# JUMBO SQUID (*DOSIDICUS GIGAS*) BIOMASS OFF CENTRAL CHILE: EFFECTS ON CHILEAN HAKE (*MERLUCCIUS GAYI*)

RUBEN ALARCÓN-MUÑOZ
Instituto de Investigación Pesquera Octava Región S.A.
Av. Colón 2780, Talcahuano, Chile
ralarco@inpesca.cl

LUIS CUBILLOS
Laboratorio de Evaluación de Poblaciones Marinas,
Departamento de Oceanografía, Facultad de Ciencias Naturales y Oceanográficas
Universidad de Concepción
Casilla 160-C, Concepción, Chile.

CLAUDIO GATICA
Instituto de Investigación Pesquera Octava Región S.A.
Av. Colón 2780, Talcahuano, Chile

## ABSTRACT

Jumbo squid (*Dosidicus gigas*) off central Chile (32°00'S–41°30'S) was estimated using data collected from July to November during 2005 and 2006 on board the commercial bottom trawl fleet, where *D. gigas* is part of the bycatch. A geostatistical approach was applied to estimate the jumbo squid biomass in Chilean hake (*Merluccius gayi*) fishing grounds, which reached almost 135,000 t in 2005 and 131,000 t in 2006. The consumption-biomass ratio and the diet composition from a jumbo squid predation study during 2005 and 2006 were used to estimate the consumption of *Merluccius gayi* by *D. gigas* between 2001 and 2006. Assuming a direct relationship between the biomass and the catch per unit effort, *D. gigas* biomass and its consumption were estimated for 2001 to 2004. We also consider that the predation of jumbo squid on Chilean hake played an important role in the biomass reduction of this species off central Chile.

## INTRODUCTION

The jumbo squid (*Dosidicus gigas*, d'Orbigny 1835), called "jibia" in Chile and "pota" in Peru, is one of the most abundant squid in the Eastern Pacific Ocean (Nesis 1970; Nigmatullin et al. 2001; Anderson and Rodhouse 2001; Argüelles et al. 2001; Ibáñez and Cubillos 2007) and is one of the largest marine invertebrates of the Chilean fauna (Schmiede and Acuña 1992; Fernández and Vásquez 1995). The geographic distribution of *D. gigas* extends from approximately 40°N to 42°S in the Eastern Pacific Ocean (Wormuth 1998; Nigmatullin et al. 2001), in both oceanic and neritic waters, and from the surface down to depths of 1,200 m (Nesis 1970; Roper et al. 1984; Fernández and Vásquez 1995; Markaida and Sosa-Nishizaki 2001; Nigmatullin et al. 2001; Tafur et al. 2001; Taipe et al. 2001). This species typically lives in areas of high productivity and is most often concentrated in coastal waters from 25°–30°N to 25°–30°S, but in 2004 jumbo squid were confirmed to have been caught as far north as Alaska (57°N) (Hatfield and Hochberg 2007), and in the south near Chiloe island (43°00'S) in 2006.

Like most cephalopods, jumbo squid are characterized by rapid growth and short life spans, and typically reach 120–150 cm of dorsal mantle length (DML) (Lipiński and Underhill 1995; Argüelles et al. 2001; Tafur et al. 2001; Taipe et al. 2001). Nesis (1983) reported that jumbo squid can reach large sizes of up to 360 cm in total length (up to 200 cm in DML) and up to 150 kg in weight, however, Clarke and Paliza (2000) suggest that those sizes could be exaggerated because the maximum dimensions they recorded from specimens found in sperm whales' stomachs caught off Peru had dorsal mantle lengths of 120 cm and body weights of 58–65 kg.

In Chile, most of the existing literature available on *D. gigas* describes the length structure and reproductive activity, the strandings that have occurred in coastal areas, and/or the sporadic and short-term pulses in abundance that can be deduced from the catch records (Wilhelm 1951; Schmiede and Acuña 1992; Fernández and Vásquez 1995; Rocha and Vega 2003; Chong et al. 2005).

The existence of *D. gigas* invasions along the Chilean coast during the 19th century is well-documented. Alcides d'Orbigny, a French naturalist who visited South America at the beginning of the 19th century, wrote in his monumental 1834 work, "Voyage dans l'Amerique Méridionale," that high abundances of *D. gigas* in Chile occurred between Arica (18°20'S) and Valparaíso (33°01'S) during the summer of 1830 (Wilhelm 1930). Wilhelm (1930) reported events of high abundance of *D. gigas* off the central part of Chile, and related those high abundances to the impressive jumbo squid beachings at the end of the summer of 1930 in Concepción Bay (36°41'S–73°02'W). Jumbo squid was abundant off Chile between 1992 and 1994 (Schmiede and Acuña 1992; Arancibia et al. 2007)[1], and since 2001, a new period of high abundance has occurred, with total catch reaching 297,000 t in 2005 (SERNAPESCA 2006, Anuario Estadístico de Pesca 2005. http://www.subpesca.cl).

[1]Arancibia, H., M. Barros, S. Neira, U. Markaida, C. Yamashiro, L. Icochea, C. Salinas, L. Cubillos, Ch. Ibáñez, R. León, M. Pedraza, E. Acuña, A. Cortés, and V. Kesternich. 2007. Informe Final Proyecto FIP 2005-38. Análisis del impacto de la jibia en las pesquerías chilenas de peces demersales. Universidad de Concepción/Universidad Católica del Norte, 299 pp. + Anexxes.

*D. gigas* are characterized by a complex size structure, high fecundity, sexual dimorphism, and a differentiated sexual ratio (Markaida 2001; Markaida et al. 2004). On the other hand, food habit studies indicate that these animals prey on a number of stocks of commercial and ecological importance in the central part of Chile, including Chilean hake (*Merluccius gayi*), jack mackerel (*Trachurus murphyi*), Chilean common sardine (*Strangomera bentincki*), anchovy (*Engraulis ringens*), lantern fish (*Hygophum* spp.), rattails (*Coelorhynchus* spp.), rockfish (*Helicolenus lengerichi*), deepwater cardinalfish (*Epigonus crassicaudus*), and euphausiids (Ulloa et al. 2006; Arancibia et al. 2007).

Geostatistics is a relatively young statistics field in which spatially-explicit phenomena are studied (Journel and Huijbregts 1978). Petitgas (1993) defines geostatistics as the application of probability theory to estimates of spatial or regionalized variables. Geostatistics is applied in many fields, especially mineral resources, in order to estimate and simulate regionalized variables (Isaaks and Srivastava 1989; Martínez-Vargas and Ramírez-Garcia 2005). Geostatistics was initially applied to fisheries data in 1985 for biomass estimates (Conan 1985; Gohin 1985) using a technique that had been developed for mineral resource estimation (Rivoirard et al. 2000).

While geostatistics has mainly been applied to mining applications, the generality of the subject and diversity of applications are increasing. It has also been applied to terrestrial issues in hydrology (Bardossy 1992; Gardner et al. 2003), agriculture (Lacaze et al. 1994), and forestry (Lyon et al. 2006), and to marine problems in bathymetry (David et al. 1986), mapping sea surface temperature (Gohin 1989), and estimation of various marine biological resources. Included in this latter class are shellfish (Conan 1985), crustaceans (Loch et al. 1995; Rufino et al. 2004), fish eggs and larvae (Fletcher and Sumner 1999; Bez 2002; Castillo-Jordán et al. 2007), spatial plankton distribution (Bez and Rivoirard 2001; Simard et al. 2003), biomass of fishes (Simard et al. 1993; Petitgas 1993; Maravelias 1999; Barange et al. 2005), and the present subject, squids.

The consumption of Chilean hake by *D. gigas* is considered one of the factors that could explain the recent biomass reduction and the quasi-collapse of the Chilean hake fishery (Arancibia and Neira 2005[1]). But, there are no estimates of jumbo squid biomass with which to assess the total consumption of Chilean hake. The objectives of this work are: (1) to estimate the biomass of *D. gigas* in the fishing grounds of Chilean hake between 2001 and 2006; and (2) estimate the jumbo squid consumption of Chilean hake using consumption-biomass ratio estimates (Q/B) and jumbo squid diet composition (DC) during the same period.

## METHODS

### Biomass Estimates in 2005 and 2006

To estimate the biomass of *D. gigas* in the study area (fig. 1), density data, measured as catch per unit of swept area (cpua, t/km$^2$), was collected between July and November in 2005 and 2006 on board commercial bottom trawl vessels from the Chilean hake fishery, between 32°00'S–41°30'S. This study area represents the main distribution area of the Chilean hake fishery.

The total study area was separated into two geographic zones, defined according to the orientation and shape of the coastline and the extension and distribution of the continental shelf (Lillo et al. 2007)[2]. The limit between the geographic zones was arbitrarily fixed at 37°06'S, defining a north area and a south area (fig. 1).

All the data used were collected on board by scientific observers as part of a joint monitoring program between the Chilean hake fishing industry and the Instituto de Investigación Pesquera (INPESCA). The jumbo squid catch was weighed directly on board after being separated from the Chilean hake specimens. *D. gigas* is caught as bycatch in the Chilean hake fishery and the jumbo squid catch is independent of the fishery, which means that the jumbo squid catch can be considered a random sample of its abundance, a condition needed to apply the swept-area method to this species (Godø 1994).

The density (tons/km$^2$) of jumbo squid in each haul was calculated as:

$$z(x_i) = \frac{C_i}{WS_i \cdot sd_i}, \quad (1)$$

where $z(x_i)$ is the value of the density (tons/km$^2$) of jumbo squid at $x_i$, which is the trawl middle point; $C_i$ is the catch (tons) of jumbo squid; $WS_i$ is the wing spread of the net; and $sd_i$ is the swept distance.

The wing spread of each haul used in this study was measured directly on board by the scientific observers, as we only use data from vessels that have electronic devices to measure both wing spread and the vertical spread of the net. At least five measures of the wing spread were taken during the hauls; for each haul the average of those measures were used. The wing spread of the nets fluctuated between 16 and 20 m.

In using the geostatistical approach to estimate the biomass of *D. gigas* in the Chilean hake fishing grounds, the spatial relationship between densities was explored by computing an empirical semivariogram, the basic geostatistics tool (Rivoirard et al. 2000). The empirical var-

[2]Lillo, S., R. Bahamonde, J. Olivares, J. Saavedra, E. Díaz, E. Molina, M. Braun, S. Núñez, A. Sepúlveda, R. Alarcón, and A. Saavedra. 2007. Evaluaciones hidroacústicas de merluza común, año 2006. Informe Final Proyecto FIP 2006-03. 597 pp.

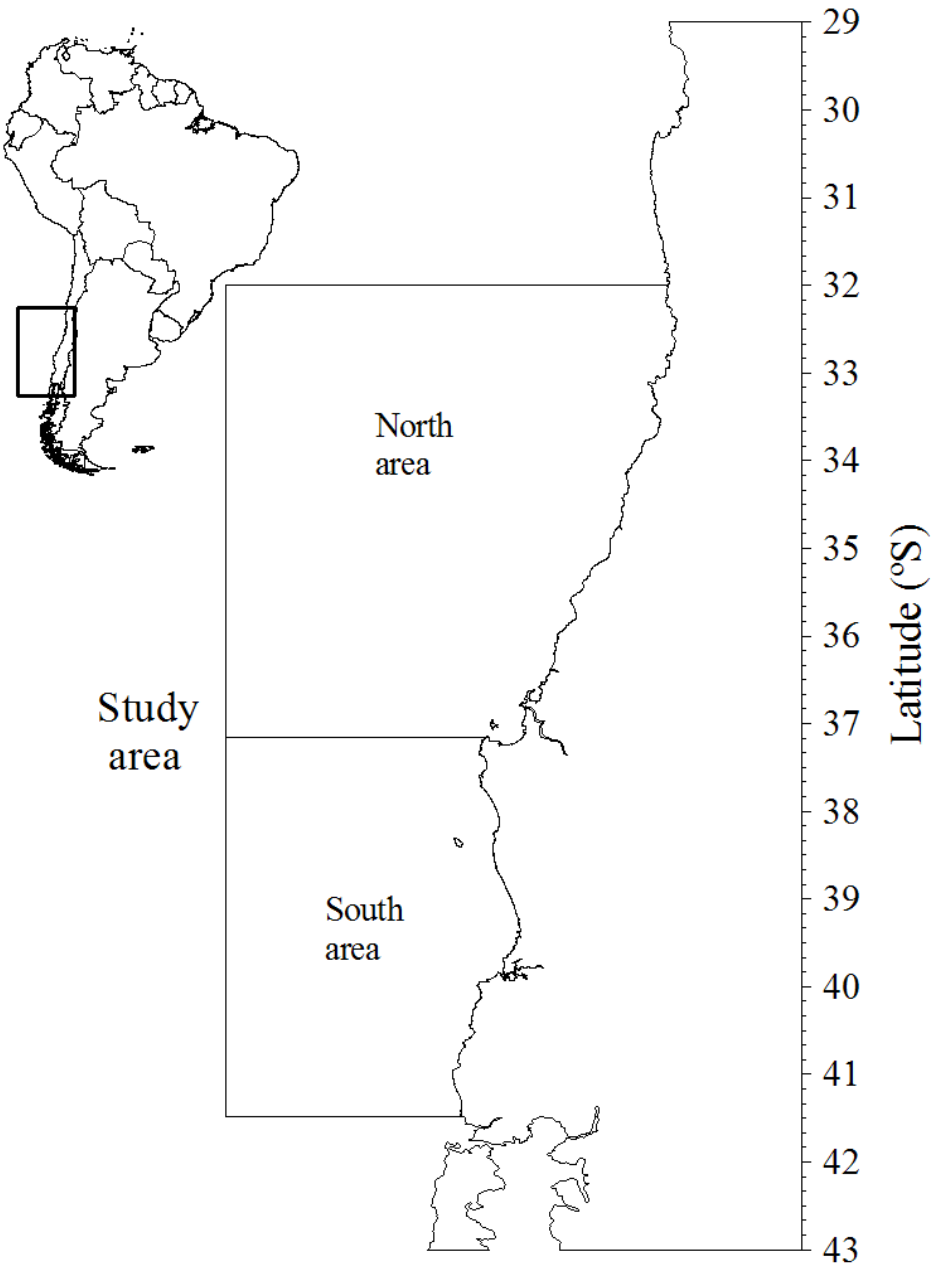



Figure 1. Study area shown separated in two working areas (north and south).

iogram is defined as the variance of difference between values that are $h$ units apart and is a function of variance and covariance, i.e.:

$$\gamma^* = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left(z(x_i) - z(x_i + h)\right)^2, \quad (2)$$

where $h$ is a vector of distance and direction, and $N(h)$ is the number of pairs of observations at distance $h$ and a given direction. However, we also chose the robust (or stable) variogram estimator (Cressie and Hawkins 1980; Cressie 1993) since it permitted a better definition for the variogram pattern for the spatial distribution of *D. gigas* densities (Sullivan 1991):

$$\gamma^* = \frac{\left( \sum_{i=1}^{N(h)} \left(z(x_i) - z(x_i + h)\right)^{\frac{1}{2}} \right)^4}{2N(h)^4 \left(0.457 + \frac{0.494}{|N(h)|}\right)}. \quad (3)$$

In the present analysis, second-order stationarity was assumed (Journel and Huilbregts 1978), where the following applied: (1) the mathematical expectation (or

mean) of the random function, $E(Z(x))$, is independent of the support point $x$; and (2) for each pair of regionalized variables $(z(x_i) - z(x_i + h))$ the covariance, $C$, is independent of the separation distance, $h$ (Matheron 1971; Journel and Huilbregts 1978). The stationarity of the covariance implies the stationarity of the semivariogram (Journel and Huilbregts 1978). In order to explore and to detect whether the intensity of spatial autocorrelation varies according to direction (anisotropic process), experimental semivariograms were calculated in four directions (0°, 45°, 90°, and 135°).

To characterize the spatial structure of the *D. gigas* density, three mathematical models were tested: the spherical, exponential, and the Gaussian models. These models, in terms of the semivariogram, are described in Cressie (1993):

$$\gamma(h;\theta) = \begin{cases} 0, & h = 0 \\ c_0 + c\left(\frac{3}{2}\left(\frac{\|h\|}{r}\right) - \frac{1}{2}\left(\frac{\|h\|}{r}\right)^3\right), & 0 < \|h\| \le r \\ c_0 + c, & \|h\| \ge r \end{cases} \tag{4}$$

for the spherical model,

$$\gamma(h;\theta) = \begin{cases} 0, & h = 0 \\ c_0 + c\left(1 - \exp\left(-\frac{\|h\|}{r}\right)\right), & h \neq 0 \end{cases} \tag{5}$$

for the exponential model, and

$$\gamma(h;\theta) = \begin{cases} 0, & h = 0 \\ c_0 + c\left[1 - \exp\left(-\frac{3\|h\|^2}{r^2}\right)\right], & h \neq 0 \end{cases} \tag{6}$$

for the Gaussian model, where $c$ is the sill of the variogram that represents the maximum level of variability, $r$ is the range of the variogram beyond which data are no longer autocorrelated, and $c_0$ is the nugget effect. The models were fitted to the variogram estimates according to an approximate weighted-least-squares (WLS) procedure (Cressie 1993; Pelletier and Parma 1994).

To select the best model and evaluate alternative models for kriging, a cross-validation was performed. In cross-validation analysis, each measured point in a data set is individually removed from the set and its value is then estimated via kriging as though it were never there (Davis 1987). In this way, the prediction error for each sampled locality is defined as the difference between the measured value and the estimated value from the rest of the data (Isaaks and Srivastava 1989). The mean squared deviation ratio (MSDR) of residuals was used as a goodness of fit measure:

$$\text{MSDR} = \frac{1}{n}\sum_{i=1}^{n}\frac{[z(x_i) - \hat{z}(x_i)]^2}{\hat{\sigma}^2(x_i)}, \tag{7}$$

where $\hat{\sigma}^2(x_i)$ is the kriging variance at cross-validation point $x_i$.

Ordinary point kriging was used as the interpolation method to reproduce the stochastic processes within the distribution regions (loci) of *D. gigas* in the study area. An interpolation grid was imposed into each abundance locus with internodal distance as the average minimum distance between hauls. The abundance region (locus) was defined according to the presence/absence of *D. gigas* in trawls.

Both variogram and kriging parameters were used to estimate the density, $z^*(x_0, y_0)$, of *D. gigas* in the localities $(x_0, y_0)$:

$$z^*(x_0, y_0) = \sum_{i=1}^{n} \omega_i z(x_i, y_i), \tag{8}$$

where $\omega_i$ represent the weights for each sampled locality. The sum of the weights is equal to 1.

Inside of each abundance locus, the mean density $(z^*_{kg})$ was estimated by averaging the local estimates. The biomass of *D. gigas* in each abundance locus $(\hat{B}_j)$, was calculated as:

$$\hat{B}_j = \frac{1}{\bar{a}}\ \hat{S}_j \cdot z^*_{kg}, \tag{9}$$

where $\hat{S}_j$ is the area (km$^2$) of the $j$-locus, and $\bar{a}$ is the average local capturability index which, for simplicity, was assumed equal to 1. Then, the total biomass of *D. gigas* is the sum of all abundance regions identified in the study area, i.e.:

$$\hat{B} = \sum_{j=1}^{n} \hat{B}_j. \tag{10}$$

**Jumbo Squid Biomass Between 2001 and 2004**

We established that no direct estimates of jumbo squid biomass between 2001 and 2004 existed. Then, with annual *D. gigas* CPUE (tons by sweep hour, t/sh) from 2001 to 2006 (fig. 2), and the direct relationship between CPUE and biomass (Sparre and Venema 1997),

$$\text{CPUE} = q \cdot B, \tag{11}$$

the capturability coefficient ($q$) was obtained separately for 2005 and 2006, as was the two-year average ($\bar{q}$). With this average capturability coefficient, and the annual CPUE data, *D. gigas* biomass was calculated for 2001 to 2004, according to the following expression:

$$\hat{B}_\gamma = \frac{\text{CPUE}}{\bar{q}}. \tag{12}$$

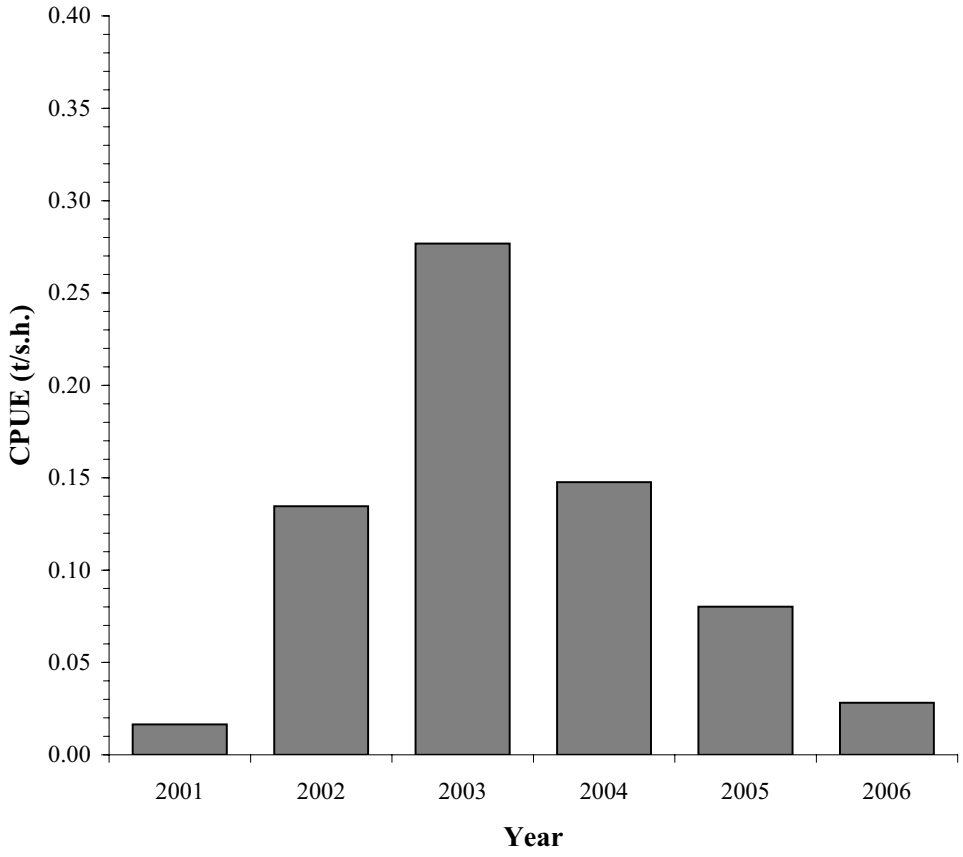



Figure 2. Annual catch per unit effort (tons by sweep hour, t/s.h.) of jumbo squid (*Dosidicus gigas*) off central Chile between 2001 and 2006.

**Consumption of Chilean Hake**

To estimate Chilean hake consumption ($Q_i$) by *D. gigas*, three parameters have to be known: (1) the biomass of the predator ($B_j$), (2) the consumption-biomass relationship of the predator $(Q/B)_j$, and (3) the diet composition ($DC_{ij}$) of the prey ($i$) in the stomach contents of the predator ($j$). The expression to calculate the consumption is:

$$Q_i = \sum_{i=1}^{n} B_j \cdot \left(\frac{Q}{B}\right)_j \cdot DC_{ij} . \qquad (13)$$

## RESULTS

From analysis of positive and negative trawls (zero catch) for *D. gigas*, ten abundance foci were identified in 2005, and thirteen in 2006 (fig. 3), covering 19,346.7 km² and 12,695.5 km², respectively (tab. 1).

The analysis of directional variograms showed differences in the spatial autocorrelation between both years and areas. Therefore, a directional variogram was calculated for each area, except in the south area for 2006 where an omni-directional variogram was adjusted. In all cases, the spherical model showed the best fit (fig. 4). The range of the variogram fluctuated between 11.2 km in the south area in 2005 and 19.0 km in the north area in 2006 (tab. 2).

*D. gigas* biomass in the Chilean hake fishing grounds estimated through the geostatistic method reached more

TABLE 1
**Number of biomass loci of *Dosidicus gigas* identified in the study area in 2005 and 2006, the coverage area (km²), and the biomass (t) estimated in each locus and total.**

| | 2005 | | 2006 | |
|---|---|---|---|---|
| Locus | Area (km²) | Biomass (t) | Area (km²) | Biomass (t) |
| 1 | 278.7 | 2,577.5 | 293.0 | 3,680.0 |
| 2 | 182.4 | 2,332.0 | 392.8 | 6,954.0 |
| 3 | 563.2 | 2,630.5 | 170.4 | 2,076.0 |
| 4 | 677.8 | 3,072.0 | 163.5 | 5,724.5 |
| 5 | 5,956.8 | 45,627.0 | 1,987.1 | 17,604.5 |
| 6 | 779.2 | 7,380.5 | 2,290.0 | 14,259.0 |
| 7 | 63.7 | 641.5 | 292.5 | 8,008.5 |
| 8 | 2,755.9 | 27,104.5 | 93.6 | 767.5 |
| 9 | 3,718.6 | 17,016.0 | 545.9 | 5,980.0 |
| 10 | 4,370.4 | 26,291.0 | 93.5 | 868.5 |
| 11 | — | — | 569.3 | 11,973.5 |
| 12 | — | — | 2,008.5 | 21,090.0 |
| 13 | — | — | 3,795.4 | 32,200.5 |
| Total | 19,346.7 | 134,672.5 | 12,695.5 | 131,186.5 |




Figure 3. Spatial localization of the biomass loci of jumbo squid (*Dosidicus gigas*) off central Chile in 2005 (A: north area; B: south area), and 2006 (C: north area; D: south area). In parenthesis appears the number of the locus.

TABLE 2
**Parameters of the spherical variogram model fitted to the empirical variogram for the spatial distribution of the density of *Dosidicus gigas* off central Chile in 2005 and 2006. RSS = Residual Sum of Squares.**

| | 2005 | | 2006 | |
|---|---|---|---|---|
| Parameter | North area | South area | North area | South area |
| Range (km) | 11.639 | 11.169 | 18.966 | 12.174 |
| Sill | 0.242 | 0.345 | 0.368 | 1.306 |
| Nugget | 0.445 | 0.360 | 0.176 | 0.545 |
| RSS | 0.072 | 0.098 | 0.105 | 2.082 |

than 134,000 t in 2005 and almost 131,000 t in 2006. Then, using equation 11 we estimate the catchability coefficient for 2005 and 2006 as equal to $4.054 \times 10^{-7}$ (tab. 3).

To estimate the annual total biomass of *D. gigas*, it is necessary to add together the corresponding landings from the same area and year. Thus, *D. gigas* landings for the study area were 213,393.0 t in 2005 and 180,355.0 t in 2006. Therefore, the annual biomasses of jumbo squid in 2005 and 2006 were 348,065.5 t and 311,541.5 t, respectively (tab. 3).

Once the catchability coefficient and CPUE were determined, we used equation 12 to calculate the annual biomass of *D. gigas* as more than 680,000 t in 2003 and almost 40,000 t in 2001. According to official landings, there is no evidence of high jumbo squid abundance off central Chile, since at least five years before 2001. Finally, with the biomass estimate and the consumption-biomass relationship ($Q/B$) for *D. gigas* ($Q/B = 5.3$), and the diet composition ($DC$) of Chilean hake in the stomach contents of the predator ($DC = 15\%$), parameters taken from Arancibia et al. (2007), the annual hake consumption was estimated for the years 2001 to 2006 as more than 500,000 t in 2003 (tab. 3).

## DISCUSSION

Since December 2001, jumbo squid have been found in relatively high abundances in both the purse seine and bottom trawl fleet catches off the central-south coast of Chile. These high abundances were apparently due to the reproductive success of the species, associated with cold oceanographic conditions that occurred in 1999 and 2000, after the El Niño event of 1997–98 (Cubillos et al. 2004)[3]. The increase in the relative abundance of *D. gigas* resulted in the species being found both in the oceanic and coastal sector from August 2003 and January 2004 (fig. 5), with captures fluctuating between a few kilos to almost 100 t per haul.

Nevertheless, in spite of the increase in the presence of jumbo squid in the industrial and artisan captures reflected in the landings as 15,000 t in 2003, 296,000 t in 2005, and 210,000 t in 2006 (SUBPESCA 2007, www.subpesca.cl), biomass estimates of the resource do not exist for that period, except in the recent work of Arancibia and Neira (2007). They estimated the jumbo squid biomass for 2005 at 400,000 t using an ECOPATH model, which is not significantly different from our estimate of nearly 348,000 t (tab. 3).

Arancibia and Neira (2007), using the same ECOPATH model, estimate Chilean hake consumption by jumbo squid for the same year that they estimate the jumbo squid biomass (2005). Chilean hake consumption was calculated to be 300,000 t, which is comparable to our estimate of almost 277,000 t (tab. 3).

Concurrent with the increase in jumbo squid abundance off central Chile was a reduction in the availability/abundance of traditional fishing resources such as Chilean hake, Chilean hoki (*Macruronus magellanicus*), and cardinal fish (*Epigonus crassicaudus*)(Arancibia et al. 2007). Before 2002, the Chilean hake fishery was considered healthy with a robust population structure, stable average weights at age, and an increasing trend in abundance (Lillo et al. 2007, tab. 4).

Reduction in Chilean hake abundance during 2004–06

[3]Cubillos, L., Ibáñez Ch., González C., and A. Sepúlveda. 2004. Pesca de Investigación: Pesca de Jibia (*Dosidicus gigas*) con red de cerco entre la V y X Regiones, año 2003 (Research Fishery: Catch of Jumbo flying squid (*Dosidicus gigas*) with purse seine between V and X Region, Year 2003). Inst. Inves. Pesq. VIII Región. Talcahuano (Chile): pp.1–48.

TABLE 3
**Annual CPUE (tons per sweep hour, t/s.h.) of jumbo squid (*Dosidicus gigas*), capturability coefficient ($q$), estimate of jumbo squid biomass in Chilean hake (*Merluccius gayi*) fishing grounds ($B_{fg}$, tons), *D. gigas* landings, estimate of annual biomass of *D. gigas* off central Chile, and estimated consumption of *M. gayi* by *D. gigas* between 2001 and 2006.**

| Year | CPUE (t/s.h.) | $q$ | $B_{fg}$ (t) | Landings (t) | Annual Biomass (t) | Consumption of Chilean hake (t) |
|---|---|---|---|---|---|---|
| 2001 | 0.016 | | | | 40,440.3 | 32,150.1 |
| 2002 | 0.135 | | | | 331,878.8 | 263,843.6 |
| 2003 | 0.277 | | | | 682,646.5 | 542,704.0 |
| 2004 | 0.148 | | | | 364,139.3 | 289,490.7 |
| 2005 | 0.080 | $5.959 \times 10^{-7}$ | 134,672.5 | 213,393.0 | 348,065.5 | 276,712.1 |
| 2006 | 0.028 | $2.148 \times 10^{-7}$ | 131,186.5 | 180,355.0 | 311,541.5 | 247,675.5 |
| | | Average = $4.054 \times 10^{-7}$ | | | | |

TABLE 4
**Biomass (tons) of *Merluccius gayi* estimated in acoustics surveys made between 1995 and 2006 in central Chile (Lillo et al. 2007).**

| Year | Biomass (t) |
|---|---|
| 1995 | 505,765 |
| 1997 | 712,878 |
| 1999 | 899,307 |
| 2000 | 891,598 |
| 2001 | 917,133 |
| 2002* | 1,555,422 |
| 2004 | 273,860 |
| 2005 | 222,721 |
| 2006 | 266,596 |

*This value of biomass is considered highly overestimated.

has been attributed to three important factors: (1) a high predation of Chilean hake by jumbo squid (Arancibia and Neira 2005); (2) a high degree of cannibalism (Jurado-Molina et al. 2006); and (3) overestimation of the stock size in 2002 that relates to high capture quotas (Arancibia and Neira 2006).

Before 2007, the true impact of jumbo squid predation on Chilean hake was very difficult to determine because absolute abundance of the predator as well as basic aspects of its feeding biology were not known. In that sense, the biomass estimates made within the framework of this study and the estimates of the consumption-biomass ratio (Q/B) calculated by Arancibia et al.

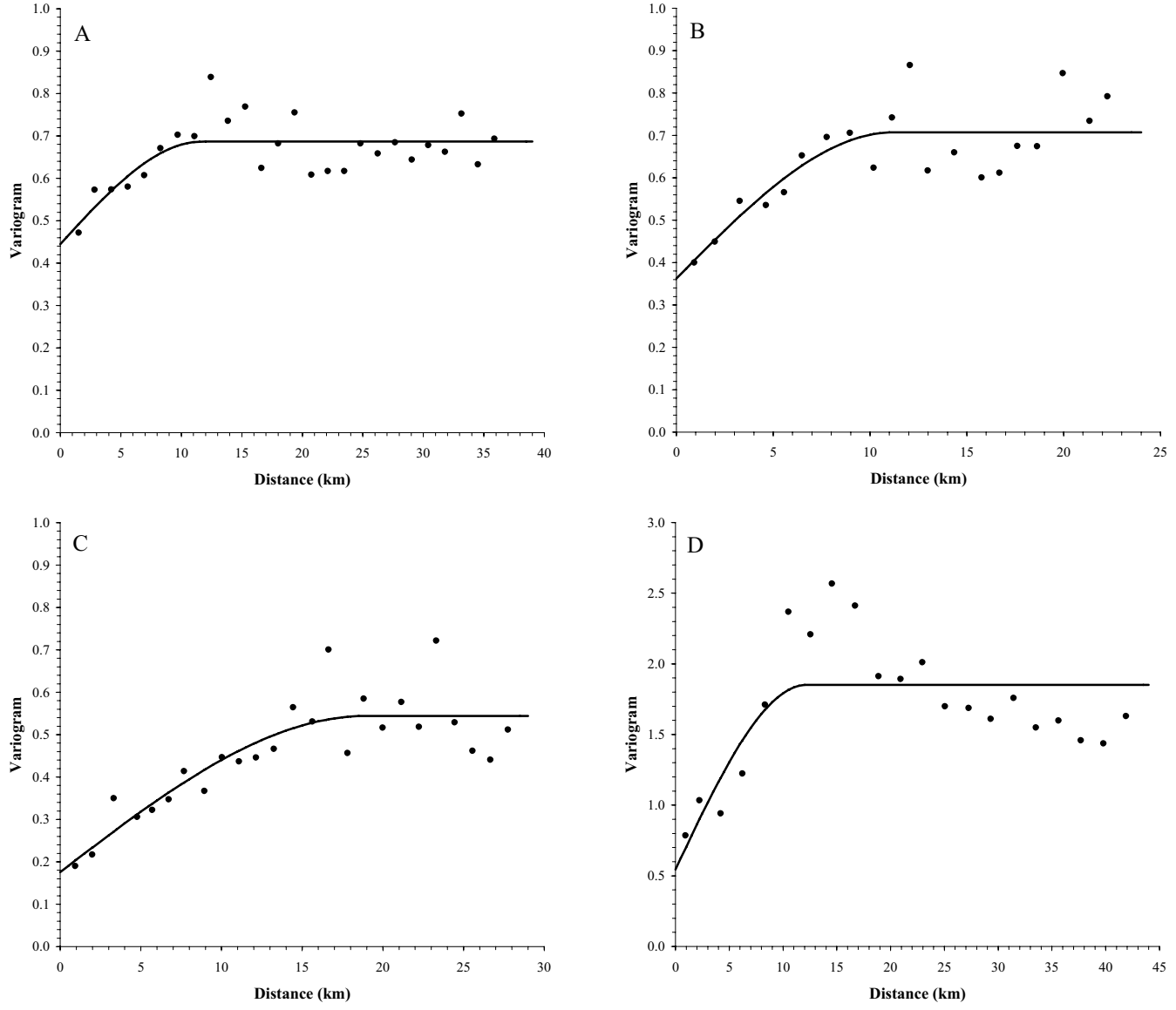



Figure 4. Theoretical variogram (black line, spherical model) adjusted to the empirical variogram (black dots) for the spatial distribution of the density of jumbo squid (*Dosidicus gigas*) in central Chile in 2005 (A: north area; B: south area), and 2006 (C: north area; D: south area).

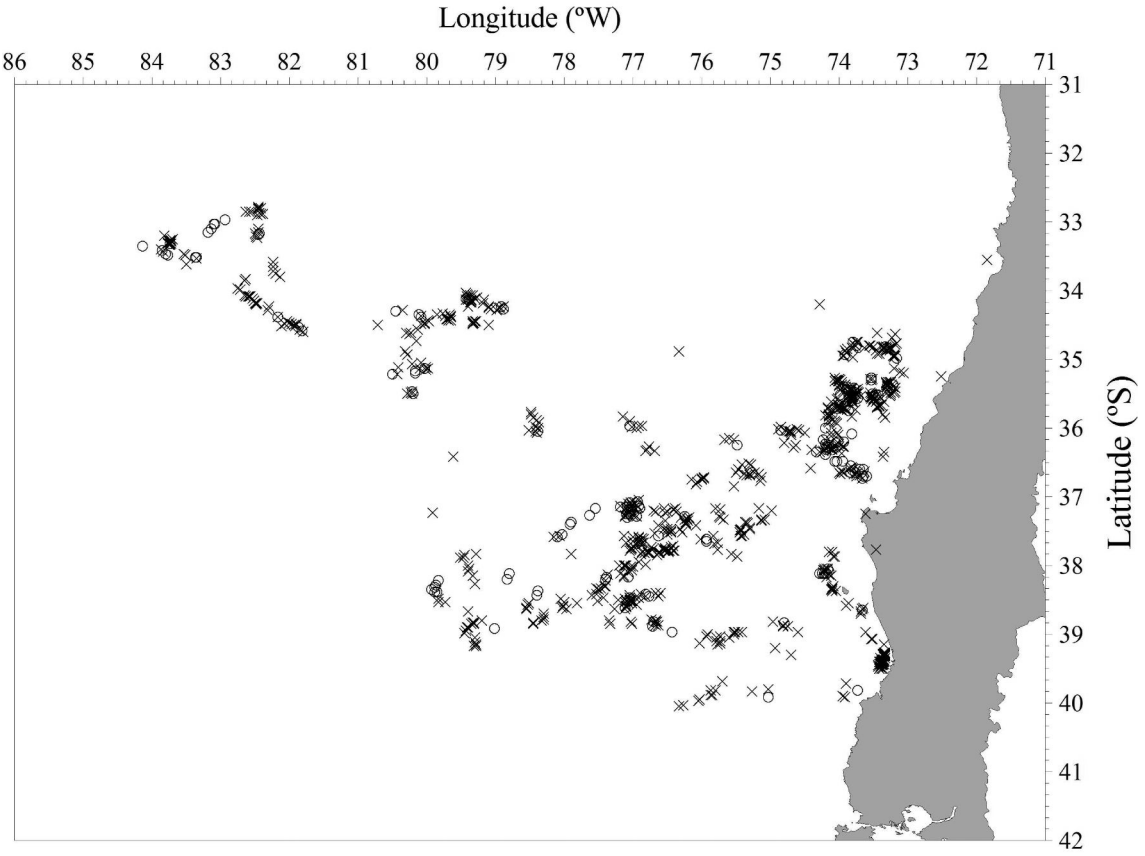



Figure 5. Spatial distribution of hauls with presence of *Dosidicus gigas* (o, white points) in the industrial Jack mackerel (*Trachurus murphyi*) purse seine fisheries off central Chile between August 2003 and January 2004. Crosses (x) are hauls without jumbo squid.

(2007), both used to estimate the consumption of Chilean hake by jumbo squid, allow us to conclude that jumbo squid predation on Chilean hake played an important role in the reduction of its biomass.

## LITERATURE CITED

Anderson, C. I. H., and P. G. Rodhouse. 2001. Life cycles, oceanography and variability: ommastrephid squid in variable oceanographic environments. Fish. Res. 54:133–143.

Arancibia, H., and S. Neira. 2005. Modelling the predation of common hake (*Merluccius gayi*) by jumbo squid (*Dosidicus gigas*) in central Chile (33–39°S). ICES CM 2005/BB: 16, 16 pp.

Arancibia, H., and S. Neira. 2006. Assessing the potential role of predation by jumbo squid (*Dosidicus gigas*) and fishing on small pelagics (common sardine *Strangomera bentincki* and anchovy *Engraulis ringens*) and common hake (*Merluccius gayi*) in central Chile, 33–39°S. *In* Robert J. Olson and Jock W. Young, eds. GLOBEC Report No. 24 The role of squid in open ocean ecosystems. 16–17 November 2006, Honolulu, Hawaii, USA. 106 pp.

Arancibia, H., and S. Neira. 2007. An overview of the present state of common hake (*Merluccius gayi*) stock with a forecast of its biomass including jumbo squid (*Dosidicus gigas*) prey-predator relationship in central Chile (33–39°S). CalCOFI Conference Abstracts. CalCOFI Conference 2007 "Featuring a Symposium on Jumbo Squid Invasions in the Eastern Pacific Ocean." 26–28 November 2007. San Diego (CA), USA.

Argüelles, J., P. G. Rodhouse, P. Villegas, and G. Castillo. 2001. Age, growth and population structure of the jumbo flying squid *Dosidicus gigas* in Peruvian waters. Fish. Res. 54:51–61.

Barange, M., J. C. Coetzee, and N. M. Twatwa. 2005. Strategies of space occupation by anchovy and sardine in the southern Benguela: the role of stock size and intra-species competition. ICES J. Mar. Sci. 62:645–654.

Bardossy, A. 1992. Geostatistical methods: Recent developments and applications in surface and subsurface hydrology. UNESCO, Paris.

Bez, N. 2002. Global fish abundance estimation from regular sampling: the geostatistical transitive method. Can. J. Fish. Aquat. Sci. 59:1921–1931.

Bez, N., and J. Rivoirard. 2001. Transitive geostatistics to characterize spatial aggregations with diffuse limits: an application on mackerel ichtyoplankton. Fish. Res. 50:41–58.

Castillo-Jordán, C., L. A. Cubillos, and J. Paramo. 2007. The spawning spatial structure of two co-occurring small pelagic fish off central southern Chile in 2005. Aquat. Living Resour. 20:77–84.

Chong, J., C. Oyarzún, R. Galleguillos, E. Tarifeño, R. D. Sepúlveda, and C. M. Ibáñez. 2005. Parámetros biológico-pesqueros de la jibia, *Dosidicus gigas* (d' Orbigny, 1835) (Cephalopoda: Ommastrephidae) frente a la costa de Chile central (29°S y 40°S) durante el período 1993-1994. Gayana. 69:319–328.

Clarke, R., and O. Paliza. 2000. The Humboldt Current squid *Dosidicus gigas* (Orbigny, 1835). Rev. Biol. Mar. Ocean. 35:1–39.

Cressie, N. A. C., and D. M. Hawkins. 1980. Robust estimation of the variogram. I. J. Int. Assoc. Math. Geol. 12:115–125.

Conan, G. Y. 1985. Assessment of shellfish stocks by geostatistical techniques. International Council for the Exploration of the Sea council meeting paper, 1985/D:30.

Cressie, N. A. C. 1993. Statistics for spatial data. JohnWiley and Sons, New York. 900 pp.

David, M., D. Crozel, and J. M. Robb. 1986. Automated mapping of the ocean floor using the theory of intrinsic random functions of order K. Mar. Geophys. Res. 8:49–74

Davis, B. M. 1987. Uses and abuses of cross-validation in geostatistics. Mathematical Geology 19(3):1573–8868.

Gohin, F. 1985. Planification des experiences et interprétation par la théorie des variables régionalisées: application à l'estimation de la biomasse d'une plage. International Council for the Exploration of the Sea council meeting paper, 1985/D:3.

Gohin, F. 1989. Analyse estructurale de la température de surface de la mer. *In* Geostatistics: Proceedings of the Third International Geostatistics Congress, Avignon, 5–9 September 1988, Vol. 1, M. Armstrong, ed. Kluwer-Amsterdam. pp. 433–444.

Fernández, F., and J. A. Vásquez. 1995. La jibia gigante *Dosidicus gigas* (Orbigny, 1835) en Chile: Análisis de una pesquería efímera. Est. Ocean. 14:17–21.

Fletcher, W. J., and N. R. Sumner. 1999. Spatial distribution of sardine (*Sardinops sagax*) eggs and larvae: an application of geostatistics and resampling to survey data. Can. J. Fish. Aquat. Sci. 56:907–914.

Gardner, B., P. J. Sullivan, and A. J. Lembo. 2003. Predicting stream temperatures: geostatistical model comparison using alternative distance metrics. Can. J. Fish. Aquat. Sci. 60:344–351.

Godø, O. R. 1994. Factors affecting the reliability of groundfish abundance estimates from bottom trawl surveys. In Marine Fish Behaviour in Capture and Abundance Estimation, A. Ferno and S. Olsen, eds. Oxford: Fishing News Books, pp. 166–199.

Hatfield, E. M. C., and F. G. Hochberg. 2007. *Dosidicus gigas*: northern range expansion events. CalCOFI Conference Abstracts. CalCOFI Conference 2007 "Featuring a Symposium on Jumbo Squid Invasions in the Eastern Pacific Ocean." 26–28 November 2007. San Diego (CA), USA.

Ibáñez, C. M., and L. A. Cubillos. 2007. Seasonal variation in the length structure and reproductive condition of the jumbo squid *Dosidicus gigas* (d'Orbigny, 1835) off central-south Chile. Scientia Marina 71(1):123–128.

Issaks, E. I., and R. M. Srivastava. 1989. An introduction to applied geostatistics. New York: Oxford University Press. 561 pp.

Journel, A. G., and C. J. Huijbregts. 1978. Mining geostatistics. London: Academic Press. 600 pp.

Jurado-Molina, J., C. Gatica, L. Cubillos. 2006. Incorporating cannibalism into an age-structured model for the Chilean hake. Fish. Res. 82:30–40

Lacaze, B., S. Rambal, and T. Winkel. 1994. Identifying spatial patterns of Mediterranean landscapes from geostatistical analysis of remotely-sensed data. Int. J. Remote Sensing 15(12):2437–2450.

Lipinski, M. R., and L. G. Underhill. 1995. Sexual maturation in squid: Quantum or continuum? S. Afr. J. Mar. Sci. 15:207–223.

Loch, J. S., M. Moriyasu, and J. B. Jones. 1995. An improved link between industry, management and science: review of case history of the Southwestern Gulf of St. Lawrence snow crab fishery. Aquat. Living Resour. 8:253–265.

Lyon, S. W., A. J. Lembo, M. T. Walter, and T. S. Steenhuis. 2006. Defining probability of saturation with indicator kriging on hard and soft data. Advances in Water Resources. 29:181–193.

Maravelias, C. D. 1999. Habitat selection and clustering of a pelagic fish: effects of topography and bathymetry on species dynamics. Can. J. Fish. Aquat. Sci. 56:437–450.

Markaida, U. A. 2001. Biología del calamar gigante *Dosidicus gigas* Orbigny, 1835 (Cephalopoda: Ommastrephidae) en el Golfo de California, México. Tesis Doctoral. Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, Baja California, México. 387 pp.

Markaida, U., and O. Soza-Nishizaki. 2001. Reproductive biology of jumbo squid *Dosidicus gigas* in the Gulf of California, 1995–1997. Fish. Res. 54:63–82.

Markaida, U., C. Quiñónez-Velásquez, and O. Soza-Nishizaki. 2004. Age, growth and maturation of jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae) from the Gulf of California, Mexico. Fish. Res. 66:31–47.

Martínez-Vargas, A., and J. Ramírez-Garcia. 2005. Desarrollo actual de la geoestadística en el mundo. Minería y Geología 21(4):21 pp.

Matheron, G. 1971. The theory of regionalized variables and its applications. *In* Cahiers du CMM. No. 5. École nationale supérieure des mines de Paris, Fontainebleau, France.

Nesis, K. N. 1970. The biology of the giant squid of Peru and Chile, *Dosidicus gigas*. Oceanology. 10:140–152.

Nesis, K. N. 1983. *Dosidicus gigas*. *In* Cephalopod Life Cycles, Vol. 1: Species Accounts, P. R. boyle, ed. London: Academic Press, pp. 215–231.

Nigmatullin, Ch. M., K. N. Nesis, and A. I. Arkhipkin. 2001. A review of the biology of the jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae). Fish. Res. 54:9–19.

Pelletier, D., and A. M. Parma. 1994. Spatial distribution of Pacific halibut (*Hippoglossus stenolepis*): an application of geostatistics to longline survey data. Can. J. Fish. Aquat. Sci. 51:1506–1518.

Petitgas, P. 1993. Use of a disjunctive kriging to model areas of high pelagic fish density in acoustic fisheries surveys. Aquat. Living Resour., 6:201–209.

Rivoirard, J., J. Simmonds, K. G. Foote, P. G. Fernandes, and N. Bez. 2000. Geostatistics for estimating fish abundance. Oxford: Blackwell Science. 2006 pp.

Rocha, F., and V. M. Vega. 2003. Overview of the cephalopod fisheries in Chilean waters. Fish. Res. 60:151–159.

Roper, C., J. Sweeney, and C. Nauen. 1984. Cephalopods of the world (FAO species catalogue (vol 3), an annotated and illustrated catalogue of species of interest to fisheries. FAO Fish. Synop., 3(125):1–127.

Rufino, M. M., F. Maynou, P. Abelló, and A. B. Yule. 2004. Small-scale non-linear geostatistical analysis of *Liocarcinus depurator* (Crustacea: Brachyura) abundance and size structure in a western Mediterranean population. Mar. Ecol. Prog. Ser. 276:223–235.

Schmiede, P., and E. Acuña. 1992. Regreso de las jibias (*Dosidicus gigas*) a Coquimbo. Rev. Chil. Hist. Nat. 65:389–390.

Simard, Y., D. Marcotte, and G. Bourgault. 1993. Exploration of geostatistical methods for mapping and estimating acoustic biomass of pelagic fish in the Gulf of St. Lawrence: size of echo-integration unit and auxiliary environmental variables. Aquat. Living Resour. 6:185–199.

Simard, Y., D. Marcotte, and K. Naraghi. 2003. Three-dimensional acoustic mapping and simulation of krill distribution in the Saguenay–St. Lawrence Marine Park whale feeding ground. Aquat. Living Resour. 16:137–144.

Sparre, P., and S. C. Venema. 1997. Introducción a la evaluación de recursos pesqueros tropicales. Parte 1. Manual. FAO Documento Técnico de Pesca. N° 306.1 Rev. 2:420 pp.

Sullivan, P. J. 1991. Stock abundance estimation using depth-dependent trends and spatially correlated variation. Can. J. Fish. Aquat. Sci. 48:1691–1703.

Tafur, R., P. Villegas, M. Rabí, and C. Yamashiro. 2001. Dynamics of maturation, seasonality of reproduction and spawning grounds of the jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae) in Peruvian waters. Fish. Res. 54:33–50.

Taipe, A., C. Yamashiro, L. Mariategui, P. Rojas, and C. Roque. 2001. Distribution and concentrations of jumbo squid (*Dosidicus gigas*) off the Peruvian coast between 1991 and 1999. Fish. Res. 54:21–32.

Ulloa, P., M. Fuentealba, and V. Ruiz. 2006. Hábitos alimentarios de *Dosidicus gigas* (D' Orbigny, 1835)(Cephalopoda: Teuthoidea) frente a la costa centro-sur de Chile. Revista Chilena de Historia Natural. 79:475–479.

Wilhelm G., Ottmar. 1930. Las mortandades de jibias (*Omastrephes gigas*) en la Bahía de Talcahuano. Boletín Sociedad de Biología de Concepción (Chile) Tomo III y IV. Pág. 6-30.

Wilhelm, O. 1951. Algunas observaciones acerca de las mortandades de jibias (*Dosidicus gigas* d'Orbigny) en el litoral de Concepción. Rev. Biol. Mar. 4:196–201.

Wormuth, J. H. 1998. Workshop deliberations on the Ommastrephidae: A brief history of their systematics and a review of the systematics, distribution, and biology of the genera *Martialia* Rochebrune and Mabille, 1889, *Todaropsis* Girard, 1890, *Dosidicus* Steenstrup, 1857, *Hyaloteuthis* Gray, 1849, and *Eucleoteuthis* Berry, 1916. *In* Systematics and biogeography of cephalopods. Vol. I.,Voss, N. A., M. Vecchione, R. B. Toll, and M. J. Sweeney, eds. Smith. Contrib. Zool. 586 (II):373–383.