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Mortality and stock assessment of the brown shrimp, *Penaeus aztecus* (Crustacea: Penaeidae), in the northwest Gulf of Mexico

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Abstract: Fishing mortality of the brown shrimp (*Penaeus aztecus*) was estimated off Tamaulipas (northwest Gulf of Mexico). Monthly age structure and fishing effort data for the 1974-1980 period, and cohort analysis by the virtual population analysis (VPA) technique were used. Catchability estimates indicate higher values for the first maturity age (six months old), fishing mortality increases with age, with an asymptotic tendency after 8-9 moths old, F=0.5 (1/year). Variance of F also increases with age. Population size has strong interannual variations because of recruitment, though the seasonal recruitment pattern was similar during the period. The monthly cohort tendency suggests a stable situation for the stock during this period.

Key words: Mortality, stock assessment, *Penaeus aztecus*, Gulf of Mexico.

The coastal region of northwest Gulf of Mexico, off Tamaulipas, is an important fishing ground for the Mexican shrimp industry. Annual yields have increased during the last decade (Fig. 1), with the brown shrimp (*Penaeus aztecus*, Ives 1891) making between 70% to 90% of the total catch. It has been suggested that part of the landings come from other regions, such as the Campeche Bank, on the Southern Gulf. Even so, this fishery exhibits a growing or sustained tendency in yields for both, inshore and offshore fisheries.

Different kind of events have influenced the development of the shrimp fishery, mainly those related to fishing effort. The most important aspect in the last two decades was the change of ownership of the fishing boats, from private companies to the associated fishermen known as Sociedades Cooperativas, which was implemented in 1982-1984. This caused not only decrement of the fishing effort of around 40% (Arreguín-Sánchez 1984), but a change in fishing strategy.

To understand the implications of those events and future development of this fishery there is a need for more information on the population dynamic of the resource. This work aims to study the fishery development, i.e.

fishing mortality and stock assessment for the period 1974-1980.

MATERIALS AND METHODS

Virtual Population Analysis (VPA) (Gulland 1965, Pope 1972) was carried out in this work. This method, particularly the age-VPA, provide an estimation of the fishing mortality with age and population size, giving an independent estimates of natural mortality, M. Although VPA can be solved without knowledge of fishing effort, its inclusion will provide more accurate estimates of fishing mortality through specific values of catchability per age and fishing effort (E).

Catch-at-age structure data was taken from Castro y Arreguín-Sánchez (1991), which describe survival of monthly cohorts using different values of M per year (Table 1), assuming M constant within the year. This information was available for the period of 1974 to 1980.

Since several algorithms can be applied to solve VPA (see Pope and Shepherd 1985, Megrey 1989, Hilborn and Walters 1992) we used that suggested by Walters (Carl Walters 1981. Apple catch at age analysis system. User´s manual. Inst. Animal Res. Ec. Vancouver, B.C.) through the equation:

$$C_{t+1} = \left\{1 - \left[M \Big/ \mathrm{Ln}\left(N_{t+1} - N_t\right)\right]\right\}\left\{N_t - N_{t+1}\right\} \quad (1)$$

where N_t and N_{t+1} are stock size at successive units of time, and C_{t+1} is catch at age t+1.

This equation is iteratively solved for N_t giving values of C_{t+1} and M using the Newton´s method to obtain successive values of N_{t+1}. For the VPA-cohort analysis using fishing effort data, it is necessary to assign the recentiest value of fishing mortality, formerly named terminal fishing mortality F_T, which is estimated by assigning a value to the catchability coefficient q_T in the relationship $F_T = q_T E$. Estimates of numbers N_t at age and catchability-at-age, q_a, per month were obtained from the relationship

$$q_{t+1} = \frac{\left(C_{t+1}\right) \bullet E \bullet M}{\left(N_t - N_{t+1} - C_{t+1}\right)} \quad (2)$$

RESULTS

A preliminary analysis of catch structure (Fig. 2) shows that recruitment age at the offshore fishery varied between 3 and 4 months old, when they exhibit higher variability in abundance, as expressed by the standard error.

This variability decreases until they are 6-7 months old, remaining almost constant for older individuals. These differences on recruitment age and abundance variability, reflects seasonal effects acting on the population structure and a the relative abundance of the cohorts.

TABLE 1

Natural mortality (1/year) estimates for the brown shrimp (Penaeus aztecus) *of the offshore shrimp fishery on the NW Gulf of Mexico (adapted from Castro 1987)*

Year	Natural mortality, M
1974	7.128
1975	5.683
1976	5.260
1977	6.349
1978	4.980
1979	5.172
1980	5.358

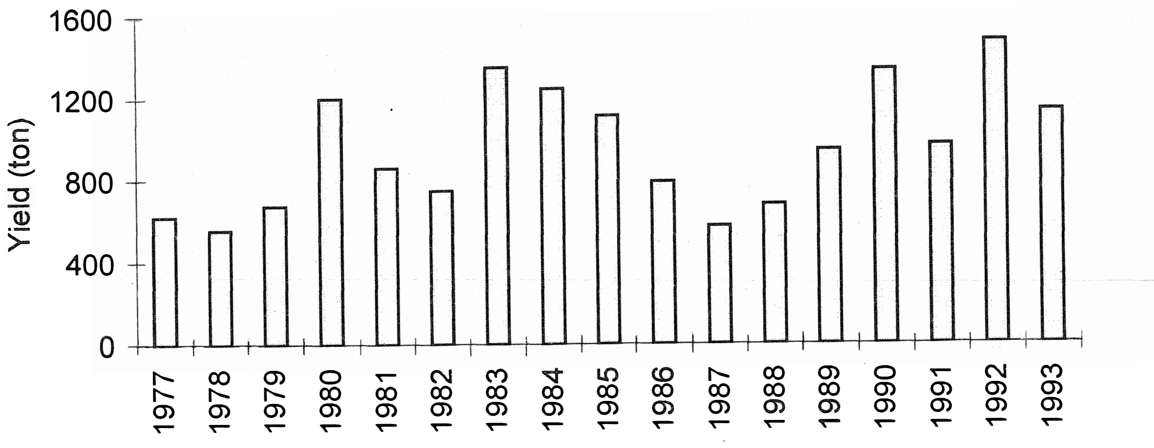


Fig. 1. Annual yield for the offshore shrimp fishery off Tamaulipas, in the NW Gulf of Mexico (adapted from Castro *et al.* 1994).

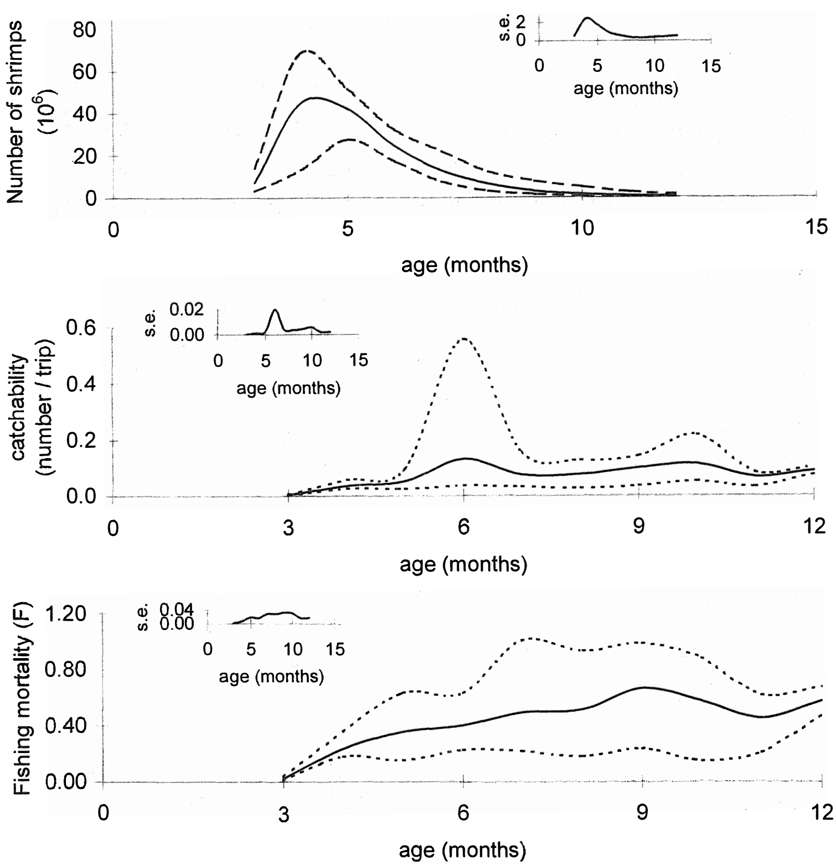


Fig. 2. Catch-at-age structure (Upper), Catchability-at-age pattern (Middle) and Fishing mortality-at-age pattern (Lower) of the brown shrimp (*Penaeus aztecus*) of the NW Gulf of Mexico. Solid line indicates average trend. dashed lines the minimum and maximum values for the 1974 to 1980 period, s.e. is the standard error.

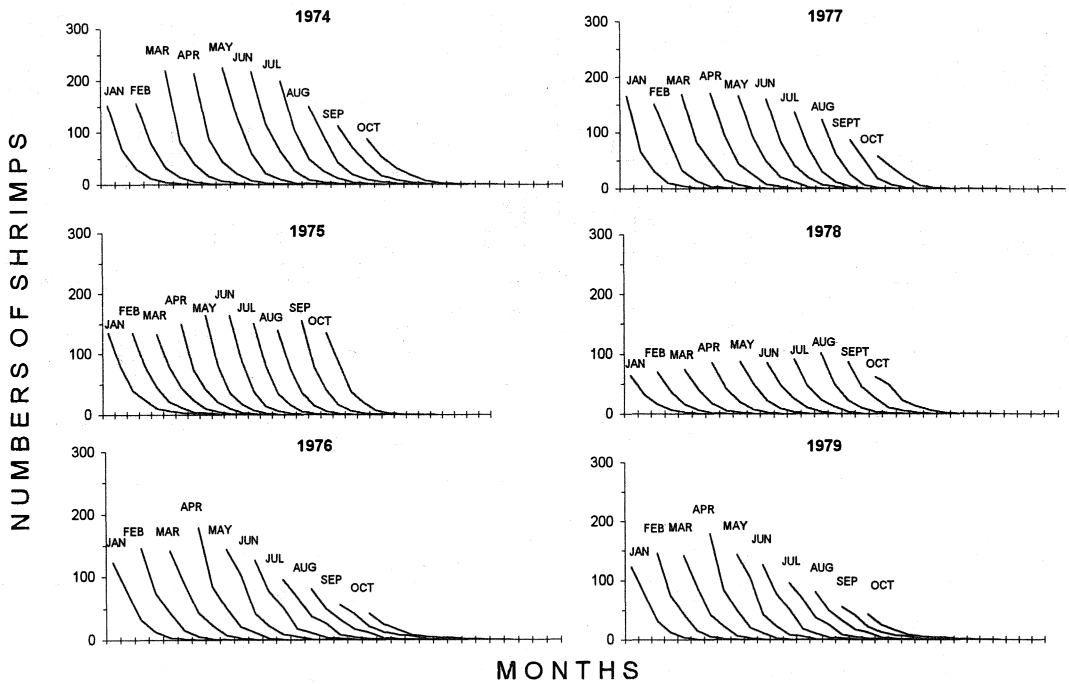


Fig. 3. Monthly cohorts of the offshore brown shrimp fishery in the NW Gulf of Mexico during the 1974 to 1980 period.

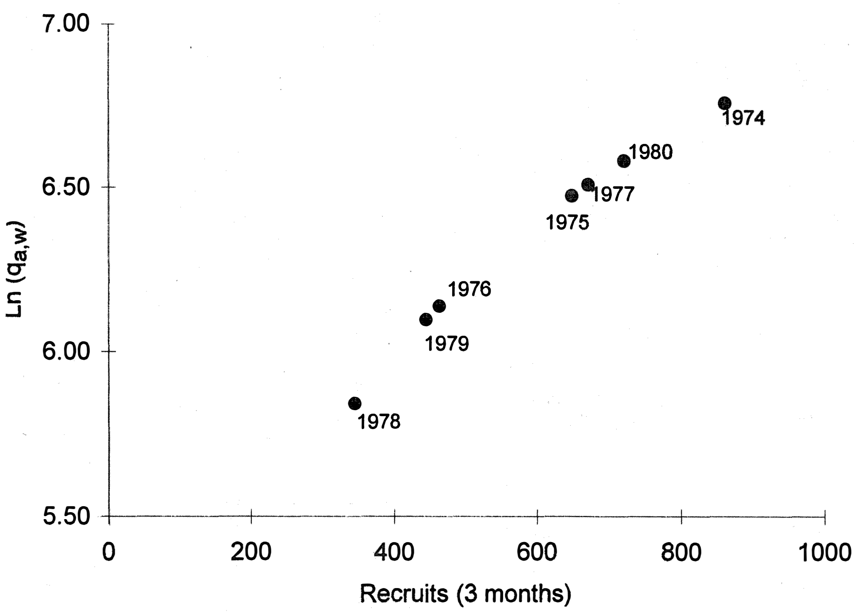
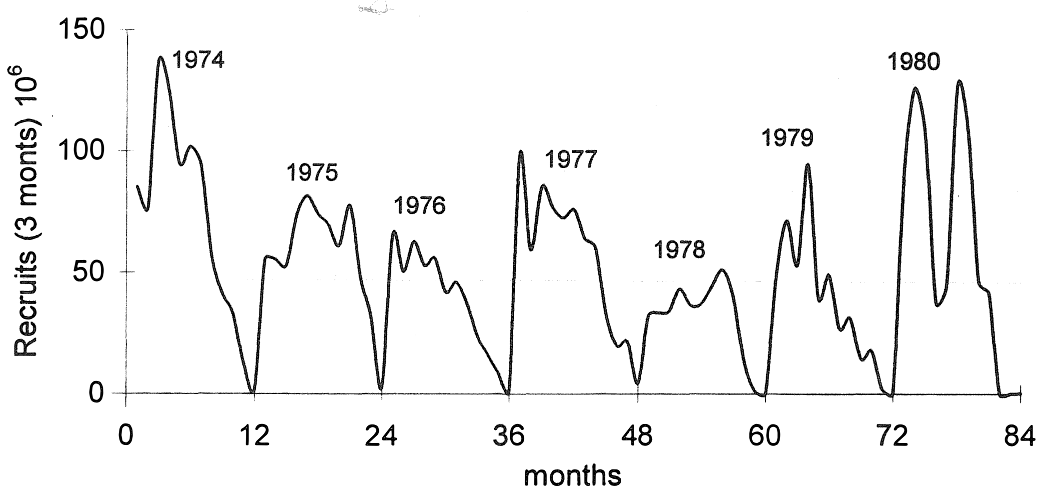


Fig. 4. Relationship between the natural logarithm of weighted catchability (q_w) with cohort strength. $q_w=q_q N_a^*$, where q_q= estimated catchability-at-age from VPA. and N_a^*= proportion of the relative abundance of age a in the stock.



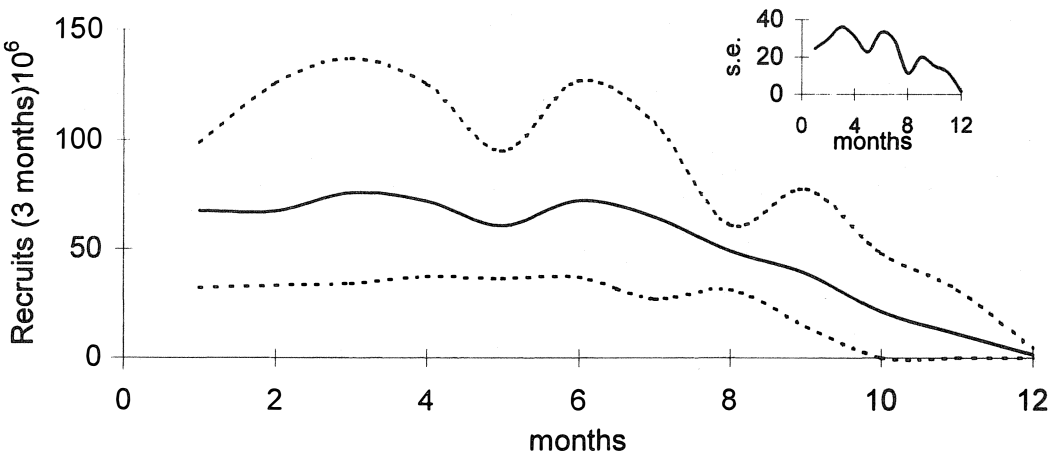


Fig. 5 Seasonal recruitment pattern (number of shrimps of 3 months of age in the average population). Upper, for individual years during the period 1974 to 1980. Lower, seasonal pattern: solid line, annual average. dashed lines, maximum and minimum values for the period of 1974 to 1980. s.e. = standard error.

TABLE 2

Catch, catchability, fishing mortality and stock size by age (months), for the brown shrimp (Penaeus aztecus) *from VPA analysis after Walters (1981).*

Age	1974	1975	1976	1977	1978	1979	1980
			Catch 10^6				
3	9.6	6.7	3.8	13.9	5.5	3.2	
4	51.8	66.1	38.7	68.4	37.3	38.8	13.1
5	40.2	39.9	49.0	50.1	27.5	51.7	35.8
6	20.8	27.5	23.2	24.3	17.2	26.2	32.2
7	7.5	14.2	15.1	9.9	8.2	13.0	21.9

Continues

Table 2 (continued)

8	3.0	7.4	7.3	6.8	3.8	4.2	12.1
9	1.4	3.2	2.7	1.8	1.9	1.8	7.7
10	0.7	1.6	1.1	0.7	0.6	0.6	4.8
11	0.4	0.4	0.2	0.1	0.3	0.6	2.5
12	0.5	0.3	0.2	0.1		0.2	1.4
			Catchability				
3	0.0026	0.0021	0.0016	0.0044	0.0051	0.0021	
4	0.0248	0.0290	0.0302	0.0372	0.0279	0.0326	0.0564
5	0.0342	0.0374	0.0654	0.0563	0.0450	0.0956	0.0236
6	0.0368	0.5560	0.0575	0.0692	0.0578	0.0951	0.0347
7	0.0302	0.0671	0.0802	0.0669	0.0648	0.1522	0.0427
8	0.0244	0.0869	0.0958	0.1244	0.0719	0.0778	0.0384
9	0.0333	0.1198	0.0909	0.1051	0.1377	0.1397	0.0509
10	0.0491	0.1248	0.0965	0.1170	0.1094	0.2153	0.0666
11	0.0598	0.0808	0.0824	0.0819		0.0316	0.0643
12						0.1017	0.0740
			Fishing mortality				
3	0.018	0.013	0.010	0.033	0.036	0.014	
4	0.175	0.183	0.199	0.279	0.199	0.215	0.353
5	0.238	0.233	0.453	0.422	0.320	0.631	0.149
6	0.259	0.350	0.380	0.518	0.410	0.628	0.219
7	0.210	0.423	0.520	0.502	0.460	1.003	0.269
8	0.171	0.547	0.632	0.930	0.510	0.514	0.242
9	0.233	0.755	0.600	0.788	0.980	0.922	0.321
10	0.344	0.788	0.624	0.878	0.774	0.142	0.420
11	0.419	0.509	0.544	0.614		0.209	0.405
12						0.671	0.466
			Stock size 10^6				
3	860.8	648.9	463.8	671.4	345.4	445.3	721.2
4	503.9	459.2	380.3	418.9	239.5	330.2	524.4
5	256.8	242.6	199.6	213.7	137.7	203.5	362
6	118	126.5	97.6	92.6	70.2	98	226
7	51.6	56.7	48.6	39.3	31.2	45.3	132.7
8	24.1	25.9	19.9	15.6	13.4	20.3	74.9
9	10.9	9.8	7.9	4.5	5.3	10.2	40.8
10	4.8	4.2	3.1	1.6	1.7	5.3	23.1
11	2.2	3.2	1.3	0.4	1	2.9	11.4
12	0.8	1.9	0.7	0.4	0.1	1.1	6

Catchability estimates show some differences with age (Fig. 2), being higher (as well as the standard error) for shrimps of 6 months of age, decreasing for older organisms. A slight increase in catchability with age is also observed with shrimps of 10 to 11 months of age. In practice, this catchability-at-age pattern represent differences in vulnerability of shrimps and, as consequence, a different fishing mortality with age.

Fushing mortality with age, but tend to be constant (F_a = 0.5) with shrimps 8-9 months old (fig. 2). The standard error of F_a also increase with age, with higher values at 7-9 months old, when its magnitude is twice than observed for recruitment age. This may be related with size distribution in space.

Table 2 shows the interannual variation in stock size with values ranging from $845 \cdot 10^6$ shrimps in 1978, to $1834 \cdot 10^6$ in 1974. It has to be noted that in 1980, fishing effort was strongly reduced because both, change of fleet ownership, and US fleet stopped fishing in Mexican waters. The impact was obviously on survival, and stock size was estimated in $2122 \cdot 10^6$ shrimps. In spite of this, cohorts dynamics along the period of study (Fig. 3) shows that the stock of *P. aztecus* rather stable.

DISCUSSION

A previous study by Castro and Arreguín-Sánchez (1991), based in cohort analysis (but not VPA) assuming constant catchability with age, showed that population average catchability is directly related with cohort strength, and a function of population abundance (Fig. 4).

Results here agree with the above statement in the sense that catchability is a function of age abundance, but differences between ages are of importance because of highest vulnerability occurs at the first maturity age (six months according to Cook and Lindner 1965). providing more spawners (Fig. 2). We may infer that migrating shrimps (from inshore waters to the continental shelf) are most vulnerable because they belong to most abundant age, though there are environmental and behavioral factors conditioning their relative lower abundance. Migration occurring at different points along the coast, combined with a rapid dispersion, promotes lower densities. It is important to note that because of the small size and value of the shrimps during migration, fishermen avoid to trawl in shallow waters. In fact, in 1974 fishermen and officials agreed on an experimental closure because numbers at small sizes in catch (Castro y Santiago 1976). Currently areas 5 miles from shore are permanently closed to trawlers, and a seasonal closure was implemented, since three years ago, covering part of the time of massive migration and the beginning of the reproductive season (Castro et al. 1994).

Higher vulnerability of shrimps at first maturity age has not been reported previously for this species. If we accept that vulnerability increases with stock abundance, the explanation may be sought with reproductive aggregations, which are larger at the first maturity age. For other significant ages (95% of catch are from 3 to 8-9 months old), catchability tend to be approximately constant. The small increment in vulnerability at 10th month old (Fig. 2), may also be associated with reproduction, as older individuals coming from deeper waters not exposed to fishing may aggregate during reproduction.

Dynamics reflected through catchability is of importance under a high fishing pressure scheme, where controls on fishing mortality must be imposed to avoid recruitment overfishing. Currently, besides a minimum legal size, there is a closure season annually adjusted (Castro et al. 1994) at the end of the spring and early summer aiming to reduce fishing mortality on spawners and increase survival of recruits to the offshore fishery. Fig. 5 showing monthly recruitment, taken as the abundance of shrimps of 3 months old, suggests that most of them are recruited during the first six months of the year, just when spawners are more abundant and more vulnerable.

On the other hand, the time of seasonal recruitment exhibits an interannual constancy, suggesting all related processes are well defined each year. This aspect is of importance because survival of juveniles in the inshore region to pre-adults, after migration to offshore waters, depends on the carrying capacity of the coastal areas, which is highly influenced by abiotic factors, such as rains (Arreguín-Sánchez 1994,1995) and river discharge (Gracia 1989, 1991). In this regards, Arreguín-Sánchez (1995) notes the interannual differences in the Recruits/Spawning Stock relationship (R/SSr), based on a generalized global pattern.

Catchability analysis shows that two important processes are influencing fishing success: recruitment, directly related to cohort strength and shrimp density, and reproductive behavior, with highest vulnerability at the first maturity age. The mechanisms responsible are still unknown.

Results suggest that it is possible to identify a common pattern of recruitment year after year, characterized by intensity and seasonally. In this context, catchability emerge as one of the key parameters reflecting population processes. This was the case for cohort strength, and changes with age, but of particular importance to management is the highest vulnerability at the first maturity age. Current measures to control fishing mortality are in accordance with this results, in the sense that for full exploited resources with the above characteristics, the most important aspect for the offshore fishery is to prevent recruitment overfishing.

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RESUMEN

Se hace una estimación de la mortalidad por pesca para el camarón café (*Penaeus aztecus*) de las costas de Tamaulipas (noroeste del Golfo de México). La estructura por edades mensuales de las capturas y el esfuerzo de pesca para el período de 1974 a 1980, fueron utilizados para efectuar un análisis de cohortes usando el análisis de población virtual. Las estimaciones de capturabilidad con la edad indican una vulnerabilidad más alta para la edad de primera madurez (seis meses). El patrón de la mortalidad por pesca muestra un incremento de este parámetro con la edad, con una tendencia asintótica hacia edades de 8-9 meses, tomando valores de F=0.5. La varianza de F también incrementa con la edad. El tamaño de la población mostró fuertes variaciones interanuales debido al reclutamiento, aunque los patrones estacionales del reclutamiento fueron similares entre años. La tendencia mensual de las cohortes sugiere una situación estable del stock para el período de estudio.

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