

## MANAGEMENT STRATEGY FOR THE GIANT SQUID (*DOSIDICUS GIGAS*) FISHERY IN THE GULF OF CALIFORNIA, MEXICO

AGUSTÍN HERNÁNDEZ-HERRERA

Centro de Investigaciones Biológicas del Noroeste, S. C.  
Evaluación y Manejo de Recursos, División de Biología Marina  
Km 1, Carretera San Juan de la Costa "El Comitan"  
Apartado Postal 128  
23000 La Paz, B.C.S.  
México  
ahndez@cibnor.mx

ENRIQUE MORALES-BOJÓRQUEZ

Centro Regional de Investigación Pesquera de la Paz  
Carretera a Pichilingue, km. 1  
23020 La Paz, B.C.S.  
México  
criplp@balandra.uabcs.mx

MIGUEL A. CISNEROS-MATA, MANUEL O. NEVÁREZ-MARTÍNEZ, AND GABRIEL I. RIVERA-PARRA

Centro Regional de Investigación Pesquera de Guaymas  
Calle 20-Sur 605  
85400 Guaymas, Sonora  
México  
cripgym@tetakawi.net.mx

### ABSTRACT

A single-cohort biomass model was developed for a management strategy using proportional escapement as a reference to control fishing effort for the giant squid (*Dosidicus gigas*) in the Gulf of California. Biological information (length and weight frequencies) and fishery statistics (catch and effort) from November 1995 to November 1996 for the commercial fleet were analyzed. The data showed the presence of one cohort of *D. gigas*, which recruited in May. This cohort supported the fishery throughout the year. Using a biomass estimate from a research cruise in the central area of the Gulf of California in October 1996, the model predicted the highest levels of abundance from October 1996 to January 1997. We suggest a proportional escapement, estimated from the point of maximum biomass, between 27% and 40%, with a remaining biomass of between 65,560 and 34,890 metric tons in May, a month in which a new recruitment can be expected in the fishery.

### INTRODUCTION

Giant squid (*Dosidicus gigas*) landings during 1996 in the Gulf of California exceeded 100,000 metric tons (t) live weight. In this fishery, there are three fishing fleets: one from Baja California Sur, and two from Sonora, Mexico. Landings by these fleets vary seasonally according to the availability of squid. Off Baja California Sur, fishing is done during spring and summer; in Sonora, during fall and winter. Increased catch of giant squid during the last year has caused an increase in fishing effort, a situation that should be analyzed to avoid damaging the squid population.

The dynamics of a single cohort can be analyzed by interpreting the combined effects of changes in the natural mortality ( $M$ ) and individual growth, given an ini-

tial recruitment ( $N_0$ ; Alverson and Carney 1975). In previous studies on squids (Rosenberg et al. 1990; Morales-Bojórquez et al. 1997) the management strategy was to determine the number of recruits at the beginning of the fishing season, their exploitation rate, and the stock size at the end of the fishing season.

The strategy we propose is to determine a proportional escapement useful for controlling the fishing effort. Proportional escapement is defined as the number of spawners alive at the end of the fishing season as a proportion of those that would have been alive had there been no fishing (Beddington et al. 1990; Basson and Beddington 1993; Nevárez-Martínez and Morales-Bojórquez 1997). We simulate growth of a cohort and, from the point of maximum biomass, establish a management strategy that considers an increment of the fishing effort and the proportional escapement.

### METHODS AND MATERIALS

#### Research Cruise

A biomass survey was done from the R/V *Lugo* from 9 to 29 October 1996 (LUGOCT). A total of 46 fishing operations covering 39 stations were made. The catch system consisted of an automatic device with jigs, and lighting. For each fishing operation, we recorded the initial and final position of the vessel, number of squid captured, fishing time, and time of illumination prior to the operation of the jigs. When the catch allowed it, 100 squid were measured, and 20 to 25 were selected at random for biological sampling; mantle length and weight, total weight, sex, and stage of maturity were recorded.

#### Abundance Estimation

We estimated the biomass of squid by the swept-area method, using total catch in weight (Pierce and Guerra 1994). To reduce the error of the estimate, we divided

the study area into five strata (fig. 1).

The biomass estimate was obtained as follows (Pierce and Guerra 1994):

$$B_T = \sum_{i=1}^n \left( Y_i \star \frac{A_i}{a_i} \right)$$

with variance

$$\hat{V}(B_T) = \sum_{i=1}^n \left( \frac{A_i^2 \star n_i \star s_i^2}{a_i^2} \right)$$

where  $B_T$  = total biomass;

$Y_i$  = total catch in the  $i$ th stratum;

$A_i$  = total area of the  $i$ th stratum;

$a_i$  = area swept in the  $i$ th stratum;

$s_i^2$  = variance of the catch of the  $i$ th stratum;

$n_i$  = number of fishing operations of the  $i$ th stratum.

The swept area at each station was defined as the drift of the vessel (nautical miles) multiplied by the distance of influence of the jigs (established arbitrarily as 10 m from the ship's hull).

### Biological Data and Fishery Information

Biological data were collected weekly in the port of Guaymas, Sonora, from November 1995 to November 1996. The information corresponded to commercial landings by the artisanal fleet (small boats with outboard motors, called *pangas*). We recorded length of the mantle (cm); weight of the mantle (kg); sex; and stages of maturity.

Weekly catch and effort statistics were obtained from the Subdelegación de Pesca of Guaymas. This information involved records of a fleet of shrimp trawlers adapted for squid fishing and an artisanal fleet of *pangas*.

### Biological Parameters

We analyzed a mantle length (ML) frequency distribution considering biweekly periods, and used the Bhattacharya method, available in FISAT v.1.0 (Gayaniilo et al. 1995), to separate cohorts. We then computed the parameters of the von Bertalanffy model for individual growth. The parameter values were optimized to get a best fit of the function  $(Y_{Obs} - Y_{Est})^2$ , where  $Y_{Obs}$  = observed length values and  $Y_{Est}$  = estimated length values (Hilborn and Walters 1992). The mantle length-mantle weight relation was also obtained. We used sample data to compute total numbers by interval of mantle length in the weekly landing at Guaymas (Sparre and Venema 1995).

The maturity stages were determined according to Lipinski (1995). Stages I (immature), II (in transition),

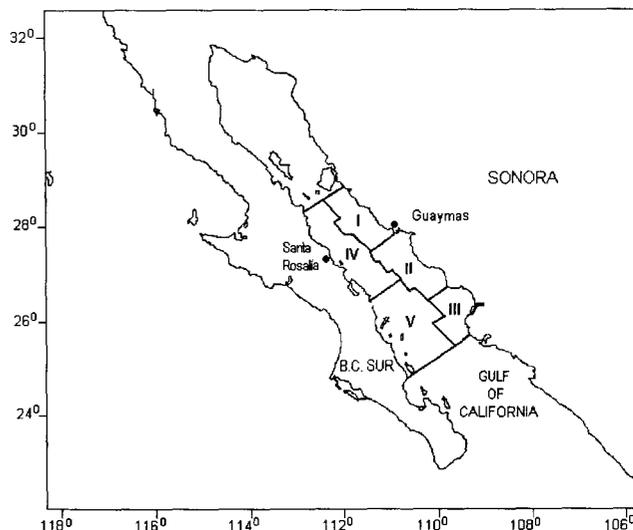


Figure 1. Study area divided into five strata according to the fishing grounds of the commercial fleets.

and VI (end of spawn) were grouped as not active for reproduction, whereas stages III (maturing), IV (mature), and V (spawning) were considered active for reproduction (Hernández-Herrera et al. 1996).

### Yield Analysis and Simulation

We did a virtual population analysis (VPA) by fortnight considering all age groups present in the length-frequency distribution (Pope 1972), using a value of terminal fishing mortality ( $F$ ) of 0.3, similar to the natural mortality value ( $M$ ) estimated by Morales-Bojórquez et al. (1997;  $M = 0.202$ /fortnight), and using estimates of fishing mortality rate ( $F$ ) and fishing effort ( $f$ ) for two different periods (Silliman 1943, cited in Ricker 1975). The initial population size ( $N_0$ ), corresponding to the size of the recruitment of *D. gigas* was thus determined.

We then used a modification of the model proposed by Alverson and Carney (1975) to explore growth and decay of a cohort. This model depends directly on the value on  $M$ ,  $k$ ,  $W_\infty$  and  $N_0$ . The expression is

$$P_t = N_0 \exp^{-M \star t} W_\infty (1 - \exp^{-k \star t})^\beta$$

where  $P_t$  = biomass of the population at time  $t$ ;  $N_0$  = initial recruitment;  $W_\infty$  = average individual weight at maximum length; and  $k$  = growth rate of the von Bertalanffy model. The modification considered incorporation of the fishing mortality ( $F$ ) according to the following:

$$P_t = N_0 \exp^{-[(M+F) \star t]} W_\infty (1 - \exp^{-k \star t})^\beta$$

In this expression, we optimized  $N_0$  with the solver tool of Microsoft Excel v. 7.0, minimizing the difference

between the direct estimate of population abundance and the population abundance calculated by the model for the corresponding fortnight. Because giant squid cannot live beyond two years,  $M$  was increased by 13% each fortnight for squid age 1 year and older. Otherwise it would appear that there is high abundance of squid larger than 80 cm mantle length in the Gulf of California, which is not the case. We optimized a biomass growth curve using an  $F$  value of 0.9 and used it as a reference to plot a family of curves for different  $F$  values, from  $F = 1$  to  $F = 1.5$ , with increments of 0.1. For each biomass trajectory, we calculated a  $K$  value as  $K = \exp^{(-F)}$  (Rosenberg et al. 1990).

Thus the management strategy was to determine an escapement level that would be useful in the control of fishing effort. This control could be implemented in two ways: by limiting the number of licenses, and by limiting the length of the fishing season (Beddington et al. 1990; Basson and Beddington 1993).

With the theoretical values of  $F$ , and according to the expression

$$f_{Est} = \frac{F}{q},$$

we estimated the calculated effort ( $f_{Est}$ ) in number of fishing nights for the adapted shrimp fleet by using  $q = 0.000429$  (Morales-Bojórquez et al. 1997). For the artisanal fleet, we standardized effort ( $f_{Sta}$ ) from  $f_{Est}$  by using a correction factor ( $F_c$ ). This was estimated as  $F_c = CPUE_{sr} / CPUE_{af}$ , where  $CPUE_{sr}$  is the mean catch per unit of effort of the shrimp fleet, and  $CPUE_{af}$  is the mean catch per unit of effort for the artisanal fleet. Hence,  $f_{Sta} = f_{Est} \star F_c$ .

## RESULTS

For the biomass survey, figure 1 shows the study area and five strata considered. The estimated total abundance of the population was 171,150 t ( $\pm 21,200$  t, 95% CI).

During the year of study, 1,934 individuals were sampled. Mantle lengths ranged between 24.3 and 86 cm, with an average of 58.6 cm. Analysis of the mantle length-frequency distribution showed one annual cohort (fig. 2), with a recruitment observed during May. Because the mantle lengths were measured biweekly, it was possible to estimate the age in years, every two weeks corresponding to 0.038 years. Thus squid recruited to the fishery at an estimated age of 6 months. The parameters of the von Bertalanffy growth model were:  $k = 0.8/\text{year}$ ;  $L_\infty = 87$  cm mantle length; and  $W_\infty = 0.013$  t mantle

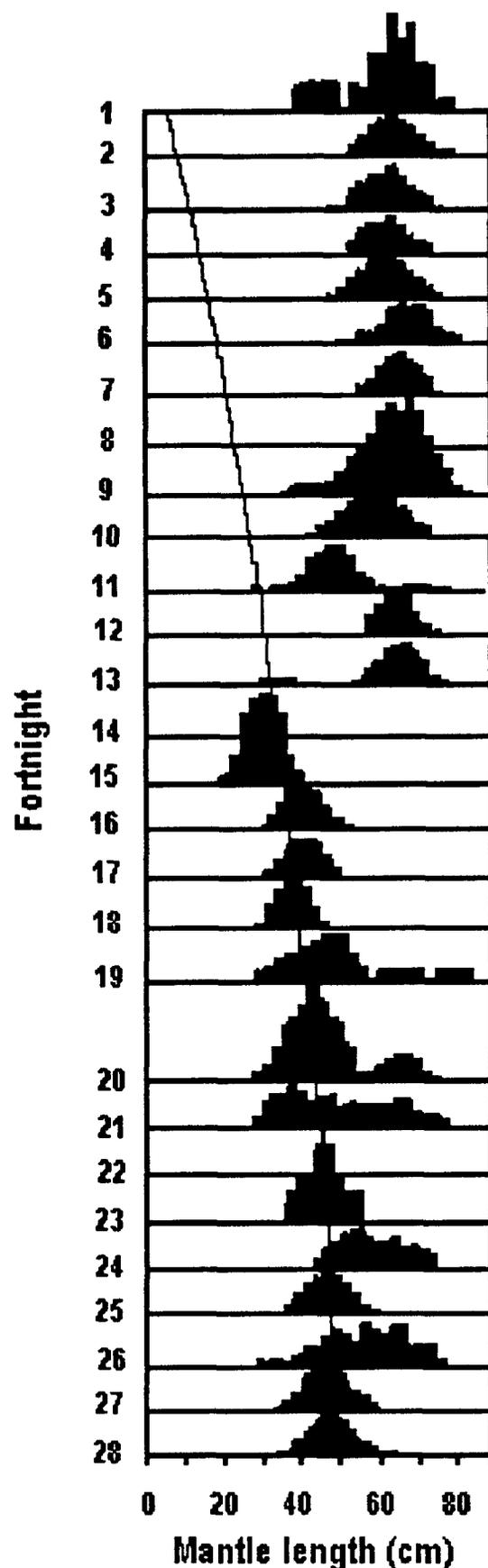


Figure 2. Progression modal analysis applied to mantle lengths (cm). Fortnight 1 is from 5 to 18 November 1995. Fortnight 28 is from 17 to 30 November 1996.

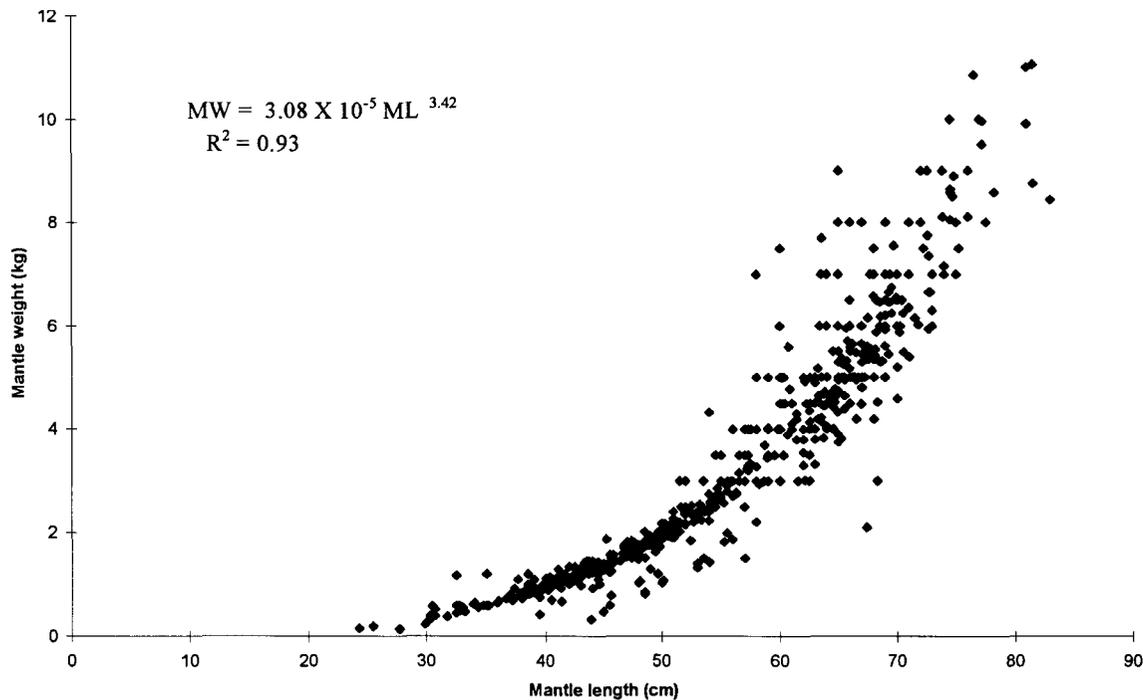


Figure 3. Mantle length (cm)—mantle weight (kg) relation for giant squid.

weight. Parameters of the length (L)—weight (W) relation for mantle were  $\alpha = 3.08 \times 10^{-5}$  and  $\beta = 3.42$  (fig. 3). The growth models in mantle length (ML) and mantle weight (MW) were

$$ML = 87 \times \{1 - \exp[-0.8 \cdot (t - 0.115)]\}$$

$$MW = 0.013 \times \{1 - \exp[-0.8 \cdot (t - 0.115)]\}^{3.42}$$

The stages of maturity showed that the spawning season lasts from February to May, with a relative frequency of active females greater than 90% during that period (fig. 4).

The estimate of  $N_0$  from virtual population analysis was  $386 \times 10^6$  individuals; the optimized value of  $N_0$  with respect to the estimate of abundance of the survey was  $303 \times 10^6$  individuals. The model to estimate biomass ( $t$ ) is

$$P_t = 303 \times 10^6 \exp^{-(0.202+F)t} 0.013(1 - \exp^{-0.8t})^{3.42}$$

Figure 5 shows (a) the biomass curve with constant natural mortality ( $M = 0.202/\text{fortnight}$ ), and (b) a biomass curve considering an increase in  $M$  from  $t = 1.076$  years and older. According to model a, squid will live longer than two years, and the maximum yield will occur from fortnight 20 to fortnight 30. According to model b, maximum yield of approximately 190,000 t occurs from fortnight 12 to fortnight 18, whereas the remaining biomass for fortnight 27 was 65,560 t, when a new recruitment could be expected.

Figure 6 shows the trajectories of biomass with different levels of  $F$ . Table 1 shows the estimates of  $K$ ,  $f_{EST}$ ,  $f_{Sta}$ , and the remaining biomass for each value of theoretical  $F$ .

## DISCUSSION

The annual mantle length—frequency analysis for the fishing grounds off Guaymas showed evidence of only one cohort with an annual recruitment. This recruitment was observed during May, when squid were 6 months old, corresponding to mantle lengths between 24 and 50 cm. During this period squid were actively reproducing off Guaymas, as described by Hernández-Herrera et al. (1996).

We assumed that recruitment observed in May was the most important, and that it sustains the squid fishery during the fishing season. This recruitment could be the result of a spawn at another time and in another area within or outside the Gulf of California. Ehrhardt et al. (1983) observed mature squid in December and January off the Pacific coast of the Baja California Peninsula, suggesting that this spawning event is of great importance because it generates the squid that recruit to the fishery from March to April and support the fishery from May to September, when fishing effort increases due to the presence of the shrimp fleet. Ehrhardt et al. (1983) also observed high percentages of mature females in May and June, which agrees with our observations

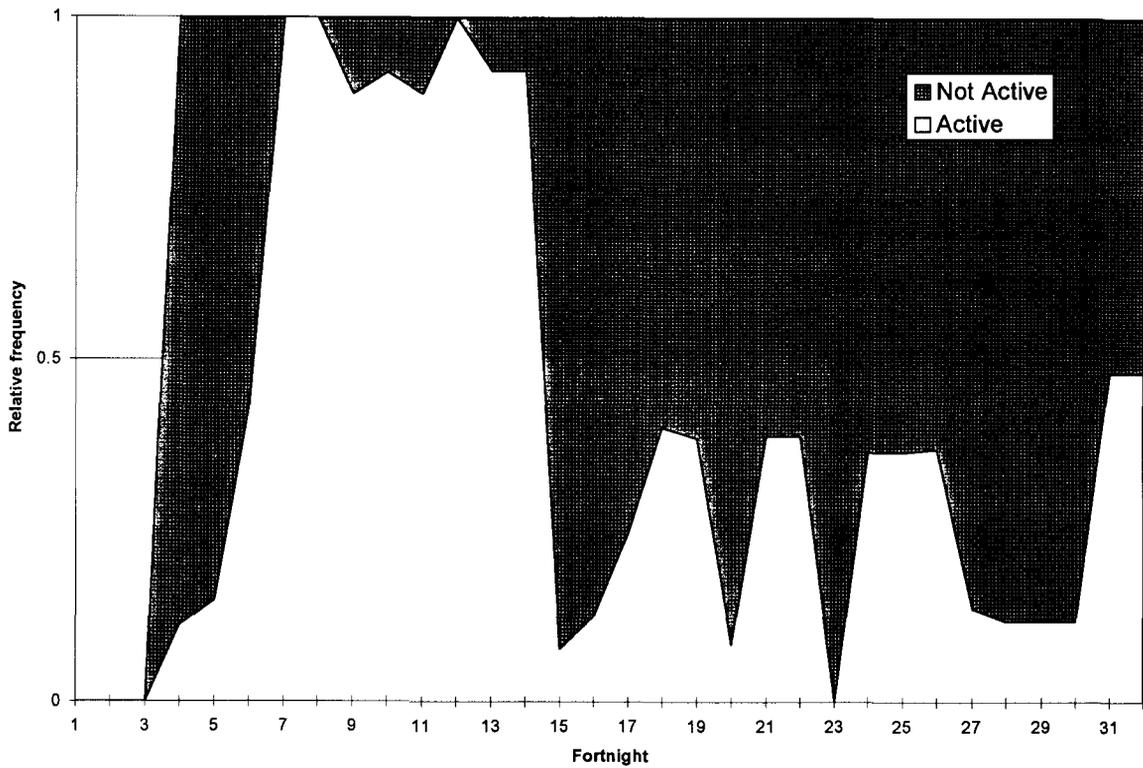


Figure 4. Proportion of females not active and active for reproduction. Not active were maturity stages immature (I), in transition (II), and final spawning (VI). Active stages were maturing (III), mature (IV), and spawning (V). Fortnight 1 is from 5 to 18 November 1995. Fortnight 32 is from 12 to 25 January 1997.

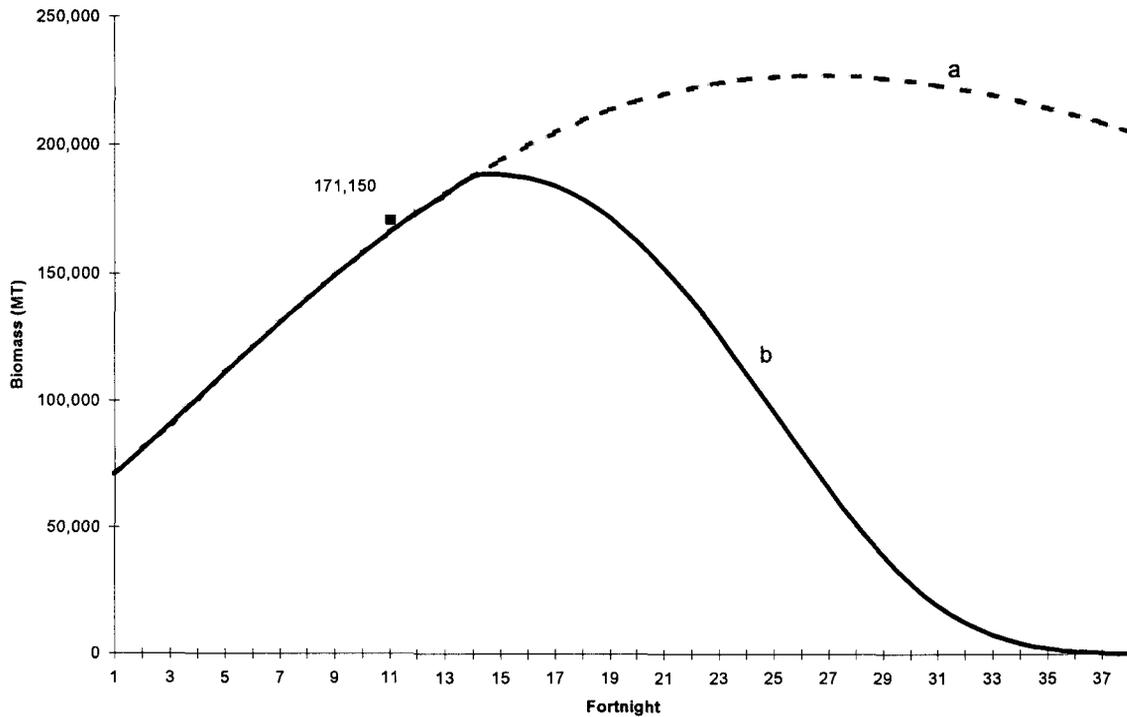


Figure 5. Biomass trend of giant squid: a, constant natural mortality; b, with an increment in natural mortality of 13% into each new instant of time  $t$  from  $t = 1.076$  years. The value of 171,150 metric tons corresponded to the biomass estimation aboard the R/V *Lugo*. Fortnight 1 is from 19 May to 1 June 1996. Fortnight 38 is from 19 October to 1 November 1997.

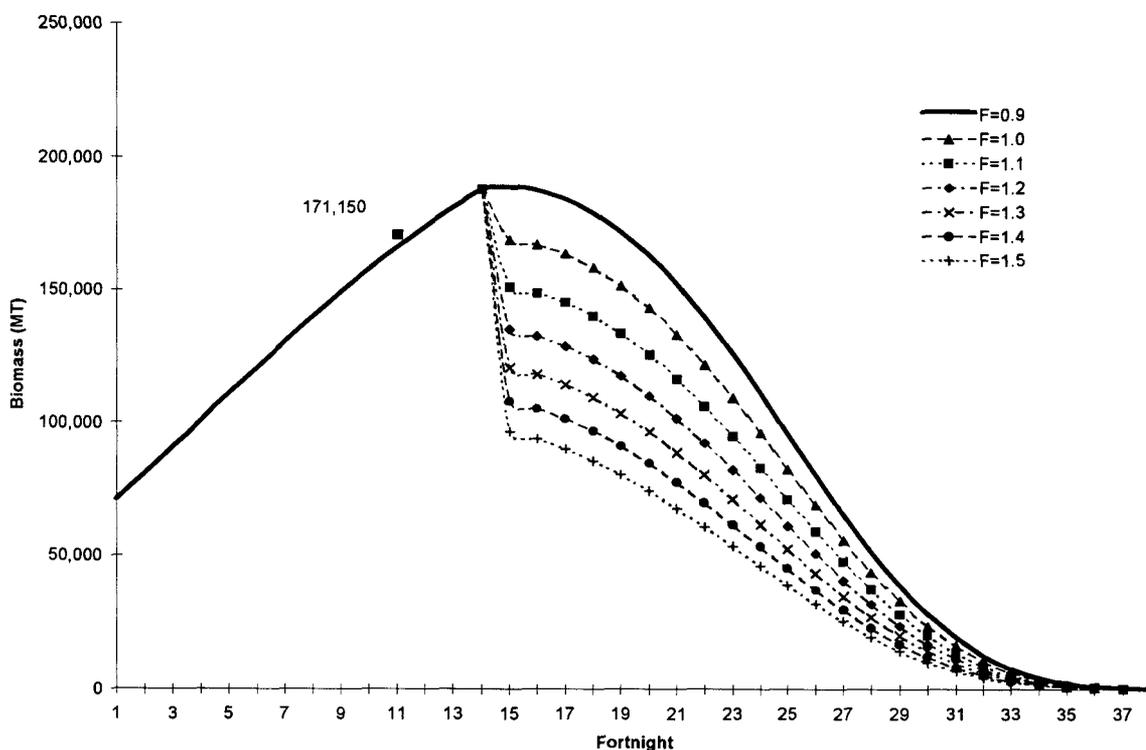


Figure 6. Biomass curves estimated with different levels of fishing mortality from 0.9 to 1.5. The value of 171,150 metric tons corresponded to the biomass estimation aboard the R/V *Lugo*. Fortnight 1 is from 19 May to 1 June 1996. Fortnight 38 is from 19 October to 1 November 1997.

TABLE 1  
 Management Scenarios at Different Levels of Fishing Mortality and Proportional Escapement

<i>F</i>	<i>K</i>	$f_{Est}$	$f_{Sta}$	Remaining biomass (t) at fortnight 27
0.9	0.407	2,096	4,192	65,560
1.0	0.368	2,329	4,658	56,000
1.1	0.333	2,562	5,124	47,830
1.2	0.301	2,795	5,590	40,850
1.3	0.273	3,028	6,056	34,890
1.4	0.247	3,261	6,522	29,800
1.5	0.223	3,494	6,988	25,450

near Guaymas during 1996. We therefore conclude that spring spawning generates individuals that eventually recruit to the fishery in September. But our observations off Guaymas do not support a second recruitment in autumn, although it is possible that this occurs in a different area. Another possibility is that in 1996 this recruitment was not successful.

Disregarding the possibility of a second recruitment to the fishery, the single-cohort model with a constant *M* (fig. 5a) assumed that squid live longer than two years, something that was not observed in the field. However, the single-cohort model with a variable *M* (fig. 5b) produced a maximum yield from fortnight 12 to fortnight 18; after that, the value of *K* was defined. Compared to the study of Rosenberg et al. (1990), in our study the

proportional escapement was not estimated directly from the initial recruitment, but from the time when the maximum computed biomass was observed. The model allowed us to construct a family of curves that simulated the decay of the cohort from the maximum value of biomass estimate with variations of *F* (fig. 6) that also correspond to an increment in the fishing effort due to the end of the shrimp fishing season. The *K* values decreased from a value of 40% as *F* increased. This was then observed in the remaining adult biomass.

Our observations indicated that variations of *K* between 27% and 40% would allow an escapement of adult biomass between 34,890 and 65,560 t in May, when biomass could increase after a new recruitment. The choice of values of *K* was arbitrary because a stock-recruitment relation for giant squid is yet unknown (Beddington et al. 1990; Rosenberg et al. 1990). However, escapement and optimal effort levels were computed relative to maximum biomass, when fishing is directed to adults that possibly have already reproduced, and not at the moment of recruitment.

In the giant squid fishery, there are two risks in management decisions. The first includes fishing without a license, changes in catchability, selectivity, and accessibility to the fishing fleets. The second risk includes factors related to the biology of squid: changes in *M* due to migration (Ehrhardt et al. 1983; Klett 1996) and re-

production (Hernández-Herrera et al. 1996). Any change in these factors affects the estimation of  $K$  and consequently the size of the estimated recruitment for the next fishing season (Basson and Beddington 1993).

## ACKNOWLEDGMENTS

We thank Araceli Ramos, Everardo Miranda, and Alejandro Balmori, of Centro Regional de Investigación Pesquera de Guaymas, for support in obtaining biological and statistical data on giant squid. Camara Nacional de la Industria Pesquera (CANAINPES) provided partial funding for the survey cruise. Ellis Glazier, CIBNOR, S. C., edited the English version of this work in manuscript form.

## LITERATURE CITED

- Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. *J. Cons. Int. Explor. Mer* 36(2):133-143.
- Basson, M., and J. R. Beddington. 1993. Risk and uncertainties in the management of a single cohort squid fishery: the Falkland Islands *Illex* fishery as an example. In *Risk evaluation and biological reference points for fisheries management*, S. J. Smith, J. J. Hunt, and D. Rivard, eds. *Can. Spec. Publ. Fish. Aquat. Sci.* 120, pp. 253-259.
- Beddington, J. R., A. A. Rosenberg, J. A. Crombie, and G. P. Kirkwood. 1990. Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Islands waters. *Fish. Res.* 8:351-365.
- Ehrhardt, N. M., P. S. Jacquemin, F. García, G. González, J. M. López, J. Ortiz, and A. Solís. 1983. On the fishery and biology of the giant squid *Dosidicus gigas* in the Gulf of California, Mexico. In *Advances in assessment of world cephalopods resource*, J. F. Caddy, ed. *FAO Fish. Tech. Pap.* (231), pp. 306-340.
- Gayanilo, F. C., Jr., P. Sparre, and D. Pauly. 1995. The FAO-ICLARM stock assessment tools (FISAT) user's guide. *FAO Computerized Information Series* (8), 126 pp.
- Hernández-Herrera A., E. Morales, M. O. Nevárez, A. Balmori, and G. I. Rivera. 1996. Distribución de tallas y aspectos reproductivos del calamar gigante (*Dosidicus gigas*, D'Orbigny, 1835) en el Golfo de California, México. *Ciencia Pesquera* 12:85-89.
- Hilborn, R., and C. J. Walters. 1992. *Quantitative fisheries stock assessment. Choice, dynamics and uncertainty*. New York: Chapman and Hall, 572 pp.
- Klett, A. 1996. Pesquería del calamar gigante *Dosidicus gigas*. In *Estudio del potencial pesquero y acuícola de Baja California Sur. Vol. I.*, M. Casas-Valdéz, and G. Ponce-Díaz, eds. CIB-CICIMAR-UABCS, pp. 127-149.
- Lipinski, M. 1995. Sexual maturation in squid: quantum or continuum? *S. Afr. J. Mar. Sci.* 15:207-223.
- Morales-Bojórquez, E., A. Hernández, M. O. Nevárez, J. Díaz de León, G. I. Rivera, and A. Ramos. 1997. Abundancia poblacional del calamar gigante (*Dosidicus gigas*) en las costas de Sonora, México. *Oceanides* 12(2): 90-96.
- Nevárez-Martínez, M. O., and E. Morales-Bojórquez. 1997. El escape proporcional y el uso del punto de referencia biológico  $F_{\%BR}$ , para la explotación del calamar gigante, *Dosidicus gigas*, del Golfo de California. *Oceanides* 12(2):97-105.
- Pierce, G. J., and A. Guerra. 1994. Stock assessment methods used for cephalopod fisheries. *Fish. Res.* 21:255-285.
- Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. *Int. Comm. Northwest Atl. Fish. Res. Bull.* 9:65-74.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* 191, 382 pp.
- Rosenberg, A. A., G. P. Kirkwood, J. A. Crombie, and J. R. Beddington. 1990. The assessment of stocks of annual squid species. *Fish. Res.* 8:335-350.
- Sparre, P., and S. C. Venema. 1995. *Introducción a la evaluación de recursos pesqueros tropicales. Parte I. Manual. FAO Documento Técnico de Pesca.* No. 306.1 Rev. 1, 440 pp.