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# Mortality, recruitment pattern and growth of the white shrimp *Litopenaeus schmitti* (Crustacea: Penaeidae) from the Gulf of Venezuela

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## Abstract

Mortality, recruitment pattern and growth of white shrimp (*Litopenaeus schmitti*) exploited by the Río Seco community, Falcón State, Venezuela were examined. This represents the first research in relation with the white shrimp fishery after the banning of the industrial bottom trawl fishing. The total length (TL) ranged 90-240 mm ($TL_{mean} \pm SD=162 \pm 19,4$ mm; SD = standard deviation). The proportion female: male (1.5:1) differed significantly from the expected proportion 1:1 ($X^2=168$; $P<0.0001$). The von Bertalanffy growth equations obtained were: $Lt = 220[1\text{-}e^{-1.60(t-0.0153)}]$ (combined sexes), $Lt = 222[1 - e^{-1.69(t-0.0127)}]$ (females) and $Lt = 201[1 - e^{-1.40(t-0.0188)}]$ (males). Total mortality values were 3.96 $year^{-1}$ for females and 5.41 $year^{-1}$ for males. The ranges of M were very wide among the different methods used: females: 1.39-3.60 $year^{-1}$, males: 1.27-3.40 $year^{-1}$; as a consequence of the above results, the ranges of F were also very wide: females: 0.36-2.57 $year^{-1}$, males: 2.01-4.14 $year^{-1}$. Finally, the ranges of E were 0.09-0.65 for females and 0.37-0.77 for males. White shrimp recruited to the fishery of the Gulf of Venezuela throughout the year, although a pulse of intense recruitment occurred between November and February. Mortality and exploitation rates indicate an overexploitation of the resource. The highly variable exploitation rates warn of the need to carefully monitor the intensity of exploitation in the study area, as well as to monitor the portion of the population exploited in Lake Maracaibo. The bulk of the white shrimp catch in Lake Maracaibo is made up of immature individuals, which restricts the recruitment of large mature individuals to the fishery of the Gulf of Venezuela, ultimately affecting the reproductive potential of the species.

**Keywords:** mortality, recruitment, growth, *Litopenaeus schmitti*, Gulf of Venezuela.

# Mortalidad, patrón de reclutamiento y crecimiento del camarón blanco *Litopenaeus schmitti* (Crustacea: Penaeidae) del Golfo de Venezuela

## Resumen

Se examinó la mortalidad, el patrón de reclutamiento y el crecimiento del camarón blanco (*Litopenaeus schmitti*) explotado por la comunidad de Río Seco, estado Falcón, Venezuela. El

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ámbito de longitud total (LT) fue 90-240 mm ($LT_{promedio}$ ± DE = 162 ± 19,4 mm; DE = desviación estándar). La proporción hembras:machos (1,5:1) difirió significativamente de la proporción teórica 1:1 ($X^2$ = 168; $P$<0.0001). Las ecuaciones de crecimiento de von Bertalanffy obtenidas fueron: $L_t = 220[1 - e^{-1,60(t-0,0153)}]$ (sexos combinados), $L_t = 222[1\text{-}e^{-1,69(t-0,0147)}]$ (hembras) y $L_t = 201[1\text{-}e^{-1,40(t-0,0188)}]$ (machos). La mortalidad total (Z) fue 3,96 $año^{-1}$ para hembras y 5,41 $año^{-1}$ para machos. El ámbito de M fue muy amplio entre los diferentes métodos utilizados: hembras: 1,39-3,60 $año^{-1}$; machos: 1,27-3,40 $año^{-1}$. El ámbito de F, consecuentemente, también fue muy amplio: hembras: 0,36-2,57 $año^{-1}$; machos: 2,01-4,14 $año^{-1}$. Finalmente, el ámbito de E fue de 0,09-0,65 para hembras y de 0,37-0,77 para machos. El reclutamiento ocurrió durante todo el año, aunque se observó un pulso de reclutamiento intenso entre noviembre y febrero. Las tasas de mortalidad y de explotación indican una sobreexplotación del recurso. Las tasas de explotación altamente variables advierten sobre la necesidad de vigilar cuidadosamente la intensidad de explotación en el área de estudio, así como también vigilar la porción de la población explotada en el Lago de Maracaibo. El grueso de las capturas de camarón blanco en el Lago de Maracaibo lo conforma individuos maduros, lo cual restringe el reclutamiento a la pesquería del Golfo de Venezuela de individuos maduros de gran tamaño, afectando, en última instancia, el potencial reproductivo de la especie.

**Palabras clave**: mortalidad, reclutamiento, crecimiento, *Litopenaeus schmitti*, Golfo de Venezuela.

## Introduction

The white shrimp (*Litopenaeus schmitti*) has a complex life cycle that includes a coastal or estuarine juvenile phase, exploited by artisanal fishers of Lake Maracaibo and the Gulf of Venezuela, and an adult phase in deeper or marine waters (1), which was exploited by the industrial bottom trawl fishing fleet until March 14, 2009, when the Venezuelan government banned the industrial bottom trawl fishing. This duality of exploitation generated serious conflicts between industrial and artisanal fishers, who accused each other of irrationally exploiting the resource. Currently, only artisanal fishers have access to the resource.

The banning of the industrial bottom trawl fishing entails new challenges for the planning and management of fish populations; therefore, the determination of fundamental biological-fishery parameters is required. In this context, this study provides information on mortality, recruitment pattern and growth of the white shrimp exploited by the community of Río Seco, Falcon State, Venezuela, essential for the design of management strategies ensuring their sustainable exploitation. To the best of our knowledge, this is the first research related to the white shrimp fishery after the banning of the industrial bottom trawl fishing.

The estimation of natural mortality (M) is emphasized, because it is critical for the evaluation of fish stocks (2-7). Several methods to estimate M based on parameters that are commonly used in biological studies were selected, including mean age at sexual maturity ($t_m$), longevity ($t_{max}$) and the parameters of the von Bertalanffy growth function (VBGF) K and $L_{00}$. Most of the selected methods were developed to deal with fish, and only three of them (8-10) are specifically recommended in studies of penaeids. Therefore, it is acknowledged that the use of these methods entails great uncertainty; however, the use of multiple methods may reduce the bias imposed by any of the methods used (2).

## Materials and methods

Sampling was carried out in the fishing area of the community of Río Seco, Falcon State, located in the coastal marine zone of the Gulf of Venezuela (figure 1) This zone was described by Zeigler (11) as a bay, with

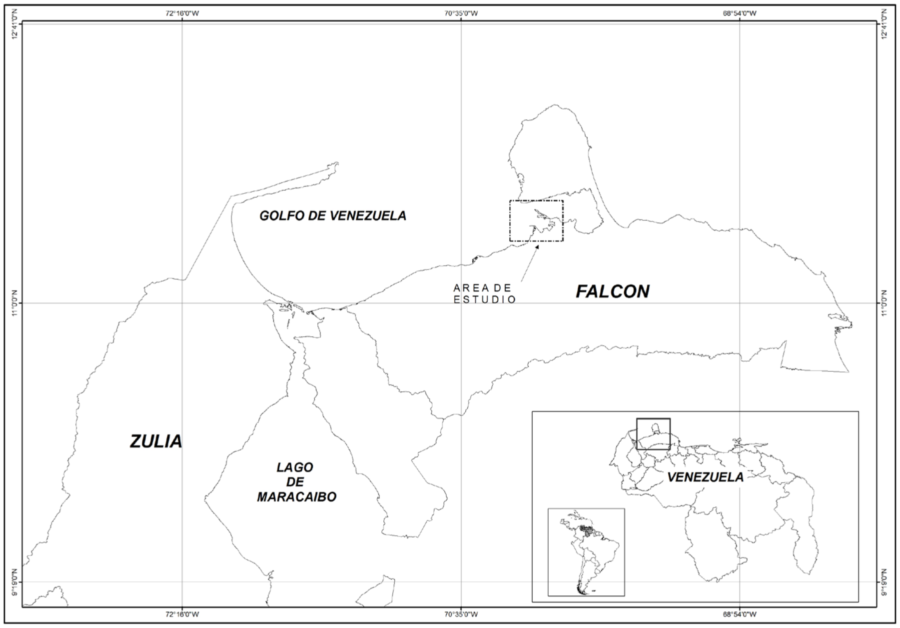


Figure 1. Study area and its relative position on the Venezuelan coast.

depths no greater than 50 m, and average depths in the western zone no greater than 20 m, which maintains direct contact with the Caribbean Sea (ocean waters, up to 37 UPS), Golfete de Coro (very saline waters, up to 45 UPS) and waters of Lake Maracaibo (estuarine waters, up to approximately 3 UPS) (12). Information was haphazardly collected onboard of artisanal fishing boats and in landing sites between September 2008 and November 2009. At each onboard and landing site sampling a random sample was selected from the total catch and identified using taxonomic keys of Perez-Farfante (13), Fisher (14) and Rodriguez (15). Rostrum-telson length (TL, mm), body weight (W, g), and sex were recorded for all specimens collected. A TL-W relation for each and combined sexes was determined by the equation $W = aTL^b$, where W was weight, TL was rostrum-telson length, a was the intercept and b was the slope. A Student's t-test (PROC TTEST; 16) was used to discern whether shrimp showed isometric ($b = 3$) or allometric ($b \neq 3$) growth. A $X^2$ test was performed to determine whether the sex proportion differed from the expected proportion (1:1) (16).

Several routines of the FISAT II (FAO-ICLARM Stock Assessment Tools) package (17) were used to analyze the monthly length frequency distributions and to obtain the parameters K and $L_\infty$ of the VBGF for each and combined sexes. Powell-Wetherall plots (18-19) were first constructed to estimate asymptotic length ($L_\infty$, mm); then, the Shepherd's method (20) was used to scan K values using the above $L_{00}$ and to conduct a response surface analysis and select the K and $L_\infty$ values resulting in the greatest Rn (goodness-of-fit index). These selected values, together with $t_0$, estimated with the von Bertalanffy plot (21), were input into ELEFAN I (22) to generate a VBGF. The parameters C (amplitude) and WP (winter point) (21) implicit in the VBGF of ELEFAN I were set to zero, so it is assumed that the growth of the white shrimp is continuous (23). To assess the relevance and reliability of the estimates of K and $L_\infty$, they were compared with those of related species according to criteria of Pauly and Munro (24), who indicated that there is a species-specific relation, at the genus level, between $Log(L_\infty)$ and Log(K) such that the relation between these parameters remains constant, independently of their values and $\Phi' = LogK + 2LogL_\infty$.

The length converted catch curve (17) based on data of length composition was used for estimating total mortality (Z); regression line was fitted to the descending limb from the modal group plus one through all ages represented by at least five individuals. Equations used for estimating M were as follows: $M = e^{1.44-0.982*Lnt_{max}}$ (7); $M = 2.996/t_{max}$ (8); $M = (1.521/t_m^{0.72}) - 0.155$ (9); $M = -Ln0.01/t_{max}$ (10); $M = 3K/(e^{0.38*K*t_{max}} - 1)$ (25 ); $LnM = -0.0152 - 0.279*LnL_\infty + 0.6543*LnK + 0.4634*LnT$ (26) and $M = 3K/(e^{K*t_m} - 1)$ (27). The parameters K and $L_\infty$ are those of the VBGF, $t_m$ = mean age at sexual maturity (year), $t_{max}$ = longevity (year), and T = mean water temperature (°C); $t_{max}$ was obtained from the equation $t_{max} = (3/K) + t_0$ (28). For estimating $t_m$, it was assumed that the mean length at sexual maturity of the white shrimp is 12 cm for males and 13 cm for females (29-31). These authors estimated the length of sexual development stage of females based on size and coloration of the ovaries with the following scale: Phase I: immature, Phase II: maturing, Phase III: mature and Phase IV: spent. In the case of males, sexual maturity was estimated in accordance with the development of the petasma: separate petasma = Phase I: immature and attached petasma= Phase II: mature. The corresponding ages to these lengths were obtained with the VBGF obtained in this research.

Once Z and M were obtained, the fishing mortality rate (F) was estimated from F = Z – M and the exploitation rate (E) as E = F/Z. All mortality rates were obtained for each sex and the mean water temperature (26°C), included in the Pauly's natural mortality equation (26), was obtained with a multiparametric probe YSI 55 (YSI Incorporated, USA) at each sampling onboard. The recruitment pattern (combined sexes) for the study zone was obtained following the methodology proposed by Moreau and Cuende (32), included as a subroutine in FISAT II.

## Results

A total of 4637 individuals, 2135 onboard (number of net sets = 56) and 2502 in landing sites (number of boats sampled = 74) was recorded. The TL range for combined sexes was 90-240 mm ($TL_{mean} \pm SD = 162 \pm 19.4$ mm; SD = standard deviation), for females it was 90-240 mm ($TL_{mean} \pm SD = 167 \pm 20.7$ mm) and for males it was 90-230 mm ($TL_{mean} \pm SD = 158 \pm 16.2$ mm). The TL-W relation indicated that the white shrimp growth was allometric (combined sexes: $W = 1.5 \times 10^{-6}TL^{3.20}$, t = 24.5, $P<0.001$; females: $W = 1.6 \times 10^{-6}TL^{3.29}$, t = 14.3, $P<0.001$; males: $W = 1.4 \times 10^{-6}TL^{3.32}$, t = 19.7, $P<0.001$). The female:male proportion was 1.5:1 (2761 females and 1876 males), and it differed significantly from the expected proportion (1:1; $X^2 = 168$, $P<0.0001$).

The final values of $L_\infty$ and K were obtained with the response surface analysis of ELEFAN I, which generated values of Rn = 167 for combined sexes, Rn = 150 for females and Rn= 213 for males; these values together with the $t_0$ estimated with the von Bertalanffy plot yielded the following growth equations: $L_t = 220[1 - e^{-1.60(t-0.0153)}]$ (combined sexes), $L_t = 222[1 - e^{-1.69(t-0.0147)}]$ (females) and $L_t = 201[1 - e^{-1.40(t-0.0188)}]$ (males). These results demonstrated that females grow faster than males, reaching lengths up to 180 mm TL in 12 months. The values of Φ were similar between sexes ($\Phi'_{females} = 2.92$, $\Phi'_{males} = 2.75$), and conform well to the values of the upper end of the range of values found in the literature for species of the same genus (2.58-3.04 for females and 2.46-3.08 for males) (33-40).

Total mortality values were 3.96 $year^{-1}$ for females and 5.41 $year^{-1}$ for males. The ranges of M were very wide among the different methods used: females: 1.39-3.60 $year^{-1}$, males: 1.27-3.40 $year^{-1}$ (table 1); as a consequence of the above results, the ranges of F were also very wide: 0.36-2.57 $year^{-1}$ for females and 2.01-4.14 $year^{-1}$ for males. Finally, the ranges of E were 0.09-0.65 for

Table 1
Values of mortality (M = natural, Z = total, F = fishing; year$^{-1}$) and exploitation (E) rates for females (FE) and males (M) of the white shrimp *Litopenaeus schmitti* in western Venezuela. The indicated methods are for calculations of M (see text for details), the other rates were obtained using the techniques given in the text and through the equation Z = F + M

| Method | M (FE) | M (M) | Z (FE) | Z (M) | F (FE) | F (M) | E (FE) | E (M) |
|---|---|---|---|---|---|---|---|---|
| Taylor (1960) | 1.66 | 1.36 | 3.96 | 5.41 | 2.30 | 4.05 | 0.58 | 0.75 |
| Alverson and Carney (1975) | 2.32 | 1.63 | 3.96 | 5.41 | 1.64 | 3.78 | 0.41 | 0.70 |
| Rikhter and Efanov (1976) | 2.28 | 1.92 | 3.96 | 5.41 | 1.68 | 3.49 | 0.42 | 0.65 |
| Pauly (1980) | 1.39 | 1.27 | 3.96 | 5.41 | 2.57 | 4.14 | 0.65 | 0.77 |
| Hoenig (1983) | 2.40 | 1.90 | 3.96 | 5.41 | 1.56 | 3.51 | 0.39 | 0.65 |
| Alagaraja (1984) | 2.60 | 2.10 | 3.96 | 5.41 | 1.36 | 3.31 | 0.34 | 0.61 |
| Roff (1984) | 3.60 | 3.40 | 3.96 | 5.41 | 0.36 | 2.01 | 0.09 | 0.37 |

females and 0.37-0.77 for males. White shrimp were recruited to the fishery of the Gulf of Venezuela throughout the year, although a pulse of intense recruitment occurred between November and February (figure 2).

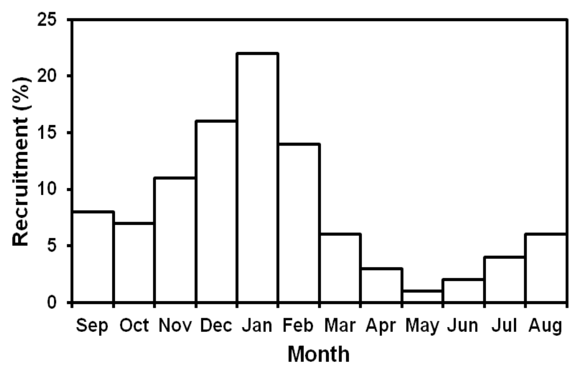


Figure 2. Recruitment pattern for white shrimp *Litopenaeus schmitti* in the Gulf of Venezuela, estimated from catch obtained in the fishing zone of the fishing community of Río Seco, Falcon State between September 2008 and November 2009, suggesting a single recruitment pulse between November and February.

## Discussion

In 2005, Andrade Morán (29) indicated that there were biological, technological and economical interdependencies in the white shrimp fishery in western Venezuela that were not recognized during the assessment and implementation of management plans. These interdependencies were the result of the white shrimp having a life cycle taking place in two different environments that were exploited by two fleets with different fishing power, and that sequentially impacted the same resource; the scientific information taken from these two fleets were usually analyzed as separate entities as regards the dynamics of the resource in each environment and the effects on each of the different fishing fleets.

One of the biological consequences of this was the underestimation of the growth parameters from length frequencies obtained only from the artisanal fishery of Lake Maracaibo. However, the results of this research indicated that, nonetheless small differences, the asymptotic lengths for the white shrimp were similar to those previously reported. In her study, Andrade Morán (29) reported length ranges of 70-175 mm TL for Lake Maracaibo and of 130-235 mm TL for the Gulf of Venezuela, from which reported values of $L_\infty$ = 217 mm TL for females and $L_\infty$ = 194 mm TL for males. In this case, the length structure obtained for both sexes was a little wider (90-240 mm TL) than that obtained by Andrade Morán (29) for the Gulf of Venezuela, allowing to obtain greater $L_\infty$ values (females: $L_\infty$ = 222 mm TL, males: $L_\infty$ = 201 mm TL).

The K values obtained in this research (females: 1.69 year$^{-1}$, males: 1.40 year$^{-1}$), nevertheless, not only differed from those of Andrade Moran (females: 0.95 year$^{-1}$, males: 1.10 year$^{-1}$) (29), but indicated that females grew faster than males. Beyond the technical connotations this can have, the most significant of these results are the following two key aspects: 1) the white shrimp fishery of the study zone is fundamentally supported by adults, and 2) the values of the growth parameters significantly influence the values of M estimated with the three applied methods.

Natural mortality of crustacean is indeed highly variable. For instance, fishery studies on blue crab (*Callinectes sapidus*) (41-42), western king prawn (*Penaeus latisulcatus*) (43) and northern shrimp (*Pandalus borealis*) (44) indicate that natural mortality rates vary considerably with respect to factors such as sex, size, habitat and season. In addition, Fu and Quinn (44) suggested that the gradual increase of the natural mortality experienced by the northern shrimp in the Kachemak Bay, Alaska may have resulted from increased predation pressure from groundfish. Even though there is no empirical evidence supporting it, in the case of the white shrimp of the Gulf of Venezuela, it is interesting to consider the above possibility. The banning of the industrial bottom trawl fishing opens up the possibility of increased predation pressure on species such as the penaeids, since it could be expected that many fish stocks previously exploited by this fishery (particularly snappers and groupers) to recover due to the decrease in fishing pressure exerted on them (45). In any case, and despite the uncertainty surrounding this type of results, from an evolutionary perspective high rates of natural mortality found in this study are consistent with other features of the life histories of shrimps, such as high rates of growth, early maturation and relatively short periods of life (2, 46-47).

The broad scope of the M values found in this research emphasizes the importance of the understanding of the population dynamics of this species. This high variability in M in turn leads to a range of E extremely large as well. The range of E for females was 0.09-0.65 year$^{-1}$; which would imply that this part of the population would be underexploited, according to the lower limit of the range, or overexploited, according to the upper limit of the range. In the case of males (0.37-0.77 year$^{-1}$), the situation would be less extreme, although the upper limit of the range would imply that this part of the population would be heavily overexploited. In any case, the largest estimates of M would imply that the exploitable fraction would be mainly composed of one or two year-classes, which is consistent with the findings of Ju *et al.* (48) and Hewitt *et al.* (2) for the blue crab (*Callinectes sapidus*) in Chesapeake Bay, USA. One of the results of all this is that the age structure of the population and its capacity to support the fishery are strongly dependent on the magnitude of the annual recruitment (2).

However, the results of this research indicate that the recruitment of the white shrimp to the study area could be failing, since only an intense pulse between November and February is observed, different from the characteristic pattern of two pulses of different intensity during the year for tropical species. This pattern is atypical for this species, such as it is confirmed by Andrade Morán (29), who reported a pulse of maximum intensity between February and May and another of lower intensity between July and December; Andrade and Stotz (33), who indicated that the pattern of recruitment of white shrimp is bimodal, with pulses in February-April and August-October; and Cadima *et al.* (50) who indicated that the white shrimp caught in the Gulf of Venezuela is recruited to the fishery throughout the year, with periods of greatest intensity around March-April and August-September

That being said, what implications could this anomalous behavior of the white shrimp recruitment have? Most of the fisheries that exploit short-lived species are based on one or more pulses of recruitment during the year, and each pulse can be a part, or the whole, of the stock exploited each year (49). The recruitment of one or more cohorts towards the population is essential, and fundamentally dependent on the reproductive success of each cohort and the survival of eggs and early life stages (49). Based on the bibliographic evidence (29-31, 40) indicating that the spawning of white shrimp is bimodal (January-June and October-November, approximately), it is suggested that the non detection of the two pulses of recruitment in this research could indicate that one of these pulses is failing. According to the literature, the pulse of recruitment that was observed between November and February would correspond to individuals spawned during January-June, when they have already reached a total length of approximately 120 mm, according to the VBGF for combined sexes, and an age of 0.5 years old.

Another aspect that could threaten the sustainability of the fishery of white shrimp in western Venezuela is the proportion of sexes, since the results of this research indicated that females dominated catches of white shrimp in the area of Río Seco; these results are consistent with reports of Andrade Morán (29). The reason for this pattern is unclear, but it could be that this is the real proportion, i.e., that there are more females than males naturally, or that there is a differential sexual migration into the area of Río Seco. The sex ratio changes considerably between different species, differs from a population to another and may vary from year to year within the same population (52), and is a good indication of the fishery status of exploited populations.

## Management implications

Despite the fact that, as noted above, the portion of the population captured by the artisanal fishery of Río Seco is characterized by large, adult individuals, the highly variable exploitation rates warn of the need to carefully monitor the intensity of exploitation in the study area, as well as to monitor the portion exploited in Lake Maracaibo, which can be considered the area where juveniles of this species are (29), because its depletion would accelerate the disappearance of the older shrimps. Gulland and Holt (53), pointed out that a value of $E > 0.5$ indicates an intense level of exploitation of the resource, and that the optimal value of the rate of exploitation occurs when $F = M$. On the other hand, Ricker (54) indicates that the overexploitation of a resource leads to reduction of the average size of the population over time.

From a management viewpoint, a significant feature of this work is that it confirms what Andrade Morán (29) postulated; i.e., that the portion of the population exploited by the artisanal fishery in the Gulf of Venezuela by the fishing community of Río Seco differs from the portion of the population exploited in Lake Maracaibo. It is believed that the reason for this difference lies in the mesh sizes of the fishing gear used.

In the case of Lake Maracaibo, the predominant white shrimp fishing gear is a type of beach purse seine called *mandinga*, with a mesh size ranging 1-2 cm (29); whereas in the Gulf of Venezuela case, the fishing gear used was a monofilament drift net called *tendedor derivante* with a mesh size of 6.35 cm (55). Now, what are the implications of all this for the white shrimp fishery in western Venezuela? It becomes evident that all this prevents the proper management of the fishery, and if continue to do so it could have negative consequences for the fishery. The bulk of the white shrimp catch in Lake Maracaibo is made up of immature individuals, which restricts the recruitment of large mature individuals to the fishery of the Gulf of Venezuela, ultimately affecting the reproductive potential of the species.

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