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Catch dynamics, growth, and reproduction of striped mojarra *Eugerres plumieri* in Lake Maracaibo, Venezuela

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Abstract

Catch dynamics, growth and reproductive aspects of striped mojarra were examined during a 3-year study in the El Tablazo Bay, an important estuarine system within the lake basin. Sampling was conducted semimonthly from January 2000 to December 2002 using beach seines and cast nets. Fluctuations in catch were substantial. The proportion female:male was 1.77:1. Length-weight relations were: $W = 0.00000791TL^{3.08}$ (W = weight, TL = total length) for females and $W = 0.000175TL^{2.47}$ for males. There were an intense recruitment pulse in April and a minor one in September. Sizes of first sexual maturity were 180 mm TL for females and 170 mm TL for males. Parameters of the von Bertalanffy growth function were: $L\infty = 374$ mm TL, $k = 1.27$ $year^{-1}$ and $t_0 = 0.27$ year for females; $L\infty = 313$ mm TL, $k = 1.78$ $year^{-1}$ and $t_0 = -0.46$ year for males. Available information suggests that catch of striped mojarra follows Lake Maracaibo natural periodic tidal-discharge rhythms. Evidence presented in this paper suggests that if either the tidal or the discharge patterns are changed, catches of strip mojarra may be affected. Striped mojarra make up an abundant fish resource that plays important ecological and fishery roles in Lake Maracaibo. Given the increasing fishery importance of striped mojarra, initiatives should be developed to protect its population in Lake Maracaibo.

Key words: striped mojarra, recruitment dynamics, growth, Lake Maracaibo, Venezuela.

Dinámica de captura, crecimiento y reproducción de la mojarra rayada *Eugerres plumieri* en el Lago de Maracaibo, Venezuela

Resumen

Se examinó la dinámica de captura, el crecimiento y aspectos reproductivos de la mojarra rayada durante tres años en la Bahía El Tablazo, un importante sistema estuarino dentro de la cuenca del lago. El muestreo se condujo quincenalmente desde enero de 2000 a diciembre 2002 usando redes playeras y atarrayas. Las fluctuaciones en la abundancia fueron substanciales. La proporción hembra:macho fue 1,77:1. Las relaciones longitud-peso fueron $W = 0{,}00000791LT^{3.08}$ (W = peso, LT = longitud total) para hembras y $W = 0{,}000175LT^{2.47}$ para machos. Hubo un pulso de reclutamiento intenso en abril y uno menor en septiembre. Los ta-

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maños de primera maduración sexual fueron 180 mm LT para hembras y 170 mm LT para machos. Los parámetros de la ecuación de crecimiento de von Bertalanffy fueron: $L\infty$ = 374 mm LT, k = 1,27 año^{-1} y t_0 = –0,27 año para hembras; $L\infty$ = 313 mm LT, k = 1,78 año^{-1} y t_0 = –0,46 año para machos. La información disponible sugiere que la captura de la mojarra rayada sigue los ritmos de marea-descarga naturales periódicos del Lago de Maracaibo. La evidencia presentada en este artículo sugiere que si los patrones de marea o descarga se cambian, las capturas de la mojarra rayada pudieran afectarse. La mojarra rayada es un recurso pesquero abundante que juega papeles ecológicos y pesqueros importantes en el Lago de Maracaibo. Dada la creciente importancia pesquera de la mojarra rayada, se deberían desarrollar iniciativas para proteger su población en el Lago de Maracaibo.

Palabras clave: mojarra rayada, dinámica de reclutamiento, crecimiento, Lago de Maracaibo, Venezuela.

Introduction

The striped mojarra *Eugerres plumieri* (Cuvier, 1830) is the most important Gerreidae in Venezuela. Four gerreid genera have been reported in Venezuela, *Eucinostomus*, *Gerres*, *Diapterus* and *Eugerres* (1). The striped mojarra has been recorded from South Carolina to western Florida in the USA, from the entire Gulf of Mexico to Brazil but it is absent from Bahamas and smaller islands in West Indies; and it is very common in the Gulf of Venezuela (2-3). Locally known as carpetas, the members of this family are common in the mangrove zones and coastal lagoons of the Lake Maracaibo basin. Although striped mojarra has been, for years, an important commercial fishery resource in coastal lagoons in tropical areas; e.g., Terminos Lagoon, Mexico (4-5), Ciénaga Grande de Santa Marta, Colombia (6) and Tacarigua Lagoon, Venezuela (7) in Lake Maracaibo this species was until recently mainly used as bait in the crab pot fishery; few people indeed consumed striped mojarra.

However, a moderate but increasing artisanal fishery of striped mojarra has developed in the last few years in western Venezuela, including the Lake Maracaibo basin (8). Any perception that the striped mojarra is an irrelevant fishery resource is changing rapidly. The increasing diminishing in the catch of traditional commercial fish species and the concomitant increasing in their prices, are encouraging an increasing demand of fish species formerly considered of second category as the striped mojarra. In addition, fish as striped mojarra are essential to the successful functioning of wetland food webs through their roles as prey and predators (4, 9). Striped mojarra feeds on aquatic insects, crustaceans, micro bivalves, plants, and detritus (10-12), and it is predated by snook (*Centropomus undecimalis*) and lake curvina (*Cynoscion maracaiboensis*) (13). The Lake Maracaibo basin is under extensive development pressure (e.g., oil exploitation, real estate development, dredging of navigational channels, establishment of shrimp farms) and fish habitat restoration plans are a due to preserving the integrity and functionality of this water body. However, gaps in baseline knowledge remain. Basic life history parameters (e.g., growth rate, age at maturation, recruitment) are needed to make predictions about fish resilience under alternative management scenarios. Currently, basic life history parameters remain to be determined even for the most common and abundant fish species in Lake Maracaibo.

Thus, objectives were to examine recruitment and catch dynamics and to evaluate growth and reproduction of striped mojarra in Lake Maracaibo. Final results of this research will not only provide a basic characterization for the striped mojarra population across time, as well as among various hydrological conditions in El Tablazo Bay, an important estuarine system within the Lake Maracaibo basin, but also basic fishery information needed to the implementation of future effective management plans.

Materials and methods

Lake Maracaibo (figure 1) is a coupled ocean-lake system connected through a partially mixed estuary, located on the Caribbean coast of Venezuela. The dynamic characteristics of this estuarine system result from the motion and interaction of sea and freshwater in its different water bodies: gulf, bay, strait, lake and rivers. The Gulf of Venezuela communicates at its southern boundary with El Tablazo Bay through three narrow inlets. El Tablazo Bay is a broad shallow embayment enclosed by barrier bars and islands and connected with the Strait of Maracaibo. El Tablazo Bay and the Strait of Maracaibo form a typical partially mixed estuary. The Lake of Maracaibo, a salt stratified water body, is located at the southern end of the Strait of Maracaibo. A navigation channel, that reaches depths of 15 m, crosses the system from the Gulf to the Lake (14). There is an extensive mangrove system in the northern part of the lake, and a substantial fluvial input in the southern part. The rain regime has a pronounced peak during the second half of the year. At that time, most of the lake exhibits freshwater conditions caused by rain runoff. The surface water salinity throughout the lake fluctuates strongly.

Sampling was conducted in El Tablazo Bay, an important estuarine system in the northern portion of Lake Maracaibo. This bay is influenced by tides, and near the sampling station salinity generally ranges from 10 to 28 and temperature ranges from 26 to 30°C. The bay has a maximum depth of about 12 m at mean low water, and its substrates are primarily fine sand and mud.

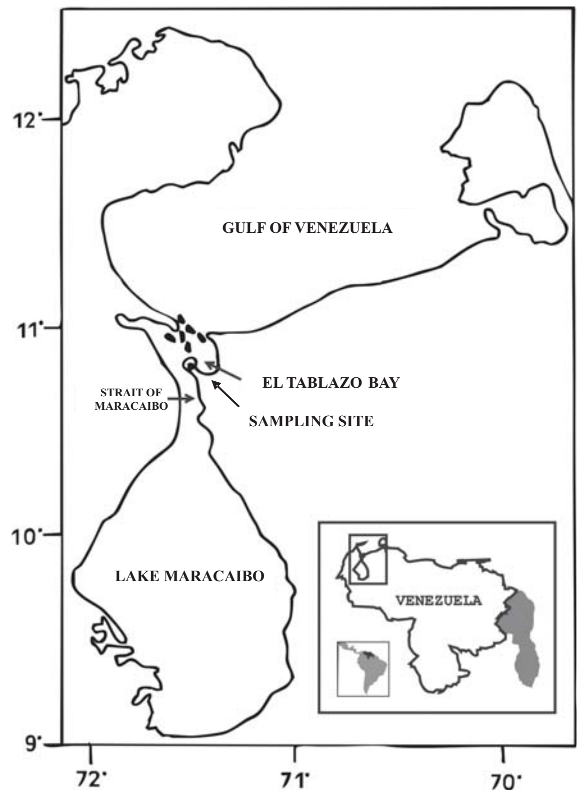

Figure 1. Sampling area and its relative position on the Venezuelan coast. Circle represents the sampling site.

Samples were collected semimonthly from January 2000 to December 2002 (excluding December 2000, January and February 2001 and June 2002), every other hour between 1000 and 2400 hours, with beach seines (12.7-mm stretched mesh, 70 m long × 2 m deep) and cast nets (25.4-mm mesh, 2.5-m diameter). Beach seines were number-9 multifilament nylon; cast nets were number-12 multifilament nylon. Eight samples with each net were taken in each sampling period for a total of 1024 samples during the entire study. To avoid potential confusion, from now on samples will be referred as catch for the sake of interpretation of results.

Fish were collected in Punta de Palmas, a town located at the north entrance of the Strait of Maracaibo; fish were typically sighted (swirls or flips) before the seines or cast nets were deployed. All striped mojarra collected were measured for total length (TL; mm) and body weight (W; g), and determined sex, and maturity stage.

Maturity stages were recorded following a modification of the generalized classification of maturity stages in fish proposed by Kesteven (15). Fish were judged to be inactive, developing, ripe or spent based on the macroscopic observation of the developmental stage of ovaries and testes. The percentage of ovaries and testes in each maturity stage was determined monthly to establish the spawning season. During each sampling, surface water salinity and temperature were measured with a Hydrolab DataSonde 4a (Hach Company), and transparency was determined with a Secchi disk. I used additional data on water salinity, temperature, and transparency, provided by Instituto Nacional de Investigaciones Agricolas (INIA) personnel.

The study of growth basically means the determination of the body size as a function of age. In temperate waters such data can usually be obtained through the counting of year rings on hard parts such as scales and otoliths. Such rings are formed due to strong fluctuations in environmental conditions from summer to winter and vice versa (16). In the tropical areas such changes do not occur and it is, therefore, difficult to use this kind of seasonal rings for age determination. Fortunately, in the last few years several numerical methods have been developed (e.g., ELEFAN, LFSA, FiSAT) which allow the conversion of length frequency data into age composition; all these methods use the von Bertalanffy growth function (VBGF; 17) as the model to describe growth in fish. The generalized VBGF is:

$$L_t = L\infty\ [1 - \exp^{-k(t - t_0)}]$$

where L_t is the length at time t, L∞ is the theoretical maximum length a fish can obtain if it lived indefinitely, k is the growth coefficient, and t_0 is the hypothetical time when length equals zero. Length frequency data were analyzed with the FAO-ICLARM Fish Stock Assessment Tools (Fisat II; 18). FiSAT II provides several options to estimate the growth parameters of the VBGF. Powell-Wetherall plots (19-20) were first constructed to estimate L∞; then, the Shepherd's (21) method was used to scan k values using the above L∞ and to conduct a response surface analysis and select the k and L∞ values resulting in the greatest R_n (goodness-of-fit index). Finally, the generated k and L∞ values were input into ELEFAN I (22) to generate a VBGF. If the curve did not appear to fit the data, the values of the input parameters were modified and reran the analysis. An automated search routine option in ELEFAN I was also used to let the computer find the best combination of parameters (best fit of the curve = greatest R_n; 23). Because t_0 cannot be estimated with length frequency analyses, the von Bertalanffy plot (16) was used for estimating this parameter. Analyses of length frequency were applied to data for each sex by separated and combined years. All methods used in this study to estimate the growth parameters showed a certain degree of subjectivity when being executed. Among all of the obtained estimates from the different methods, the ELEFAN I values were selected as the most appropriate due to this subroutine offers the most options (i.e., k-scan, response surface, and automatic search) to estimate the VBGF parameters. A modification of the Hotelling's T^2 test (24) was used to compare growth curves of the two genders. This test assumes that estimations of L∞, k and t_0 for the two genders were obtained from two normal distributions of joint probability with three variables and one common variance.

A TL-W relation was determined by the equation $W = aTL^b$, where W was weight and TL was total length. Length-weight relations were calculated independently for each sex.

A Student's t-test (PROC TTEST; 25) was used to discern whether fish showed isometric (b = 3) or allometric growth (b ≠ 3). The theoretical recruitment pattern was estimated by the methods given by Pauly (26) and Moreau and Kuende (27). These methods reconstruct the recruitment pulses from a time series of length frequency data to determine the number of pulses per year and the relative strength of each pulse.

Results

A total of 6342 (3974 females and 2368 males) striped mojarra was collected, ranging from 67 to 367 mm TL. The largest catches were in February (462 fish), May (492 fish), June (403 fish) and August (533 fish)-September (463 fish) 2000; and the smallest ones were in January (52 fish) 2000, May (93 fish), August (88 fish) and November (76 fish) 2001, and February (76 fish), April (33 fish)-May (65 fish), July (73 fish) and November (43 fish)-December (41 fish) 2002. Salinity, temperature and transparency fluctuated greatly throughout the study, and the differences were significant between different quarters of the year (F = 3,96, df = 3, $P = 0.035$). There was a relation between the physicochemical parameters and catch of striped mojarra; more fish were caught during the two quarters (January-March and April-June) that had higher salinities (28.8 and 22.4) and transparency (0.37 and 0.36 m) and lower temperature (27.8 and 29.5°C). There was a general trend for catch of striped mojarra to diminish during the sampling period, with a maximum of 3645 fish in 2000 and a minimum of 981 in 2002. Total length ranged between 67 and 367 mm for females and between 71 and 297 mm for males. Female significantly outnumbered males; the mean sex ratio was 1.7:1 ($\chi^2 = 406$; df = 1; $P < 0.005$). The annual sex proportions were consistently biased in the favor of females; the general sex ratios were 1.5:1 (2000), 1.6:1 (2001) and 3.5:1 (2002). This trend coincided with the diminishing of catch. Although few fish (~25 per cent) were in late maturity stages, analyses of ovaries indicated that striped mojarra spawn throughout the year, with pulses of spawning in March and August-December (figure 2). Females began gonad development toward sexual maturity at approximately 180 mm TL and males at approximately 170 mm, although many smaller specimens were in late maturity stages (e.g., a 104 mm TL male and a 90 mm TL female).

The TL-W relations were described by the equations $W = 7.91\times10^{-6}\ TL^{3.08}$ (females; $r^2 = 0.86$, df = 1, $P < 0.001$) and $W = 1.75\times10^{-4}\ TL^{2.47}$ (males; $r^2 = 0.66$, df = 1, $P < 0.002$). Student's t-tests on the b coefficients indicated that growth for female striped mojarra was isometric (H_0: b = 3; t = 0.736, df = 2328, $P = 0.089$), whereas for male it was negative allometric (H_0: b = 3; t = 5.27, df = 1411, $P = 0.0023$).

The fitted growth curves found by ELEFAN I are presented in figures 3 and 4. Parameters of the VBGF for the two sexes were: $L\infty = 374$ mm, $k = 1.27$ year^{-1}, $t_0 = -0.27$ year for females; $L\infty = 313$ mm, $k = 1.78$ year^{-1}, $t_0 = -0.46$ year for males. Growth parameters differed between sexes ($T^2 = 12345$, df = 1, $P < 0.001$). These results predict lengths of 299, 353, 368 and 372 mm TL for females 1, 2, 3 and 4 years old; and 289, 309 and 312 mm TL for males 1, 2 and 3 years old. Striped mojarra obtain > 90% of their theoretical asymptotic length at ages of one and two years, which indicates this is a fish species of short life and rapid growth.

The recruitment pattern suggests two recruitment pulses of different strength per year (figure 5), one strong in September and another weak in April. The weak pulse could be associated with the August-December spawning period, whereas the intense pulse could be associated with the March spawning period. This allows inferring that striped mojarra recruit to Lake Maracaibo fishing areas at around six months of age.

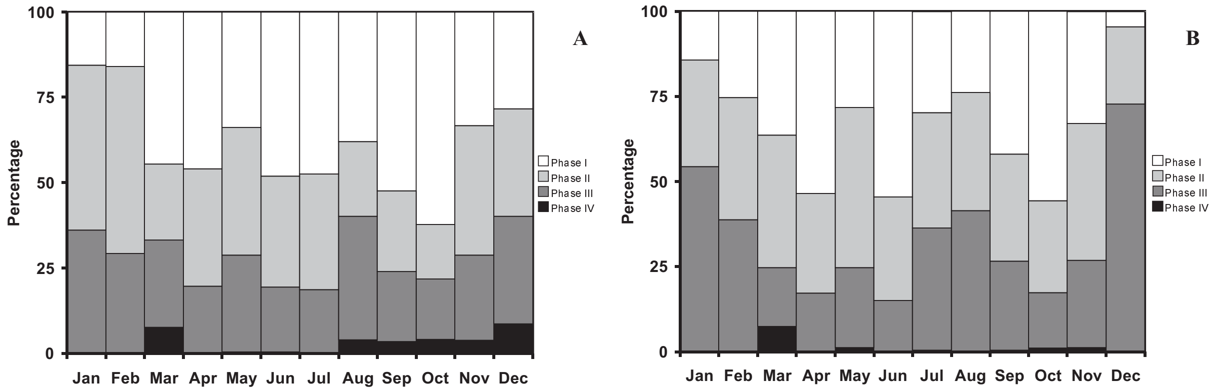

Figure 2. Monthly frequency of sexual maturity phases for females (A) and males (B) striped mojarra *Eugerres plumieri* in Lake Maracaibo, Venezuela.

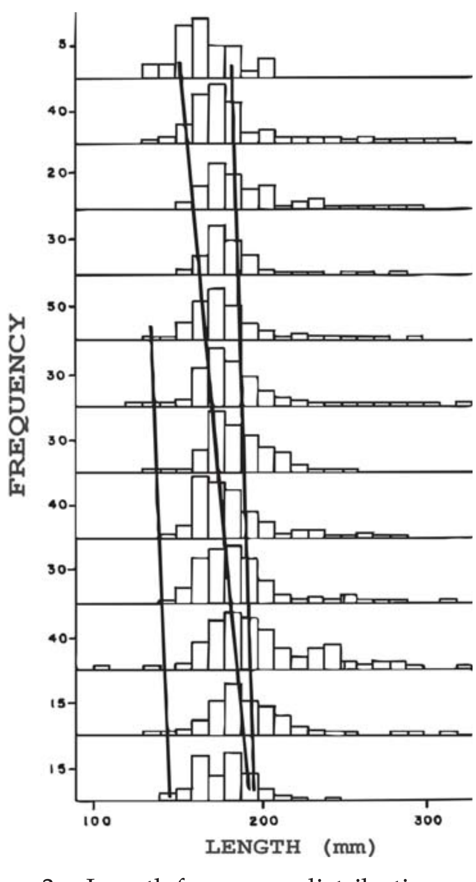

Figure 3. Length frequency distribution and fitted growth curves (parameters L∞ = 374 mm TL, k 1= 1.27 year^{-1} and t_0 = –0.27 year) found by ELEFAN I for females striped mojarra *Eugerres plumieri* in Lake Maracaibo, Venezuela.

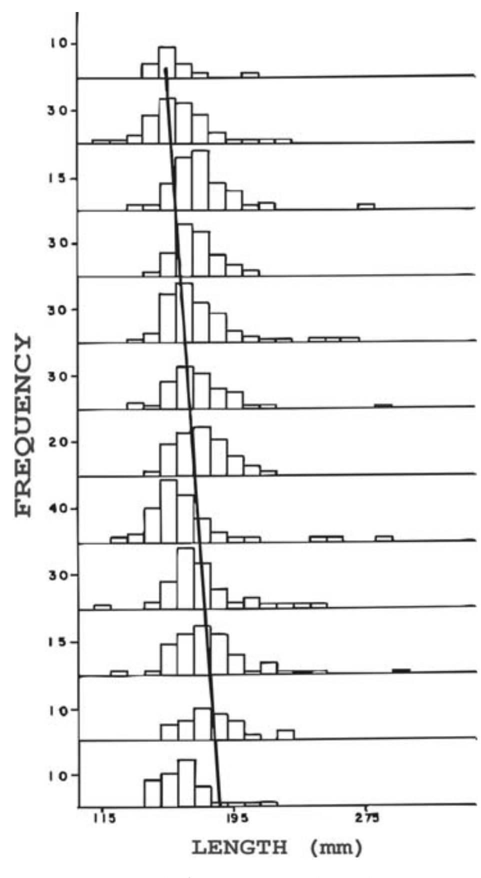

Figure 4. Length frequency distribution and fitted growth curves (L∞ = 313 mm TL, k = 1.78 year^{-1} and t_0 = -0.46 year) found by ELEFAN I for males striped mojarra *Eugerres plumieri* in Lake Maracaibo, Venezuela.

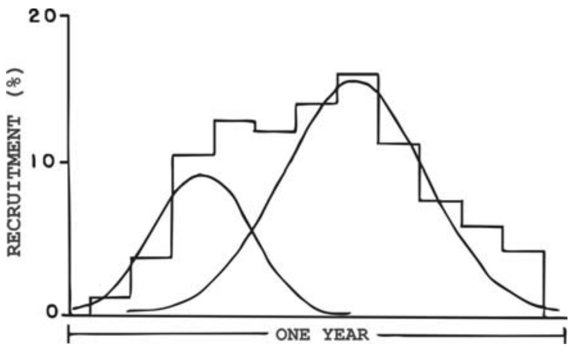

Figure 5. Recruitment pattern showing two annual pulses of recruitment for striped mojarra *Eugerres plumieri* in Lake Maracaibo, Venezuela.

Discussion

Understanding variation in the catch of fish populations has long been a central theme of fisheries research (28-29). Knowledge of the estuarine ecology of juvenile fish and the interactions among the patterns of catch, growth and reproduction should improve our ability to forecast the contribution of these fish to the ecosystem. The ecological patterns that control population fluctuations in environments like Lake Maracaibo are difficult to discern, but it may be associated with population internal feedback mechanisms, such as cannibalism, and periodical climatic factors (4, 30-32). Many physical factors have been associated with the larvae and juveniles recruitment of fish to estuaries, among them current velocity, salinity, temperature, turbidity and lunar phases (33). Individually and in concert each factor plays a role in the alteration of the behavior of organisms. Lake Maracaibo is an estuarine system with a unique tidal oscillation, in which the dominant source of current variability is the tide and its interactions with other phenomena such as winds and freshwater discharge (14). Fish and other estuarine organisms have adapted to this regular oscillations (34); communities of fish and crustaceans inhabiting estuaries represent a combination of freshwater and marine species both living at the edge of their distribution, estuarine resident and migrating species passing the estuary on their way to the spawning grounds (34-39). Due to this, the spatial organization of estuarine communities is highly correlated with salinity (40-41).

According to my results, Lake Maracaibo is not an exception to this pattern. Although the monthly variation in striped mojarra catches was substantial, greater catch levels were significantly positively correlated with salinity and transparency. During the rainy season, rivers that drain into Lake Maracaibo have strong flows, which decrease salinity and transparency. These changes may affect the behavior of the organisms, and provide stimuli for larval and juvenile striped mojarra orientation (42). These variations are also typical for white mullet (*Mugil curema*), another important fish species in Lake Maracaibo (43-44), and for blue crab (*Callinectes sapidus*) and macrobenthic organisms in the Chesapeake Bay (45-46). On the other hand, this behavior suggests that internal feedback mechanisms at the population level are not responsible for these variations (47). However, experimental evidences suggest that salinity is not an important factor regulating larval and juvenile estuarine recruitment (48). Turbidity and its associated variable, transparency, may be important factors because many fish species show preference for waters with higher turbidities than seawater (49).

The bulk of striped mojarra collected was made up mainly of juveniles or adult individuals in the early stages of gonad maturity. This pattern is typical for other migratory estuarine fish species in Lake Maracaibo (43-44) and for gerreids in general elsewhere; e.g., Aguirre León and Yánez Arancibia (4) in Mexico, Rueda Hernández and Santos Martínez (6) in Colombia, and reflects that these fish early life stages use these estuarine areas as nursery habitat. Different than elsewhere [e.g., Aguirre León and Yánez Arancibia (4)], females significantly outnumbered males in the sample. The reason for this is not clear, but it may be that this is the real proportion (that is, there is more females than males naturally), or that there is a sex selective migration into the Lake Maracaibo estuarine areas from marine areas (that is, more females than males migrate into Lake Maracaibo). In addition, the larger maximum size of females may be another likely cause for beach seines and cast nets being ineffective at collecting smaller males.

The trend of declining catch throughout the years observed for striped mojarra in Lake Maracaibo has been observed for other fish species elsewhere (e.g., bluefish *Pomatomus saltratix*; 50-52) as well, but the high mobility of striped mojarra, coupled with their year-round migration confound interpretation of these data. It seemed doubtful that the measured values of catch in a single bay could reflect the population abundance as a whole, but total loss rates of striped mojarra indicate relatively high rates of mortality, emigration, or both from beach habitats.

Gerreids in general are fish of fast growth (4, 6, 53), and my analyses indicated that striped mojarra from Lake Maracaibo was not an exception to this pattern. The growth parameters for both sexes were numerically different. The estimated $L\infty$ were lower and k values were higher than those reported by Rueda Hernández and Santos Martínez (6) for the same species and using the same method in Ciénaga Grande de Santa Marta, Colombia. It is difficult to explain this difference, especially due to the method used, but a reasonable explanation may be associated with the intensity of the exploitation rate. According to these authors, striped mojarra is a heavily exploited fish species in Ciénaga Grande de Santa Marta, which increases the chance of getting larger specimens and concomitantly larger asymptotic length. Commercial fishers in Ciénaga Grande de Santa Marta use gillnets (>5 cm mesh size) and cast nets (3-6 cm mesh size) for fishing mojarras, whereas in my study I used beach seines and cast nets with smaller mesh sizes.

Lake Maracaibo represents an important habitat for many marine fish species that have estuarine-dependent early life stages. This life history trait is particularly important in northern Lake Maracaibo, where spawning by adult fish occurs offshore and larvae and juveniles are recruited to estuaries throughout the year (44). Striped mojarra make up an abundant fish resource that plays important ecological and fishery roles in Lake Maracaibo. Early life stages and ripe adult striped mojarra, along with other fish and crustacean species (e.g., mullets and shrimp) move in and out of El Tablazo Bay following the tidal oscillations characteristics of Lake Maracaibo. These organisms are adapted to, and have evolved to live successfully within, the confines of this particular ecosystem, especially during early life (54-56). Evidence presented in this paper suggests that if either the tidal or the discharge patterns are changed, the whole biota of Lake Maracaibo may be affected. A major change in the ecosystem in any year could result in devastated year-classes of fish and crustacean (44); and if this change persists, it can produce a long-term decrease in abundance (57). The salt content of Lake Maracaibo has always been considered a concern. For example, Laval et al. (58) indicated that the salt content of Lake Maracaibo is a concern because: 1) salt stratification contributes to the persistence of anoxic conditions associated with the advanced state of eutrophication of the lake and 2) surface salinity is too high for the water to be used for irrigation or drinking water. Lake Maracaibo is not a freshwater lake, but rather an assemblage of interactive brackish water bodies, comprised of the Gulf of Venezuela, El Tablazo Bay and the Maracaibo Strait, which connect Lake Maracaibo in the interior of the basin to the Caribbean Sea (59). Current saline conditions of the Maracaibo System have been this way probably during the last few thousand years (59); salts have always been part of the Maracaibo System. Thus, another source of concern may be the entire biota, adapted to brackish water conditions, that thrives the whole Lake Maracaibo. Concern for the increasing fishery importance of fish species like striped mojarra is a due.

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