

## Population size and exploitation of giant squid (*Dosidicus gigas* D'Orbigny, 1835) in the Gulf of California, Mexico\*

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**SUMMARY:** The most important landing sites of the giant squid (*Dosidicus gigas* D'Orbigny, 1835) fishery in the Gulf of California, Mexico are Guaymas, in Sonora and Santa Rosalía, in Baja California Sur. An increase in the species biomass resulted in increased landings, ranging from 6, 200 tons in 1994 to 140,000 tons in 1996. The development of a management strategy for this fishery based on the proportional escapement has been suggested. This necessitates the estimation of the population size when the fishing season begins in order to determine the amount of fishing effort. Weekly catch and effort data were reported from October 1995 to March 1996 for three fleets operating in the Gulf of California. The population size estimated using a maximum likelihood model was 82,000 tons with a proportional escapement of 66%.

**Key words:** recruitment, likelihood, multifleet model, proportional escapement.

### INTRODUCTION

The giant squid fishery in the Gulf of California (Fig. 1) began in 1974 with a small artisanal fleet composed of small boats called "pangas" using out-board motors with a crew of two fishermen using hand jigs. This fleet fished two to three months during the summer when the stock was near the coast. The production was small and the catch was consumed locally (Ehrhardt *et al.*, 1983).

In 1978, part of the shrimp trawler fleet of the Gulf of California was devoted to the giant squid fishery during the summer months, fishing with six to ten fishermen with hand jigs per vessel. High abundance of squid was recorded from 1979 to 1981 (Fig. 2). This promoted the involvement of three fishing fleets, a vessel fleet comprising 285 shrimp trawlers of various characteristics with six to ten fishermen with hand jigs, 15 Japanese vessels with an automatic jigging system, and a small artisanal fleet with two fishermen using hand jigs.

\*Received January 18, 2000. Accepted September 19, 2000.

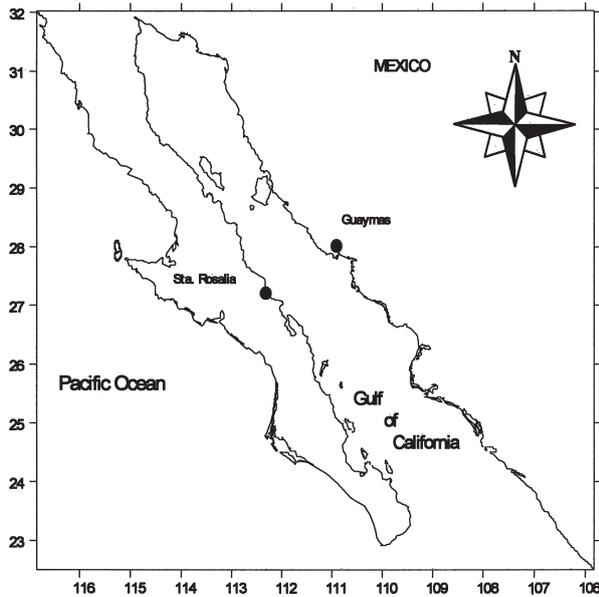


FIG. 1. – Study zone in the Gulf of California, Mexico.

Between 1983 and 1987, the fishery disappeared because the abundance of the stock was reduced (Fig. 2). The causes of the collapse were not defined, but a relation between recruitment overfishing and unfavorable environmental conditions associated to “El Niño” 1982-1983 were assumed (Klett, 1996). From 1989 to 1992, some exploratory squid fishing was carried out by a fleet of six Japanese vessels equipped with automatic jigging system. During 1995 an increase in squid abundance was observed. In 1996 a catch above 140,000 tons was obtained by three fleets (fig. 2) which were composed respectively of 150 shrimp trawlers from Sonora with six to ten fishermen using hand jigs (subsequently called “vessel fleet”), and two artisanal fleet of 646 pangas from Baja California Sur and 342 pangas from Sonora.

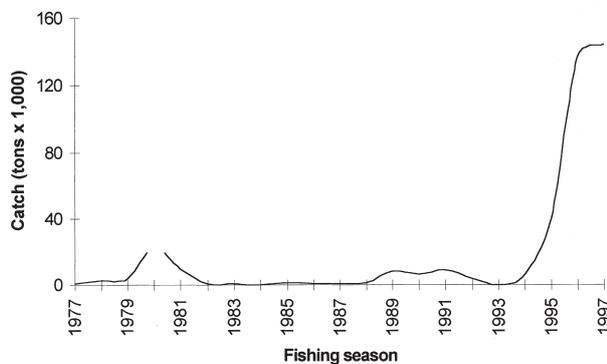


FIG. 2. – Landing records of *Dosidicus gigas* from Sonora and Baja California Sur, México.

During fishing seasons previous to collapse, the biomass estimations for the determination of the potential catch were based on virtual population analysis (Ehrhardt *et al.*, 1983), and analysis of survey data in the Gulf of California (Klett, 1996). Subsequently, Morales-Bojórquez *et al.* (1997) conducted an evaluation of the stock, using the DeLury depletion model and catch equation, whereas Nevárez-Martínez and Morales-Bojórquez (1997) determined the biological reference point (BRP) for the giant squid fishery based on the proportional escapement. Recently a single cohort biomass model was developed for the management of giant squid fishery in the state of Sonora, using proportional escapement as a reference to control fishing effort for giant squid (Hernández-Herrera *et al.*, 1998).

In the present study an estimation of the initial recruitment of the giant squid in the Gulf of California, Mexico is calculated, based on the analysis of catch per unit effort data from Santa Rosalía B. C. S. and Guaymas, Sonora, México. Between these two fishing grounds 90% of the total landings is recorded. In this way the implications for management of the resource were determined.

## MATERIAL AND METHODS

Weekly catch (tons) and effort (fishing nights) data were reported during the period October 22, 1995 to March 30, 1996. These records were obtained from three different fleets fishing simultaneously in the Gulf of California using hand jigs as fishing gear. The landing port for two of them, an artisanal and a vessel fleet, is Guaymas, whereas for the other (an artisanal fleet), Santa Rosalía. The catch in weight per week was converted to catch in number of individuals per week, using the average individual weight per week (Hernández-Herrera *et al.*, 1998).

The following multifleet model described by Rosenberg *et al.* (1990) was used:

$$N_t = (N_{t-1}e^{-M/2} - C_{t-1})e^{-M/2} \quad (1)$$

Where  $N_t$  = Population size at time  $t$ ,  $C_t$  = Total catch of all the fleets in the fishery during that period of time, and  $M$  = Natural mortality. The expression in terms of the initial recruitment is as follows:

$$N_t = N_0e^{-tM} - e^{-M/2} \sum_{i=0}^{t-1} C_i e^{-(t-i-1)M} \quad (2)$$

$N_0$  = recruitment in the beginning of the fishing season. This expression showed the size of the population as the number of individuals that survive the natural mortality, minus those individuals captured. The lower limit of the recruitment for a sustainable yield is expressed as:

$$N_0 \geq e^{-M/2} \sum_{i=0}^{t-1} C_i e^{-(t-i)M} \quad (3)$$

Which means, that the initial recruitment must be at least equal to the sum of the catches.

The estimate of the initial recruitment was obtained using a maximum likelihood model ( $L$ ) considering the interaction of different fleets according to the following expression (Rosenberg *et al.*, 1990; Pierce and Guerra, 1994):

$$\ln(L) = K - \frac{T}{2} \sum_{j=1}^J \ln \sigma_j^2 - \frac{1}{2} \sum_{j=1}^J \sigma_j^{-2} \sum_{t=1}^T (C_{jt} - q_j f_{jt} N_t \exp^{-M/2})^2 \quad (4)$$

In this model, it is assumed that catch is derived from a known effort series ( $f$ ). Effort from representative groups of the participating fishing fleets can be used as indicators and not necessarily the total effort of all the vessel. However, catch per unit effort (CPUE) is assumed to be directly proportional to the abundance of the stock during this period of time (Rosenberg *et al.*, 1990).

The maximum likelihood model was derived assuming that the catch obtained by each fleet is distributed normally with mean =  $q_j f_{jt} N_t \exp^{-M/2}$  and variance =  $\text{var}(C_{jt}) = \sigma_j^2$ . The unknown variables to be estimated are  $N_0$ ,  $q_j$  ( $j = 1, 2, \dots, J$ ), and  $\sigma_j^2$  ( $j = 1, 2, \dots, J$ );  $j$  indicates the number of fleets in the fishery and  $t$  = time in weeks ( $t = 1, 2, \dots, T$ ). Thus all the  $N_t$  can be expressed in terms of  $N_0$  (For details to see Appendix I).

To compute  $q$  of the artisanal fleet of Guaymas and Santa Rosalía, previous estimates of  $M$  (0.101 per week; Hernández-Herrera *et al.*, 1998) and of  $q$  ( $4.29 \text{ E-}4$ ; Morales-Bojórquez *et al.*, 1997) for the adapted shrimp fleet of Guaymas were used (Appendix II). These values were used as fixed parameters in the multifleet model.

The stock exploitation by the vessel fleet was considered to be representative of the whole population, because of the wide coverage of fishing grounds within the Gulf of California (Guaymas and Santa Rosalía) by the fleet.

The proportional escapement ( $K$ ) was estimated per week as follows:  $K = \exp^{-F}$  (Beddington *et al.*,

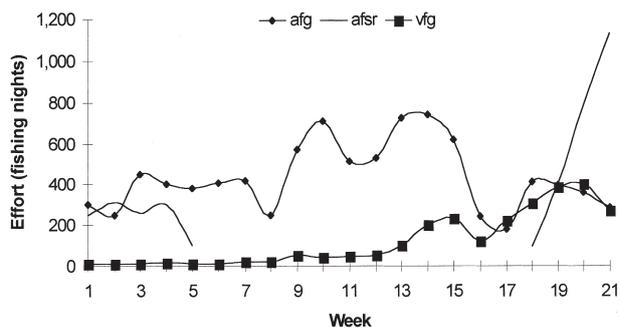


FIG. 3. – Variation in fishing effort observed, vfg = vessel fleet in Guaymas, afg = artisanal fleet in Guaymas, afsr = artisanal fleet in Santa Rosalía.

1990), where  $F$  = Fishing mortality. In this study, the conservative level of target escapement  $K = 40\%$ , was used as recommended by Rosenberg *et al.* (1990).

## RESULTS

Effort and its trend during the study period varied greatly between the three fleets (Fig. 3). The effort of the vessel fleet showed a slow increase until week 13 and subsequently varied between 50 to 400 fishing nights/week. The effort of the artisanal fleet of Guaymas was rather erratic until week 14 showing a decreasing effort toward the end of the period. The activity of the artisanal fleet of Santa Rosalía was interrupted for several weeks due to changes in the availability of the resource. During this period, giant squid are concentrated principally off the coast of Guaymas. However, from week 18, effort increased dramatically from 100 to 1000 fishing nights/week in only four weeks.

CPUE for the vessel fleet showed a peak of 47 tons, followed by a sharp decline the next 4 weeks

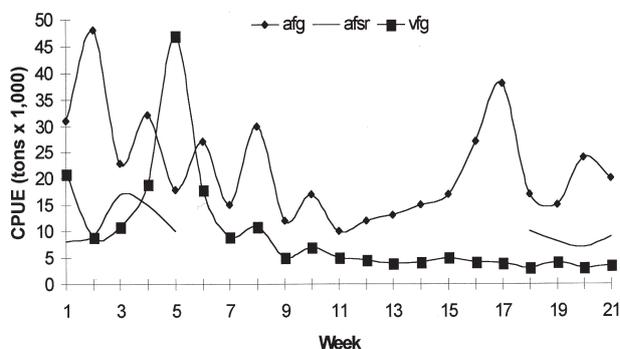


FIG. 4. – Trends of the catch per unit effort (CPUE) by fleet in the Gulf of California, Mexico, vfg = vessel fleet in Guaymas, afg = artisanal fleet in Guaymas, afsr = artisanal fleet in Santa Rosalía.

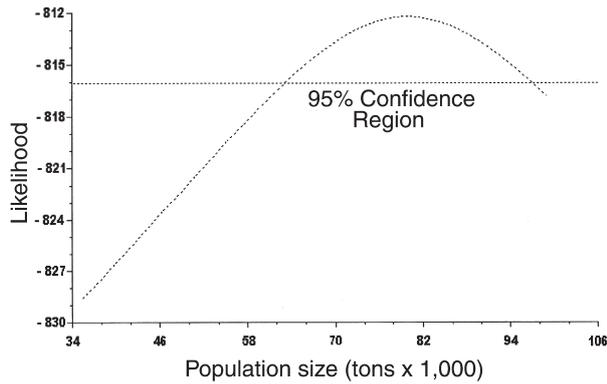


FIG. 5. – Population size estimated in the Gulf of California, Mexico.

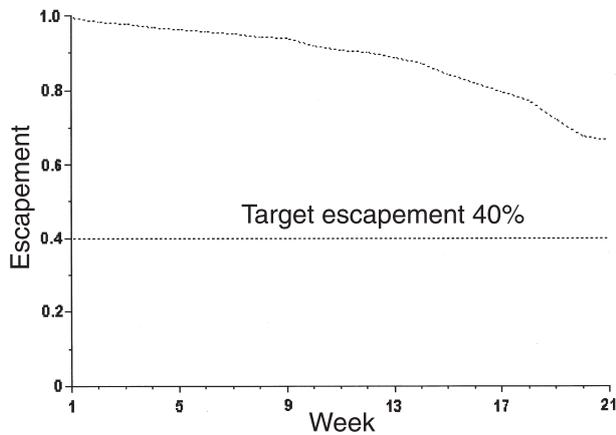


FIG. 6. – Trend of the proportional escapement during 21 weeks.

and the remained quite stable in 4 tons/vessel/week. The CPUE of the artisanal fleet of Guaymas varied between 48 and 10 tons/panga/week. CPUE of the artisanal fleet of Santa Rosalía was smaller, between 17 and 7 tons/panga/week (Fig. 4), while no clear pattern was defined, due to the scarcity of the data.

The biomass estimate of giant squid was 82,000 tons, with a range of 63,000 and 97,000 tons (95% CI) (Fig. 5). The catchability was  $1.486 \text{ E-}5$  (*s.d.*  $1.857 \text{ E-}6$ ) for the artisanal fleet of Guaymas and  $q = 6.432 \text{ E-}6$  (*s.d.*  $2.035 \text{ E-}6$ ) for that of Santa Rosalía. During 21 fishing weeks the proportional escapement decreased to a final value of 66%, higher than the 40% used as a reference in the fishery (Fig. 6).

## DISCUSSION

Catch and effort data of three squid fleets were used to estimate giant squid biomass. Our estimate does not differ from that of Morales-Bojórquez *et al.*

(1997) for the same period using only data from two fleets from Guaymas, Sonora. This is because the distribution of squid is principally off the coast of Guaymas, therefore, squid were not available to the artisanal fleet of Santa Rosalía during 12 weeks in the winter. The evolution of the CPUE for the vessel fleet reflects the trend of biomass of *D. gigas* in the Gulf of California. Weekly variations of CPUE in the artisanal fleet of Guaymas are due to movements of squid within the fishing ground, rather than to the vessels accessibility problems. According to some observations made during a survey carried out in 1996, 1997 and 1998 zones with high concentration of *D. gigas* have been shown between Santa Rosalía and Guaymas, whereas no catch was recorded South of Loreto, B.C.S, and Yavaros, Sonora. In this case, the squid fishery is developed principally between Santa Rosalía and Guaymas (Nevárez-Martínez *et al.*, 2000).

Rosenberg *et al.* (1990) showed, with CPUE data, the possibility of applying a management strategy for squid fisheries using the proportional escapement as a tool for the control of the fishing effort. They suggested two alternative management options: a) Limiting the number of licenses and determining allowable levels of effort prior to the start of the fishing season, or b) Limiting the length of the fishing season, monitoring the stock during the fishing season, and determining whether the fishing season needs to be shortened (Basson and Beddington, 1993; Beddington *et al.*, 1990; Rosenberg *et al.*, 1990). Proportional escapement is considered as a valuable tool for a management strategy if this value is directly related to a biological reference point (Nevárez-Martínez and Morales-Bojórquez, 1997). It is more reliable than to avoid recruitment overfishing, which is defined as the level of fishing pressure that reduces the spawning biomass produced by a year class over its lifetime below the spawning biomass of its parents. Recruitment overfishing, implies exploitation of fishery resource at such an intensive level that compensatory stock responses are insufficient to maintain a normal pattern of recruitment (Overholtz *et al.*, 1986; Sissenwine and Shepherd, 1987).

Some biological reference points used to avoid recruitment overfishing are: a)  $F_{\max}$  defined as the fishing mortality rate that maximizes yield per recruit, b)  $F_{\text{msy}}$  defined as the fishing mortality rate at an equilibrium condition, c)  $F_{0.1}$ , which corresponds to the point at which the yield per marginal

recruit with an increase of the fishing effort beyond 0.1 will not increase in any important way the yield derived from fishing (Gulland, 1983), and d)  $F_{rep}$  defined as the mortality rate by fishing that corresponds to an average replacement level of the population. In principle, a good biological reference point must consider: a) intrinsic biological aspects of the population, b) the variability induced by the environment, and c) the error within the estimate (Walters and Ludwig, 1981). In the case of the giant squid fishery, Nevárez-Martínez and Morales-Bojórquez (1997) used as BRP  $F_{\%SB}$  which is the fishing mortality that allows survival of a certain percentage of the spawning biomass (SB) (Caddy and Mahon, 1995).

Rosenberg *et al.* (1990) defined the 40% target proportional escapement as an adequate level for the conservation of the spawning stock of the squid *Illex argentinus* off the Falkland islands. This policy is considered also in other squid fisheries in the world (Beddington *et al.*, 1990). The goal of this management strategy is to allow an escapement value of adults such that the probability of a low recruitment is reduced (Rosenberg *et al.*, 1990; Beddington *et al.*, 1990). In our case, a final escapement of 66% at week 21 was estimated, which is higher than the objective of management.

The estimate of recruitment is important to decide the number of fishing licenses. Morales-Bojórquez *et al.* (1997) and Hernández-Herrera *et al.* (1998) showed that the squid fishery is supported by one cohort with a recruitment in May. For proper management, we must consider that the size of recruitment can vary considerably from one year to another. Moreover, the number of licenses must also consider the effort and the efficiency of the fleets. Thus, recruitment estimates will allow to amend problems associated with changes in the efficiency of the fleets, principally variations in the catchability (Basson *et al.*, 1996) or in the fishing power (Rosenberg *et al.*, 1990; Basson and Beddington, 1993).

## ACKNOWLEDGEMENTS

We thank Araceli Ramos, Everardo Miranda and Alejandro Balmori, of Centro Regional de Investigación Pesquera de Guaymas, for their support in obtaining statistical data on giant squid. Ellis Glazier, CIBNOR, S. C., edited the English version of this work in manuscript form.

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## APPENDIX I

The catchability coefficients and variances can be expressed as functions of the estimated initial population size according to Rosenberg *et al.* (1990):

$$\sigma_j^2 = \frac{1}{T} \sum_{t=1}^T (C_{jt} - q_j f_{jt} N_t \exp^{-M/2})^2 \quad \text{A1}$$

$$q_j = \frac{\sum_{t=1}^T C_{jt} f_{jt} N_t \exp^{-M/2}}{\sum_{t=1}^T (f_{jt} N_t \exp^{-M/2})^2} \quad \text{A2}$$

$$\sum_{j=1}^J \frac{1}{\sigma_j^2} \sum_{t=1}^T (C_{jt} - q_j f_{jt} N_t \exp^{-M/2}) q_j f_{jt} \exp^{-(t-0.5)M} = 0 \quad \text{A3}$$

Equation A3 cannot be solved analytically; however, it is possible to maximize the set equations for  $N_0$  (Rosenberg *et al.*, 1990).

## APPENDIX II

The estimation of catchability for shrimp trawler fleet was using a modification of the Leslie analysis proposed by Rosenberg *et al.* (1990) in accord with the next model:

$$CPUE_t = qN_0 \exp^{-(t+0.5)M} - q \sum_{i=0}^{t-1} C_i \exp^{-(t-1)M} \quad \text{A4}$$

In this model the independent variable is:

$$\sum_{i=0}^{t-1} C_i \exp^{-(t-1)M} \quad \text{A5}$$