ESTIMATIONS OF CATCHABILITY-AT-LENGTH FOR THE JUMBO SQUID (*DOSIDICUS GIGAS*) FISHERY IN THE GULF OF CALIFORNIA, MEXICO

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ABSTRACT

In this paper, we used the deterministic model of catchability (DMC) for the jumbo squid (*Dosidicus gigas*) fishery. The DMC assumes that catchability depends on length as well as on squid behavior. We analyzed the variation in the catchability coefficient (q) of *D. gigas* from the Gulf of California, Mexico, based on population length-structured data (mantle length = ML) expressed as CPUE from 5 November 1995 to 16 November 1996. The results showed two patterns: (1) low catchability for 19–27 cm, 43–49 cm, and 57–63 cm of ML; and (2) high catchability for 29–33 cm, 53–57 cm, and 65–71 cm of ML. This variation in catchability-at-length was explained by an overlap of two cohorts dominant in a recruitment period in May 1996. The catchability coefficient showed an overlap of cohorts. We found three peaks of catchability with approximately the same value ($q \approx 0.7 \times 10^{-3}$). These high values of catchability for 29–33 cm, 53–57 cm, and 65–71 cm of ML showed that these intervals have the same vulnerability. Although we recognize a dominant cohort in the fishery, the catchability estimates suggest the presence of three cohorts, since catchability is similar among intervals.

INTRODUCTION

Managers commonly use catch-per-unit-of-effort (CPUE) methods for estimating population size and catchability coefficients in squid fisheries, because these parameters are key in the exploitation. The objective for squid fisheries is to establish a management strategy that involves a limited fishing effort (licenses) and an estimation of the proportional escapement. Stock assessment for the jumbo squid (*Dosidicus gigas*) fishery has used models reviewed by Rosenberg et al. (1990) and Beddington et al. (1990), particularly the depletion model of Delury and the multifleet model (Morales-Bojórquez et al. 1997; Morales-Bojórquez, Hernández-Herrera et al. 2001).

In the Gulf of California, survey data have made it possible to tune a biomass model that includes the growth and decay of a single cohort (Alverson and Carney 1975; Hernández-Herrera et al. 1998). For jumbo squid, CPUE has been used as an index of abundance in the fishery, assuming a constant catchability during the fishing season (Morales-Bojórquez et al. 1997; Nevárez-Martínez and Morales-Bojórquez 1997; Hernández-Herrera et al. 1998). This assumption is a risk factor in the stock assessment and management of the fishery, especially if CPUE data are measured with error (Hilborn and Walters 1992).

The stock assessment for the jumbo squid fishery uses a deterministic model assuming a CPUE index without error (Nevárez-Martínez and Morales-Bojórquez 1997). The management strategy has been based on the estimation of proportional escapement (Rosenberg et al. 1990; Nevárez-Martínez and Morales-Bojórquez 1997; Morales-Bojórquez, Hernández-Herrera et al. 2001). The control mechanism is the limiting of the number of licenses before the start of the fishing season (Basson and Beddington 1993; Hernández-Herrera et al. 1998). In this management approach, recruitment and the constant catchability coefficient are the main sources of uncertainty and risk.

Basson and Beddington (1993) have analyzed the variation in recruitment in detail. However, analysis of catchability in one fishing season using time-series CPUE is usually made under the assumption that catchability remains constant (Atran and Loesch 1995; Tanaka 1997). Some mechanisms that may cause variability in catchability are sensory capabilities and behavioral response of the target species (Penn 1975); environmental factors (Hill 1985); stock area and the relative distribution of fish and fishing (Winters and Wheeler 1985); stock abundance (MacCall 1976; Martínez-Aguilar et al. 1997);

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density-dependent effects and differences between fleets (Arreguín-Sánchez 1996; Arreguín-Sánchez and Pitcher 1999); and schooling behavior (Ye and Mohammed 1999).

The variation in catchability is the greatest source of error in stock assessment methods based on CPUE data (Ricker 1975; Hilborn and Walters 1992; Atran and Loesch 1995; Ye and Mohammed 1999). Gould et al. (1997) and Gould and Pollock (1997) have evaluated the error of catch and effort data, analyzing changes in the catchability coefficient and recruitment using catch-effort regression methods. They show that, in most cases, errors in catch and effort data have inflated the parameter estimates.

In squid fisheries, changes in the catchability coefficient between seasons can be analyzed (Brodziak and Rosenberg 1993). However, variations in catchability-at-length for one fishing season remain unmeasured (Basson et al. 1996; Morales-Bojórquez et al., in press). The last problem can be solved with an analysis of variation in catchability-at-length, which can give some information about stock behavior and efficiency of fishing, and concomitantly improve the quantities used for management, such as changes in fishing mortality during the fishing season. We assumed that catchability in the *D. gigas* fishery is variable. Under this condition, the risks in management decisions and harvest strategies decrease because catchability is a parameter relating fishing effort to fishing mortality and stock abundance (Arreguín-Sánchez 1996; Arreguín-Sánchez and Pitcher 1999). For this study, we analyzed the variation in the catchability coefficient of *D. gigas* on the basis of population length-structured data expressed as CPUE.

METHODS

Weekly catch (kg) and effort (number of fishing nights of landed catch) data were obtained from the Subdelegación de Pesca of Guaymas, Sonora, Mexico (fig. 1). This information represented catch records for a fleet of shrimp trawlers adapted with hand jigs as fishing gear for squid. We analyzed the CPUE data by considering the fishing season, t (1 year, fig. 2), from 5 November 1995 to 16 November 1996, and the fishing season, $t+1$ (1 year, fig. 3), from 17 November 1996 to 29 November 1997. We selected these times because recruitment of *D. gigas* occurs in May on the fishing ground off Guaymas, Sonora (Hernández-Herrera et al. 1998), so we could observe the effect on catchability when the presence of one new cohort of *D. gigas* supports the fishery throughout the fishing season.

Nevárez-Martínez et al. (2000), Brito-Castillo et al. (2000), and Morales-Bojórquez et al. (in press) showed that during 1995–98 the jumbo squid population was found only in the north of the Gulf of California, mainly off Santa Rosalía and Guaymas (fig. 1). They observed population movement from Santa Rosalía toward Guaymas. During this movement, recruitment took place in May. A stock assessment using survey data from the Gulf of California also confirmed that *D. gigas* was not distributed in the southern Gulf of California (Nevárez-Martínez et al. 2000).

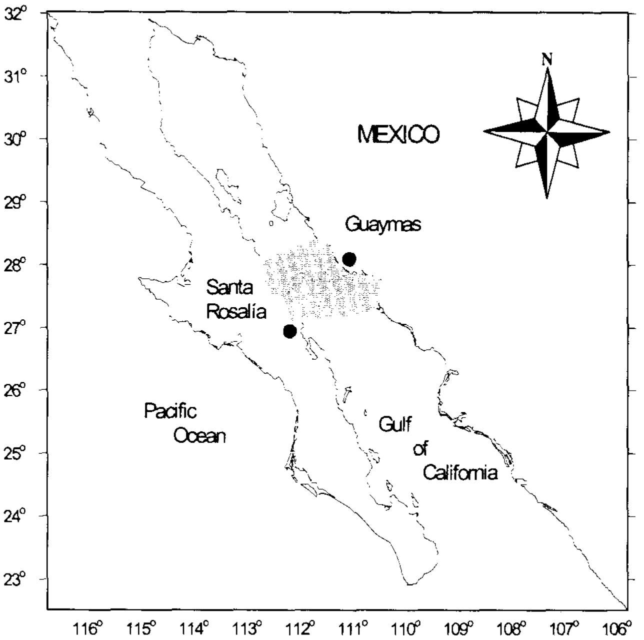

Figure 1. Study area in the Gulf of California, Mexico. Shaded area indicates where catches of *D. gigas* were made. Since 1995 over 85% of the catch has been taken in this area of the Gulf of California.

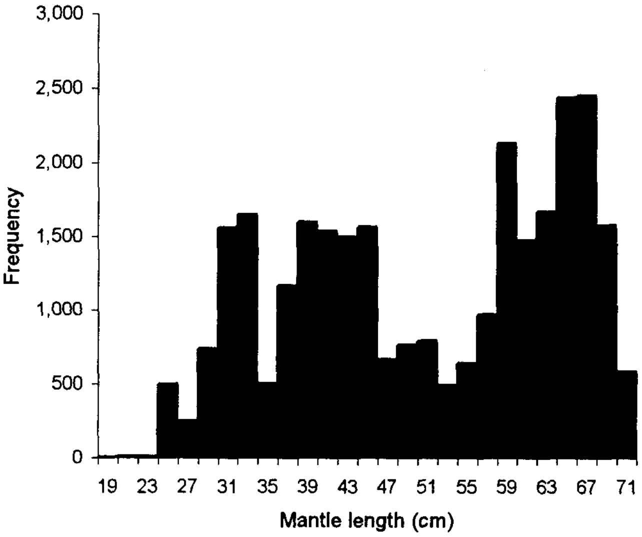

Figure 2. Mantle length distribution for *D. gigas* at time t (from 5 November 1995 to 16 November 1996).

We estimated catchability-at-length by using the deterministic model of catchability (DMC) proposed by Arreguín-Sánchez (1996). The DMC assumes that catchability (q) depends on length as well as on squid behavior

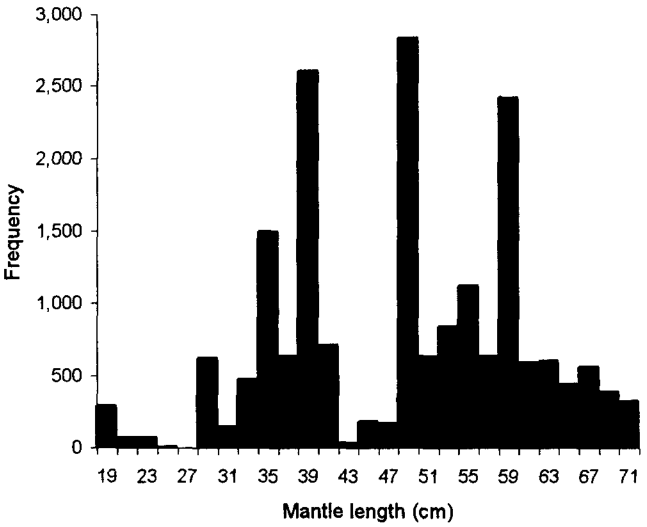

Figure 3. Mantle length distribution for *D. gigas* at time $t+1$ (from 17 November 1996 to 29 November 1997).

TABLE 1
Computations to Estimate Growth Probabilities per Length Class

1. $G(l,w) = 0$	...if...	$L(w+1) < \tilde{L}(l)$
2. $G(l,w) = [(L(w+1) - \tilde{L}(l))]/\Delta L$	...if...	$L(w) < \tilde{L}(l) < L(w+1)$
3. $G(l,w) = 1.0$	...if...	$\tilde{L}(l) < L(w)$ *and* $L(w+1) < \tilde{L}(l+1)$
4. $G(l,w) = [(\tilde{L}(l+1) - L(w))]/\Delta L$	...if...	$L(w) < \tilde{L}(l+1) < L(w+1)$
5. $G(l,w) = 0$	...if...	$\tilde{L}(l+1) < L(w)$
In the last interval of length		
6. $G(l,w) = 1.0$	...if...	$l = Lmax$ *and* $\tilde{L}(l) < L(w)$

Source: Shepherd 1987

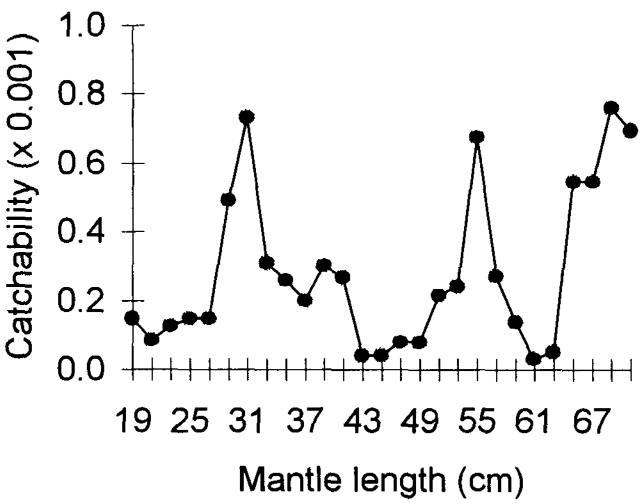

Figure 4. Estimations of the catchability-at-length coefficient.

(Arreguín-Sánchez and Pitcher 1999). The catchability must be estimated for each length class (l) in a given time (t). According to Arreguín-Sánchez and Pitcher, a convenient method for representing the transformation of one length frequency into another is a transition matrix (Shepherd 1987; Caswell 1988), expressed as $N(l,t+1) = A(l,w)N(l,t)$, where w and l are successive length intervals; $\mathbf{N(l,t)}$ is the vector of stock size in numbers at time t (from 5 November 1995 to 16 November 1996); $\mathbf{N(l,t+1)}$ is the vector of stock size in numbers at time $t+1$ (from 17 November 1996 to 29 November 1997); and A is the transition matrix that depends on growth and mortality. In both cases, $N(l,t)$ and $N(l,t+1)$ are represented as catch per unit of fishing effort. Shepherd (1987) expressed A as: $A(l,w) = G(l,w)S(w)$, where $G(l,w)$ represents growth in the absence of mortality, and $S(w)$ is the survival matrix and represents the effect of mortality.

Growth probabilities of $G(l,t)$ are defined assuming that individuals are growing following the von Bertalanffy model (VBM), and the probabilities were estimated following Shepherd (1987) as indicated in table 1. Growth parameters of the VBM were taken from Hernández-Herrera et al. (1998), where the growth of individuals of a single cohort off Guaymas, Mexico, is well-documented ($k = 0.8$, SE = 0.06 , and $L\infty = 87$ cm, SE = 2.7 cm).

$S(w)$ is defined as $S(w) = \exp^{-Z(w)t} = \exp^{-[M+F(w,t)]}$, where $Z(w)t$ = total mortality for the wth length group at time t; M is natural mortality (constant), estimated with the Silliman method (Ricker 1975) as $M = 0.101$/week (Morales-Bojórquez, Hernández-Herrera et al. 2001); and $F(w)t$ = fishing mortality for the wth length group at time t. $F(w)t$ is defined as $F(w)t = q(w,t)E(t)$, where $q(w,t)$ = catchability for the wth length group at time t, and $E(t)$ = fishing effort at time t. In this way, the stock size in numbers at time $t+1$ can be estimated as

$$N(l,t+1) = \sum_{w} G(l,w)\exp^{-[M + q(w,t)E(t)]}N^{(w,t)} \tag{1}$$

Because growth matrix, stock size in numbers at time t and $t+1$, and parameters are known, then $q(w,t)$ can be estimated from equation 1 by a simple least squares algorithm (see Arreguín-Sánchez 1996; Arreguín-Sánchez and Pitcher 1999 for details).

RESULTS

The variation of the catchability coefficient with length for *D. gigas* is shown in figure 4. The average value of catchability along the range of sizes of mantle length was $\bar{q} = 2.8 \times 10^{-4}$ (s.d. $= 2.3 \times 10^{-4}$), and the range of variation was $3.1 \times 10^{-5} < q < 7.6 \times 10^{-4}$. The standard deviation is high because of the fluctuations in catchability coefficient within a season. Catchability-at-length showed an alternating pattern of low and high values along the range of sizes as follows: (a) low catchability at 19–27 cm, 43–49 cm, and 57–63 cm ML, and (b) high catchability at 29–33 cm, 53–57 cm, and 65–71 cm ML. In this pattern, an increase in catchability is followed by a rapid decline. Three peaks in catchability coefficient are observed, at 31 cm, 55 cm, and 69 cm of mantle length. Between peaks were organisms with low catchability between 43–49 and 61–63 cm ML.

DISCUSSION

An alternative method for estimating catchability in the jumbo squid fishery is desirable because in the management strategy the size of the incoming cohort is unknown at the time of licensing and also varies from year to year. The number of licenses that are allocated in accordance with the target escapement is dependent on information about effort patterns and vessel efficiency (estimates of catchability coefficient). It is at the assessment stage during the fishing season that need for a closure can be detected and corrective action taken if required. The need for a closure can be caused by one or both of the following reasons: a low level of recruitment, and changes in the efficiency or operational practices of vessels (catchability; Basson and Beddington 1993).

Low levels of recruitment were estimated in 1998 (Morales-Bojórquez et al., in press) with a Delury model (Rosenberg et al. 1990), but the assessment failed because the model could not be fitted to the data of CPUE and cumulative catch. That is, in some cases the Delury model fit was poor and produced skewed likelihood functions or a curvature of the depletion regression (fishing season 1996–97; Morales-Bojórquez et al. 1997). This trend in the depletion regression is explained by Beddington et al. (1990), assuming that the catchability coefficient is a measure of vessel efficiency, and is constant throughout the fishing season.

Ricker (1975), and Hilborn and Walters (1992) comment that nonconstant catchability is the greatest potential source of error in depletion methods. Often the first few units of catch effort rapidly deplete more vulnerable fish, with accompanying rapid change in CPUE or other abundance indices. After this initial catch, the remaining squid have effectively lower q values, so that q declines progressively as the depletion proceeds. There may even be a large pool of squid with $q = 0$ for some reason, and this pool will not be sampled at all by the depletion process. The general effect of varying catchability among individuals is to bias the estimate of q upward and to bias the estimate of recruitment downward. This effect is likely to be much larger than the upward bias caused by statistical error, so the depletion estimate of recruitment is likely to be too low. Hilborn and Walters (1992) consider underestimates of 30% to 50%. Thus the presence of large numbers of squid with low catchability may be indicated by curvature (flattening) of the depletion regression.

This curvature could be caused by differences in the behavior of the fleet or of squid during the fishing season. In the jumbo squid fishery, we recognize changes in catchability because interactions between the shrimp and jumbo squid fisheries temporally modify the distribution of the shrimp trawlers. That is, the shrimp fishing season begins in August–September; when yields of shrimp diminish (December; Morales-Bojórquez and López-Martínez 1999; Morales-Bojórquez, López-Martínez et al. 2001), the shrimp trawlers are adapted with hand jigs as fishing gear for squid. During this time the squid stock is distributed near the coast of Guaymas, and squid with mantle lengths between 45 and 70 cm are observed in the landings. The fleet fishes near the coast, exploiting one resident cohort of adults in the fishing ground off Guaymas (Hernández-Herrera et al. 1998).

The exploitation of this cohort was observed from 5 November 1995 to 4 May 1996 (Morales-Bojórquez et al., in press). During this time only adult individuals are available (Hernández-Herrera et al. 1998), which explains low values of q for individuals from 39 to 50 cm ML (low frequency from November 1995 to May 1996), and high values of q for squid between 55 and 71 cm ML that are well represented in the samples (fig. 2). The fluctuations in q for the 55–71 cm ML can be an effect of aggregation of jumbo squid in the fishing ground, because the cohort has only squid with ML >50 cm. Basson et al. (1996) showed that the catchability coefficient can also reflect the spatial density of squid.

In May a new recruitment into the fishery of *D. gigas* is detected (Hernández-Herrera et al. 1998), coinciding with the beginning of the closed season for the shrimp fishery. At this time, the shrimp trawler fleet receives more squid licenses. During this time, there is an overlap of cohorts, dominated by the new cohort. Individuals of 20 cm ML are observed, but the recruitment is of squid with ML of 30 cm. This recruitment explains high q-values in younger individuals (fig. 4). We have no evidence for more cohorts of *D. gigas* in the Gulf of California. Previous authors show that different groups of catchability coefficients indicate two or more cohorts in the fishery (Basson et al. 1996; Agnew et al. 1998). In our study the groups of q showed an overlap of cohorts.

We found three peaks of catchability, and these peaks have approximately the same value ($q \approx 0.7 \times 10^{-3}$). High values of catchability at 29–33 cm, 53–57 cm, and 65–71 cm ML showed that these intervals have the same vulnerability. Although we recognize a dominant cohort in the fishery, the catchability estimates suggest the presence of three cohorts, since the catchability is similar among intervals. However, the first interval indicates that the cohort that has been resident on the fishing ground up to the end of May is being replaced by a new cohort, which will become resident once it has fully recruited.

In the jumbo squid fishery, real-time management (in season) is required, because an annual cohort supports the harvest, makes up an open access fishery, is highly available in the coastal zone, and has low effort costs. Thus the bias and errors in catchability cannot be omitted. It would be useful to have a supplementary method for assessing cohort size either in the absence of a successful Delury assessment or survey data. If we consider the bias and errors in the management quantities, then the advantage of the DMC method is to explain the changes in catchability as length dependent according to squid fishery behavior. In this way, we can obtain information on current stock size, project final stock biomass and escapement, and identify the type of catchability that is applicable to this fishery in order to improve its exploitation and management.

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