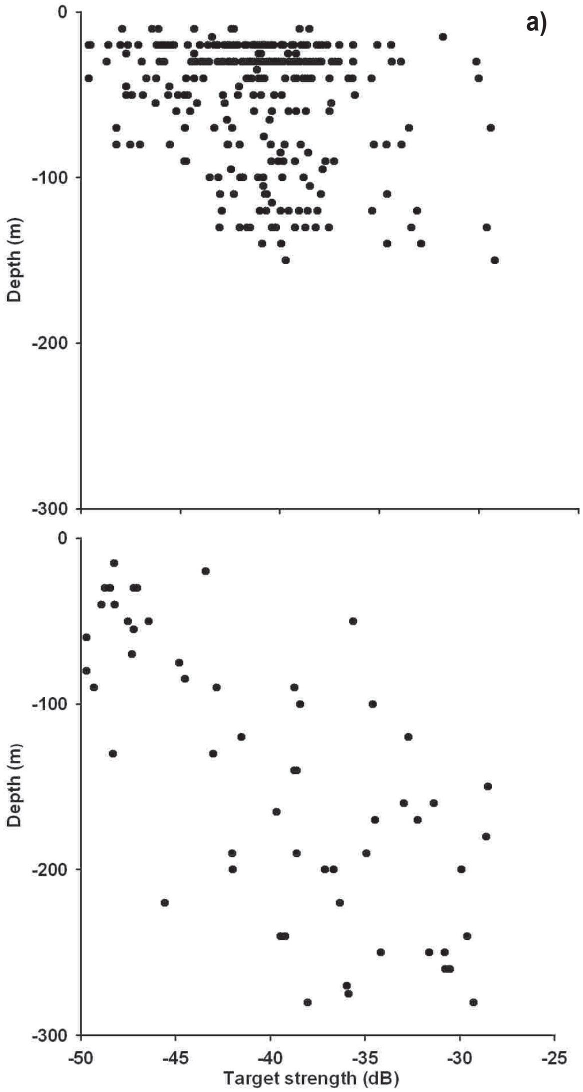

Figure 6a-b. Target strength of echoes associated with *D. gigas* as a function of depth during the cruise done in (a) March and (b) Sep-Oct 2010.

DISCUSSION

Hydroacoustic is a useful methodology to study distribution of migratory and mobile pelagic species. The use of this technique allows the sampling of large volume of water in relatively short time. However, in regions where diversity of nekton is high (multiple targets are sonified), like the subtropical Gulf of California ecosystem, species identification and discrimination become a difficult task to solve (Simmonds & MacLennan, 2005). To identify jumbo squids acoustically we used of a single split beam frequency (120 kHz) considering two criteria: a theoretically (Benoit-Bird *et al.*, 2008) and ground true range of backscattering strength and the number of individual echoes in a seawater volume; which may be useful to empirically overcome this acoustic identification problem. We are aware that acoustic identification can be refined and improved in further investigations implementing multi-frequency acoustic system (e.g. Benoit-Bird *et al.*, 2008) and/or observing jumbo squids swimming behaviour and swarm compactness under different environmental conditions. However, our empirical approach used in here seems be practical and reasonably precise approach to distinguish the jumbo squids at locations where underwater camera and jigging ground trued the presence of these animals at specific water strata (ship drifting). However, the certainty of acoustic identification surely decreases when the ship travel along the hydroacoustic track because is practically impossible to verify each target that meet the two above mentioned criteria to identify squids. Moreover, our empirical approach has the limitation that it is not known the proportion of echoes identified

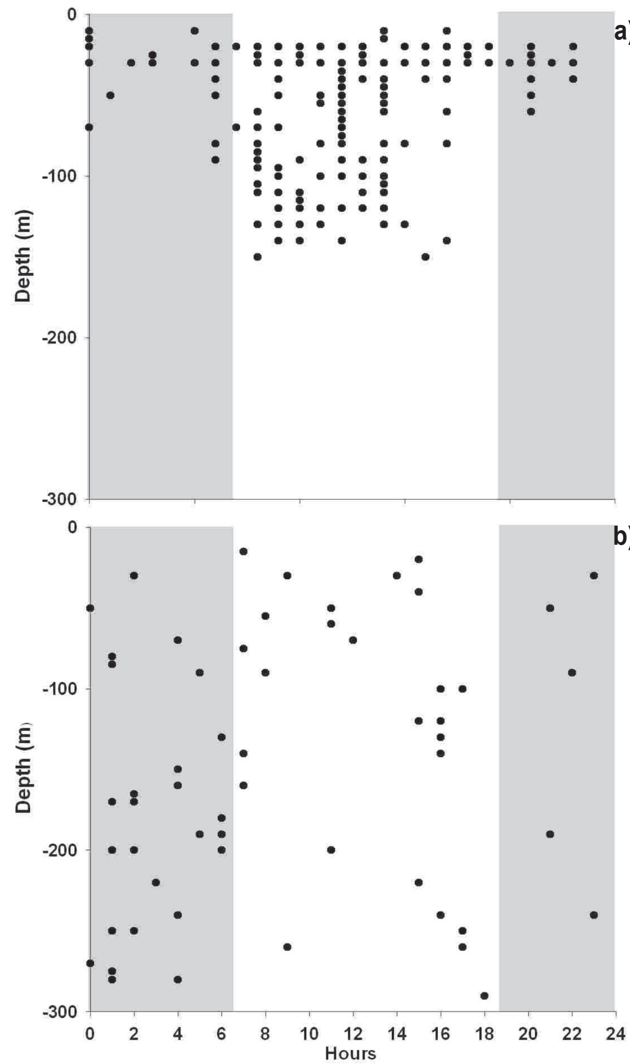

Figure 7a-b. Depth where the echoes associated with *D. gigas* was detected throughout the circadian cycle. Night-time hours are indicated with shaded area (a) March and (b) Sep-Oct 2010.

Table 1. Number of oceanographic stations with jigging, positive fishing stations, number of jumbo squid cached, squid dorsal mantle length (DML) and total weight (kg) recorded during March and September-October 2010 in the Gulf of California.

Biological variables	March			September-October		
	Mode	n	Percentage	Mode	n	Percentage
Stations sampled	—	75	—	—	100	—
Positives stations	—	23	30.6	—	28	28
Jumbo squids	—	89	—	—	79	—
DML (cm)	70	89	—	40	79	—
Total weight (Kg)	6.0	67	—	2.0	65	—

as jumbo squids that might come from other sources. We detected several interesting distributions patterns using hydroacoustic: First, during March, most of the jumbo squid were echo-detected and captured far away from the east coast of the gulf; which is the traditional fishery grounds off Santa Rosalía, as reported from fishery landing and tag-and-recapture studies (Markaida *et al.*, 2005). Second, the TS frequency distribution detected during the two cruises estimate similar jumbo squids DML range that those observed from DML frequency distribution measured from specimens collected during both cruises, as well as the DML range reported in similar seasons using jig sampling (February 2003 and October 2008) (Velázquez-Abunader *et al.*, 2010). As far as we know, this is the first work in the Gulf of California to study the jumbo squid distribution using acoustic methods over a relatively large area with the ship moving and these results may be the base line for further studies. The use of multi-frequency acoustic systems has proved to be a robust tool for target discriminations (Brierley *et al.*, 1998; Jurvelius *et al.*, 2008). Further, research is needed to validate the jumbo squid echoes using multi-frequencies while the vessel is moving because previous studies did it at a single location with the ship drifting (Benoit-Bird *et al.*, 2008).

Seasonal and geographical jumbo squid distribution. During March most of the jumbo squids were captured with jigging around the Grandes Islas region and in the southern part of this region. These areas were sampled during day and night and hydroacoustic data confirmed the presence of this cephalopod. However, in the rest of the study area the jumbo squids were captured with jigging only in three locations even though there detected frequent echoes that match our TS and compactness criteria to be associated with jumbo squids, particularly near Guaymas (where maximum chlorophyll-*a* was near the surface). This may be partially explained by the fact that vessel track was not the same during the day and during the night (when jigging sampling was done). Therefore, we were unable to corroborate with jigs the identification of the echoes associated with large groups of jumbo squids mostly detected during the day. We had frequent observations of dense jumbo squid aggregations echo detected with the same hydroacoustic method and ground true with underwater camera and jigging in previous cruises done during November 2005, and January and July, 2007 in the Gulf of California, when jumbo squids were considerably more abundant (Robinson *et al.*, 2013). In November 2005, we observed with the underwater camera and captured jumbo squids from a dense swarm with large individuals near Guaymas (27 °46′ N-111 °00 W). We have similar echograms records that those showed here. During July 2007, large groups of jumbo squids were echo detected during the day and sampled along the peninsular of the gulf, north of Santa Rosalia (27 °53′ N-112 °40 W). These observations support our empirical approach to identify squids using a combination of criteria that reflect body reflectivity (TS) and social behaviour (swarm compactness). Moreover, large swarms of jumbo squids have been recorded also with hydroacoustics methods in the Humbolt Current System off Peru, where annual fishery captures of *D. gigas* exceed the 250,000 t per year (TASA, 2008).

In late summer-early autumn (Sep-Oct), jig sampling and echo-detection indicate that the jumbo squids were located along the continental coast of the gulf with a similar summer distribution pattern previously reported using fishery data (Martínez-Aguilar *et al.*, 2004) and the conceptual migration patterns proposed by Markaida *et al.* (2005). During this survey echo integration was extremely low and we capture only three small jumbo squids. We frequently observed small jumbo squids swimming near the surface distributing within the 'blind acoustic zone' (< 10 m) above the transducer being undetected by the echosounder beam. However, the low abundance detected in the cruise coincides with Guaymas fishery records that indicate that September is the month with the lowest captures of this species (Robinson *et al.*, 2013).

Vertical distribution. Studies of the jumbo squid behaviour with electronic tagging done in the central part of the Gulf of California indicate that they perform extensive migrations toward deep waters during the day, but its vertical distribution is highly variable during the night (Gilly *et al.*, 2006). Four-dimensional spatio-temporal hydroacoustic data shown that at night in shallow water, jumbo squid were using ascending, spiral-like swimming paths to emerge from extremely dense aggregations, and were likely foraging on potential prey that were found overlapping in depth with their tracks (Benoit-Bird & Gilly, 2012). We found that during night survey in March, echoes associated to jumbo squid were detected above 50 m depth, as expected. However, during the day, echo traces were recorded only from 10 to 150 m depth (Fig. 7a) and no evidence of vertical migration was detected. This apparently lack of vertical migration may be associated with the geographical location of *D. gigas* aggregations, because in March large concentrations were detected along the continental shelf (< 200 m depth). However, large squid aggregations were also detected during the day in the middle region of the gulf. During Sep-Oct jumbo squids were detected from 10 to 300 m layer without a clear day-night vertical distribution pattern (Fig. 7b). These synoptic observations indicate that jumbo squid do not always follow typical daily vertical migration suggesting that other factors are involved in their vertical position of the squid throughout the circadian cycle.

Target strength distribution. The theoretical DML inferred from the target strength frequency distribution detected hydroacoustically and the jumbo squid DML frequency distributions measured on board during both cruises had certain similarity (Fig. 5a-d). However, our TS values did not match the TS-DML relationship estimated by Benoit-Bird *et al.* (2008). In the present work, TS estimations measured with 120 kHz at location with ground true jumbo squid observations were about –6 dB less intense than those predicted for the same DML by Benoit-Bird *et al.* (2008). This means that jumbo squids estimated in our study were about 20 cm smaller than the DML predicted with their TS-DML equations. Observations with the underwater camera; which was near or within the acoustic beam (in multiple occasions the echosounder detected the camera and it wire), showed jumbo squids swam in highly variable angle of swimming positions. This indicates that the jumbo squid, as acoustic target is highly variable and may not frequently be detected as a flat horizontal surface as calculated experimentally. But even so, Benoit-Bird *et al.* (2008) *in situ* observations showed a remarkable consistency with the relationship TS-DML obtained from jumbo squids under controlled conditions and found little difference between dorsal TS and tiled organism. In the present work the echogram system was calibrated *in situ* before both cruises and differences occurred both with the stopped vessel and travelling at > 4.5 m s^{-1} showed similar lower TS associated with free-swimming squids than those obtained in previous experimental observations with other squid species (Arnaya *et al.*, 1989; Lee *et al.*, 1992). The measurement and theoretical derivation of the TS is a stochastic measure and it is affected by the position of the organism target in the beam and the behaviour of the organisms (Simmonds & MacLennan, 2005). Substantial more effort must be invested to calibrate TS values with *in situ* jumbo squids in the Gulf of California while the ships are moving if we really pretend to use hydro-acoustic methods to estimate population distribution, abundance, and biomass systematically as an action to regulate the fishery effort and to understand the natural behaviour of *D. gigas*.

We can conclude that, the use of a single frequency (120 kHz) to infer the target strength range of the jumbo squid and the multi echoes in the volume sampled is a useful tool in the study of the jumbo squid distribution and behaviour. Using this method we corroborated the proposed distribution of this species in the Gulf of California using jigging samplings: abundant in the east coast during March and considerably less abundant and smaller individuals in the west coast during Sep-Oct. The use of hydroacoustic surveys indicates that jumbo squid may be found distributed along the water column during the day with no evident vertical migration. The use of this hydroacoustic methodology combined with multi-frequencies may provide precise information to estimate abundance of this species.

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