TIME-SPACE VARIATION IN THE CATCHABILITY COEFFICIENT AS A FUNCTION OF CATCH PER UNIT OF EFFORT IN Heterocarpus reedi (DECAPODA, PANDALIDAE) IN NORTH-CENTRAL CHILE

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SUMMARY

The catchability coefficient (q) is a key parameter in the validation process of a fishing simulation model. This parameter is generally assumed to be constant. However, in many cases this constancy is violated, especially in living marine resources with aggregated spatial distribution. The object of this study was to determine potential variations of \( q \) as a function of the catch per unit of effort (CPUE) of the shrimp Heterocarpus reedi in North-Central Chile. The variability of \( q \) was calculated weekly for three fishing seasons and two fishing zones, using the swept area method. The functional relationship between CPUE, in ton·km\(^{-2}\), and \( q \) was better explained by potential models. The analysis showed high variation in \( q \) between weeks in the same fishing season, an inverse relationship between CPUE and \( q \), and an increase in the proportion of variance explained by the model as CPUE decreased.

RESUMEN

El coeficiente de capturabilidad (q) representa un parámetro clave en el proceso de validación de un modelo de simulación pesquera, proceso en el cual generalmente se le asume como constante. Sin embargo, en muchos casos este supuesto de constancia de q es violado, especialmente en recursos marinos vivos con distribución espacial agrupada. El principal objetivo de este trabajo fue determinar las posibles variaciones de q en función de la captura por unidad de esfuerzo (CPUE) en la pesquería del camarón nailon Heterocarpus reedi en la zona centro-norte de Chile. La variabilidad de q se calculó en forma semanal para tres temporadas y dos zonas de pesca por el método de área barrida, mientras que la relación funcional entre CPUE, en ton·km\(^{-2}\), y q estimado fue mejor explicada por un modelo potencial. El análisis realizado mostró: una alta variación de q entre semanas para una misma temporada de pesca; una relación inversa entre CPUE y q; y que la varianza explicada por el modelo aumentó a medida que la CPUE disminuyó.

RESUMO

O coeficiente de capturabilidade (q) representa um parâmetro chave no processo de validação de um modelo de simulação pesqueira, processo no qual geralmente é assumido como constante. No entanto, em muitos casos este suposto de constância de q é violado, especialmente em recursos marinhos vivos com distribuição espacial agrupada. O principal objetivo de este trabalho foi determinar as possíveis variações de q em função da captura por unidade de esforço (CPUE) na pesca do camarão nailon Heterocarpus reedi na zona centro-norte do Chile. A variabilidade de q calculou-se em forma semanal para três temporadas e duas zonas de pesca pelo método de área barrida, enquanto que a relação funcional entre CPUE, em ton·km\(^{-2}\), e q estimado foi melhor explicada por um modelo potencial. A análise realizada mostrou: uma alta variação de q entre semanas para uma mesma temporada de pesca; uma relação inversa entre CPUE e q; e que a variação explicada pelo modelo aumentou a medida que a CPUE diminuiu.

Introduction

The catchability coefficient (q) is a key parameter in the validation process of a fishing simulation model. In fact, catch per unit of effort (CPUE) can be determined from an estimated biomass B in time t, which accounts for losses (catch and natural mortality) and gains (recruitment and individual weight) factors, as

\[
\text{CPUE}_t = B_t \cdot q
\]

where it is assumed that q is constant over time, though this assumption is violated in fisheries associated to pelagic and demersal fish (MacCall, 1976; Peterman and Steer, 1981; Bannert and Austin, 1983; Crecco and Savoy, 1985; Gordon and Hightower, 1991; Swain and Sinclair, 1994; Swain et al., 2000), crustacean (Ye and Mohammed, 1999) and mollusk (Prince, 1992; Chávez, 2000) stocks. Reproductive aggregation (Arreguín-Sánchez, 1996), space-time variations in distribution (Ullung, 1976; Peterman and Steer, 1981; Winters and Wheeler, 1985; Swain and Sinclair, 1994; Prince, 1992), changes in fishing power (Gulland, 1983), environmental factors (Hilborn and Walters, 1992; Swain et al., 2000) and effects related to fisherman be-
behavior (Chávez, 2000) have been invoked as potential sources of variation. Thus, an increase in $q$ as biomass decreases can lead to more rapid population extinction than would be predicted under the constant $q$ assumption (MacCall, 1990; Pérez, 1996; Chávez, 2000).

A crustacean trawling fishery is carried out in Regions III and VIII of Chile (Figure 1), with 4863 tons of total landing in year 2001. The main target species are nylon shrimp ($Heterocarpus reedi$), yellow squid lobster ($Cervimunida johni$) and red squid lobster ($Pleuroncodes monodon$). Each of these species is subject to different access regimes. Between Regions II and VIII, $H. reedi$ is declared as fully exploited. This is also the case for $C. johni$ in Regions III and IV, whereas in southern Chile this species is managed with a catch quota license system. The fleet based in Coquimbo catches a significant volume of $H. reedi$ in Region IV, whereas large landings of $C. johni$ occur in Region III (Acuña et al., 1998, 1999).

Reliable estimates of $q$ are crucial to formulate a fishery simulation model that allows objective prediction of species behavior under distinct exploitation strategies. The Secretary of Fisheries (Subsecretaría de Pesca) of Chile began recently efforts at quantifying $q$ for this fishery because of potential uncertainties surrounding $q$ and its possible behavior in space and time. The object of the present study was to determine space-time variations in $q$ as a function of CPUE of $H. reedi$ in North-Chilean waters.

Materials and Methods

Information of landing of the trawler fleet based in the harbour of Coquimbo, in the Administrative Region IV (Figure 1) was used. This fleet operates mainly in the Administrative Regions III and IV, but landings occur in Caldera and Huasco (Region III), Coquimbo and Los Vilos (Region IV).

A joint effort with industrial fishers involved in this activity, recorded catch and trawled time by haul for the fleet of Coquimbo were made aboard by technicians of the Universidad Católica del Norte (UCN). Although three species of crustacean are exploited by this fleet, $H. reedi$ was the target species. The data base included data collected daily from September 1, 1997 to June 30, 2000. The data was used to determine catch per unit of effort (CPUE) by haul.

Spatial ($k$, Region) and temporal ($t$, week) variation of the catchability coefficient ($q_{k,t}$) was independently calculated for Regions III and IV, according to the Baranov (1918) equation

$$q_{k,t} = \frac{a_{k,t}}{A_k}$$

where $a_{k,t}$: area swept per fishing haul in zone $k$ at time $t$, and $A_k$: stock distribution area in Region $k$ (Subpesca, 2001). Thus, the measurement unit for $q$ is haul$^{-1}$. Caddy (1975) and Seijo et al. (1994) have suggested that this equation provides a good $q$ estimate for fisheries like this. An implicit assumption in Eq. 2 is a probability of capture equal to 1. Estimation of $q$ was done per fishing season from year 1997 to year 2000 (i.e. 97-98; 98-99 and 99-00), each running from 1 September to 30 June (Acuña et al., 1998).

The functional relationship between CPUE$_{k,t}$ and $q_{k,t}$ was fitted to a potential model, explicitly incorporating Eq. 2 according to Chávez (2000), as follows:

$$q_{k,t} = \alpha \text{CPUE}_{k,t}^{-\beta}$$

The pairs of $q_{k,t}$ and CPUE$_{k,t}$ represent average values generated with the central limit theorem (Zar, 1995). To obtain the mean distributions for $q_{k,t}$ and CPUE$_{k,t}$, the bootstrap technique (Efron, 1981) was used, in which a sample size equivalent to 25% of the weekly observed fishing hauls was randomly chosen (including those with zero catch) each week. The mean was then calculated for this subsample, according to the information provided by 3000 bootstrap runs. Parameters $\alpha$ and $\beta$ of Eq. 3 were subject to analysis of covariance, ANCOVA (Zar, 1995), to evaluate within-Region differences between fishing seasons (treatments), using CPUE as the covariate. When significant differences between treatments were detected, the Tukey test (Zar, 1995) was applied.

**Results**

Both CPUE and $q$ values for Regions III and IV exhibited high between-week variability (Figure 2), with an inverse relationship between them. This was particularly evident in Region III, fishing seasons 97-98 and 98-99, where CPUE markedly decreased from 8 ton·km$^{-2}$ at the beginning of the first season, to 6 ton·km$^{-2}$ at its end. An increase in $q$ was also observed in this period, from 3·10$^{-5}$·haul$^{-1}$, at the beginning of the season, to 4·10$^{-5}$·haul$^{-1}$, at season’s end. The inverse correlation between both variables was more evident for fishing season 98-99, with CPUE declining to levels as low as 4 ton·km$^{-2}$, and $q$ increasing on average to ca. 5·10$^{-5}$·haul$^{-1}$.

A similar pattern, though less evident, was observed for Region IV, with a sustained decrease in CPUE from the 97-98 season to the 99-00 season, accompanied by an increase in $q$ (Figure 2). During this period, the CPUE declined from values greater than 4 ton·km$^{-2}$, in the first season, to less than 3 ton·km$^{-2}$, in the third season, while $q$ increased from an initial value of ca. 4·5·10$^{-5}$·haul$^{-1}$ to approximately 6·10$^{-5}$·haul$^{-1}$.

In all cases, inverse relationships between CPUE and
Despite this, the regression model explained a low percentage of the variance, and at least in one fishing season (97-98, Region IV) this relationship was not significant (p>0.05).

Region III, during fishing season 98-99, had an evident inverse relationship between CPUE and \( q \), in which the model explained 55% of variance and had the highest slope in comparison with the other seasons (Figure 3). During fishing season 99-00, which had stability in CPUE and \( q \), the slope was lower (0.31) but still significant (\( R^2 = 0.25 \), p<0.05), and the model explained 80% of variance. This inverse relationship between CPUE and \( q \) was also evident in Region IV (Figure 3), where a slope as a percentage of variance explained by the model increased as CPUE decreased, changing from a low \( R^2 \) and a slope not significantly different from zero in the first season (p>0.05), to a model explaining 66% of variance, with a slope of 0.56 (p<0.05) and the lowest CPUE’s during the 99-00 fishing season.

ANOVA revealed that the slope relating CPUE and \( q \) for Region III was significantly different between fishing seasons 97-98 and 98-99 (Tukey test: p<0.01), while between fishing seasons 98-99 and 99-00 there were no significant differences in terms of slope and intercept. For Region IV, the slope for the 97-98 season was statistically different from the other two (Tukey test: p<0.01), while for the 98-99 and 99-00 seasons, there were no significant differences in the slope (p=0.19) but in the intercept (p<0.01).

Discussion

Three main elements emerge from the results of this study, i.e.; high between-week variation of \( q \) during the same season, an inverse relationship between CPUE and \( q \), and an increase in the proportion of variance explained by the model as CPUE decreased. The high between-week variation of \( q \) within the same fishing season and the low, but significant, \( R^2 \) for the relationship between CPUE and \( q \), indicate that causes not contemplated in this study affect \( q \) estimates. Evidence exists of an inverse relationship between CPUE and \( q \), especially for fish species with patchy distribution (MacCall, 1976; Ulltang, 1976; Peterman and Sterr, 1981; Csirke, 1989; Rose and Leggett, 1991; Arreguín-Sánchez, 1996).

When the stock is highly aggregated, the fishing
method used is capable of removing a higher percentage of individuals with respect to the total population, causing q to increase. Potential sources of variation affecting q have been identified, such as temperature, distribution area, abundance and fishing effort, among others (MacCall, 1990; Hilborn and Walters, 1992, Arreguín-Sánchez, 1996). In the case of H. reedi, however, the results suggest that as CPUE decreases the explanatory power of Eq. 3 increases, which is more evident in Region IV. The degree of spatial heterogeneity in resource distribution could also explain this behavior. Patchy distribution, reflected in catch variability when trawling gears are used (Taylor, 1953), is a tentative explanation for the observed variation between weeks. Though each study Region has been contemplated as a continuous distribution band of H. reedi (Aciúna et al., 1998, 1999, 2000), it seems reasonable that the stock occurs in patches with different distributions. This would be reflected in catch variation even when the area swept per fishing haul is the same within the different patches. In this case, the trade-off between effective trawl distance and resource distribution area will directly affect Eq. 2. A stock can be divided into different loci, each with different density. Each locus is considered as the smallest geographical unit, within which population density can be homogeneous (Caddy, 1975). Thus, spatial changes in abundance can affect the area trawled per fishing haul and effective area of distribution (Crecco and Overholtz, 1990), increasing q variability. As abundance decreases, these patches tend to become more homogeneous within them, producing greater homogeneity in q between weeks, as observed for fishing season 1999-2000 in Region III.

The decrease in CPUE for H. reedi did not generate noticeable changes in q. Variability in q has generally been addressed on an annual scale (see Gordoa and Hightower, 1991; Arreguín-Sánchez, 1996; Puga et al., 1996), though weekly changes in q have been reported by Atran and Loesch (1995) for Brevoortia tyrannus. These authors demonstrated that q could remain relatively constant when determined at an annual scale, but when the analysis is seasonally done, this assumption is generally violated. Significant weekly changes in q have been observed in the small-scale Mesodesma donacium bivalve fishery in Chile and were associated to density-dependent effects (Chávez, 2000). In this case, as a patch of M. donacium was depleted over a period of weeks, q increased due to the increase in the area swept by each dive to attain a catch amount that fulfills his economic expectations (Pérez, 1996; Chávez, 2000).

Another relevant aspect is the degree of synchronization between concurrent changes in q and relative abundance denoted by the CPUE. For example, during fishing season 1999-98 in Region IV, observed CPUE’s ranged between 2 and 8 ton-km². The slope was not different from zero, determining a lack of relationship between variables. In contrast, in fishing season 1999-2000 the correlation between variables was -0.80 (R²=0.64; p<0.05) for the same range of values. If a relationship between the variables exists, then it would always be expected to exist, especially if the same range of CPUE values is analyzed in different times. This was not the case, however, in Region IV for the fishing season 97-98. The most notable difference between both seasons was that the most frequently observed CPUE’s in fishing season 99-00 were less than 4 ton-km², while in fishing season 97-98 they were higher than this value. A similar situation was seen in Region III. Given this, the change in the relationship between CPUE and q appears to be mediated by a certain catch threshold that accomplishes fishers’ expectations (Pérez, 1996; Chávez, 2000).

In summary, our results reinforce the view that CPUE can be considered an efficient abundance estimator if, and only if, the β parameter of Eq. 3 is significantly lower than, and statistically different from zero (Ulltang, 1976; Richards and Schnute, 1986; and Chávez, 2000). This is undoubtedly an important issue when validating any fisheries simulation model.

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