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Research Article

Assessment and management of the Gulf corvina *Cynoscion othonopterus* (Jordan & Gilbert, 1882) in the Upper Gulf of California

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ABSTRACT. The Gulf corvina, *Cynoscion othonopterus*, is a sciaenid endemic to the Gulf of California. Its fishery is one of the most important in the region, and catches have shown an increasing trend over the past decade; therefore, permanent monitoring is essential for generating vital information to understand variations in population better. We applied an integrated analysis model of catch-at-age to assess stock status, integrating biological and fisheries information to identify reference points such as fisheries mortality (F_{MSY}) and reproductive biomass (SSB_{MSY}), both of which are associated with the maximum sustainable yield, thereby determining population status. A total of 47,035 Gulf corvina specimens were sampled from 2002 to 2023. There was a decrease in mean length, which went from 650 to 564 mm in total length, reflected in the absence of individuals in age groups 7, 8, and 9, and in the increase of individuals in age groups 3 and 4. Total biomass oscillated between 21,100 and 35,200 t, whereas spawning biomass fluctuated between 10,000 and 25,600 t. Fishing mortality was $F_{MSY} = 0.250$ yr^{-1}, and the annual exploitation rate was $U_{MSY} = 0.221$ yr^{-1}. The control rule was exceeded by up to 61.7% in 2023. According to the exploitation levels, $F_{2023}/F_{MSY} = 1.309$ and $B_{2023}/B_{MSY} = 0.986$, the population status of the Gulf corvina should be considered precautionary, given the increasing overfishing.

Keywords: *Cynoscion othonopterus*; fishing reference points; statistical analysis of catch-at-age; Kobe diagram; catch quota; risk analysis

INTRODUCTION

Cynoscion othonopterus (Jordan & Gilbert, 1882), commonly called Gulf corvina (GC), is a marine fish belonging to the family Sciaenidae, endemic to the Gulf of California. It undertakes migrations to spawning areas in the Upper Gulf of California and Colorado River Delta (UGC and CRD). In this region, fishing activities have been particularly problematic due to their wide spatial distribution and marked social disparity (Doode & Wong 2011).

Fisheries for this species were resumed in 1993 in the UGC and CRD, emerging as a continuing fishery that followed the shrimp fishery in the Gulf of California (Román-Rodríguez 2000). It constitutes currently one of the most important marine scalefish resources in the UGC region, second only in importance to the bigeye croaker (*Micropogonias megalops*) fishery. Over the past decade, *C. othonopterus* catches have ranged between 3,944 and 7,681 t, with an average of 4,817 t. GC are caught mainly from February to April, when 85% of annual

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catches occur, coinciding with the annual reproductive migration to maturation, spawning, and rearing grounds in the northern end of the UGC and CRD Biosphere Reserve (CRDBR) (Enciso-Enciso 2014, Enciso-Enciso et al. 2018, Erisman et al. 2019).

Several aspects of the biology, ecology, and population dynamics of this species have been described. Interannual size variations have been observed; specimens measuring up to 1,013 mm total length (TL) have been found, and up to nine age groups have been described (Román-Rodríguez 2000, Gherard et al. 2013). This species is reproductively active from February to June, with maturity reached at 294.7 mm TL and 2.3 years of age. It is considered a multiple batch with asynchronous oocyte development, presenting a natural mortality rate of 0.31 to 0.41 yr^{-1} (Román-Rodríguez 2000, Gherard et al. 2013, Cotero-Altamirano et al. 2018, Enciso-Enciso et al. 2018).

From a fisheries perspective, evaluating exploited resources is paramount; this is an important aspect for management, as it enables the assessment of population exploitation to inform decision-making for managing fishery resources (Srinath 2017). In particular, the GC fishery has been evaluated using various approaches, including dynamic biomass models (Schaefer & Pella-Tomlinson), which utilize catch series and abundance indices such as catch per unit effort (CPUE). It was found that the population was not healthy during the 1993-2010 period, as fishing effort had exceeded the optimum (Ruelas-Peña et al. 2013). Enciso-Enciso (2014), using three models (Catch-MSY, Thomson-Bell, and Schaefer-Gordon's bioeconomic model), concluded that the population has stayed at healthy levels during the years of exploitation (1995-2013). Mendivil-Mendoza et al. (2018), based on Froese's sustainability indicators (1994-2015), noted that total catches exceeded catch quotas and that the fishery was targeting mega-spawners, presenting issues of overexploitation. In recent years (1991-2019), the corvina population has been evaluated using non-linear models in which the effect of the hyperstability that can occur in the fishery of breeding aggregations such as the GC was included; an important reduction in stock size was found, close to 75% compared with the virgin stock, which would require the use of precautionary measures (Urías-Sotomayor et al. 2024).

Currently, the resource is being exploited at the maximum sustainable yield (DOF 2023a), according to the terms and conditions for corvina exploitation provided through different management measures, such as the General Sustainable Fishing and Aquaculture Law (DOF 2015), the NOM-063-PESC-2005 (DOF 2007), the Management Plan of the GC (*Cynoscion othonopterus*) in the northern Gulf of California (DOF 2012), and the National Fishing Charter Sheet (DOF 2023b), which establishes a temporal ban from May 1 to August 31 every year, a minimum legal size (MLS) of 650 mm TL, with a tolerance range 30% below MLS, and a variable annual quota as a management tactic, published annually in the Official Federal Gazette, among other management measures.

The fishing management plan outlines research lines and activities, including fishery-dependent monitoring, which provides biological and fisheries information that is incorporated into stock assessment models to estimate reference points for the sustainable management of the resource. The present study is the first to apply an analysis of catch-at-age (ACA) that integrates biological and fisheries information along with the fisheries-dependent CPUE index, thus contributing to improving GC stock assessments and obtaining updated scenarios regarding the status of the resource. It will contribute to the management and sustainable use of GC, an important resource for the UGC and CRDBR region.

MATERIALS AND METHODS

The information and biometric data were obtained from the Corvina Program of the Mexican Institute of Research on Sustainable Fishery and Aquaculture (IMIPAS, by its Spanish acronym), which has integrated a database ranging from 2002 to 2023 that includes information on catches obtained from fishery statistics provided by the National Commission on Fisheries and Aquaculture (CONAPESCA, by its Spanish acronym) and biometric data from artisanal fleet landings in UGC communities: the Gulf of Santa Clara in Sonora, el Zanjón, and San Felipe in Baja California (Fig. 1).

Length composition

The normality test for the total length distribution was evaluated using the Kolmogorov-Smirnov and Lilliefors tests. After verifying that the data were not normally distributed ($P < 0.05$), the non-parametric Kruskal-Wallis test (H) (StatSoft 2001) was applied to analyze the interannual variation in TL using the statistical package Statistica 7.0.

Statistical analysis of catch-at-age (ACA)

One of the essential parameters when performing the ACA analysis is the instantaneous natural mortality (M) coefficient. In the present study, we used the coefficient

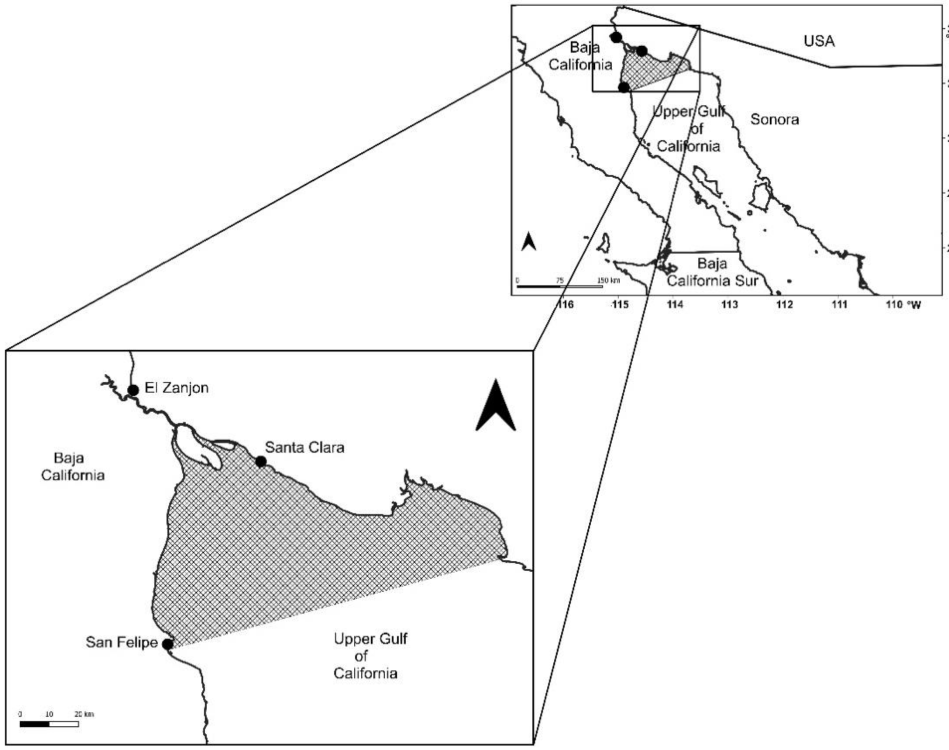

Figure 1. Capture area of the Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California.

calculated by Enciso-Enciso (2014) for specimens from the same stock, obtained from Pauly's empirical equation (1980).

Conversions between TL and total weight (TW) were performed using the constants estimated by Enciso-Enciso et al. (2018) for the length-weight relationship:

$$TW = 3.14^{-6} \times TL^{3.138} \quad (1)$$

The ACA was assigned considering the size structure for each year, grouped in 20-mm TL intervals, using the criterion of Enciso-Enciso et al. (2018), which was achieved using the following formula: amplitude = interval / number of classes, and subsequently converted to age using age-size data by Román-Rodríguez (2000). GC stock evaluation was performed annually, considering age classes from 1 to 9 years, applying the ACA according to Haddon (2011). A 22-year catch-at-age data series (2002-2023) was used; initial recruitment values were estimated using Pope's function (1972). Fishery-dependent information (CPUE) was used to stabilize the model.

The F-value for the oldest age group in the catch was estimated based on the catch-at-age matrix and the instantaneous mortality rate due to fisheries (F), which was considered constant during the exploitation phase of each cohort (Sparre & Venema 1998).

A matrix of the number of individuals per age was constructed based on initial recruitment values and the maximum F rate at each age for each year, combined with M (Haddon 2011). In the case of recruitment in each analyzed year, we incorporated the effect of surface sea temperature (SST). To obtain SST, we used the Geospatial Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) system for UGC (https://giovanni.gsfc.nasa.gov)

$$N_{a+1,t+1} = N_{a,t} * e^{-(M+F_{a,t})} * e^{(q*SST)} \quad (2)$$

where: $N_{a,t}$ is the number of corvina at age a and time t; $e^{-(M+F_{a,t})}$ is cohort survival (this is survival from age a to age $a+1$ and from time t to time t+1); M is natural mortality, which is considered constant for all cohorts through time; $F_{a,t}$ is fishing mortality at age a during year t; the expression $e^{(q*SST)}$ represents the forcing factor only at recruitment for each analyzed year (2002-2023), where q is the proportionality coefficient used to standardize, and SST (or "anom") is the SST anomaly during the three previous years, calculated as:

$$anom = T'_i - \left[\frac{\sum_{i=1}^{n} T'}{n}\right] \quad (3)$$

where i is the year, T'_i is the mean SST in a given year, and n is the total number of years of the study period (2002-2023).

Fishing mortality was estimated considering age selectivity (Haddon 2011).

$$F_{a,t} = \hat{F}_t \times S_a \quad (4)$$

where $F_{a,t}$ represents fishing mortality at age a and time t, $\hat{F}_t$ is the instantaneous fishing mortality rate at time t estimated in the model, and S_a is selectivity at age a, calculated with the logistic model:

$$S_a = \frac{1}{1 + \left(e^{-\mathrm{Ln}(19)\frac{(e-e_{50})}{(e-e_{50})}}\right)} \quad (5)$$

where S_a is selectivity at age a, and e_{50} and e_{95} are parameters estimated with the selectivity model at 50 and 95% respectively.

Once the number of specimens by age group was estimated, we calculated the estimated catch at age $\widehat{C}_{a,t}$ (Baranov 1918):

$$\widehat{C}_{a,t} = \frac{F_{a,t}}{M + F_{a,t}} N_{a,t}\left(1 - e^{-(M + F_{a,t})}\right) \quad (6)$$

The analytical solution of the standard deviation (σ) for later estimation of the partial likelihood function in the model was calculated as (Haddon 2011):

$$\sigma = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(\mathrm{Ln}C_{o,t} - \mathrm{Ln}\widehat{C}_{o,t}\right)^2} \quad (7)$$

where C_o is the catch at the observed age and $\widehat{C}_{o,t}$ is the catch at the estimated age at time t.

We also estimated the annual proportion of the observed exploitation rate (F_o) at time t; this was standardized by multiplying catchability (q) by effort at time t (f_t).

$$F_{ot} = q \times F_t \quad (8)$$

where f_t is the effort in fishing trips at time t, and q is a parameter obtained by fitting the model.

As the estimated F_{ot} values are a catch rate (F_t), they were recalculated as (Haddon 2011):

The analytical solution of the standard deviation (σ) for later estimation of the partial likelihood function in the model was calculated as (Haddon 2011):

$$F_t = -\mathrm{LN}\,(1 - F_{ot}) \quad (9)$$

$$\sigma_F = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(\mathrm{Ln}F_o - \mathrm{Ln}F_E)^2} \quad (10)$$

where F_o is the observed value recalculated at time t, and F_E is the adjustment parameter in the model at. time t.

We also estimated recruitment for the following years using Beverton & Holt's (1957) stock-recruitment function (S-R) (Hilborn & Walters 1992, Chen et al. 2002):

$$R_{r,t+r} = \frac{\alpha(S_{t-r} - \lambda}{\beta + (S_{t-r} - \lambda)} \quad (11)$$

where r is age at recruitment; t+r is the year plus the time elapsed before recruits are incorporated into the fishery; S_{t-r} is the breeding stock size at time t-r; λ is the estimated minimum number of breeders that guarantees recruitment for the next year t+r. The α, β, and λ parameters were obtained by fitting the modified Beverton & Holt S-R relationship.

The number of recruits was estimated as the number of fish aged between 1 and 2 years. The GC is a fast-growing species that attains sexual maturity at a young age (2.3 years) during each fishing season. The mega spawner stock abundance was expressed as the sum of all individuals from 3 years of age until the oldest age group, which was 9 years (Gherard et al. 2013).

The analytical solution of the standard deviation (σ) for later estimation of the partial likelihood function in the model was calculated as (Haddon 2011):

$$\sigma_R = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(\mathrm{Ln}R_o - \mathrm{Ln}R_E)^2} \quad (12)$$

where R_o is the observed value recalculated at time t, and R_E is the value of the adjustment parameter at time t.

We also incorporated the fleet CPUE index (catch/boat/tide) during the 2002-2023 fishing years into the model, which was used as auxiliary information to stabilize the model and increase precision in the estimation of parameters (Deriso et al. 1985, Methot 1989, Hilborn & Walters 1992, Hilborn et al. 1994), assuming that the observed CPUE was proportional to population abundance.

$$\bar{Y} = B_t \times q \quad (13)$$

where Bt is total biomass at time t and q is catchability for each CPUE, estimated as:

$$q = \exp\left[\frac{\sum_t \mathrm{Ln}\left(\frac{Y_t^{obs}}{B_t}\right)}{n}\right] \quad (14)$$

where n is the number of data points available for the CPUE, and Y_t^{obs} represents the observed fleet CPUE at time t.

The analytical solution of the standard deviation (σ) for later estimation of the partial likelihood function in the model was calculated as (Haddon 2011):

$$\sigma_{CPUE}=\sqrt{\frac{1}{n}\sum_{t=1}^{n}[LnB_o-Ln(q\times CPUE)]^2} \qquad (15)$$

where B_o is the estimated biomass for the model at time *t*, CPUE is the abundance index of CPUE at time *t*, and *q* is the catchability (proportionality coefficient).

Optimal parameter values were obtained by maximizing the log-likelihood of each partial function (Haddon 2011).

For observed and expected catches in numbers for each age *a* at each year *t*.

$$LL^C=\left(-\frac{n}{2}\right)\times(Ln\ (2\pi)+2\times Ln(\sigma_C)+1) \qquad (16)$$

For observed and expected fishing mortality for each year.

$$LL^F=\left(-\frac{n}{2}\right)\times(Ln\ (2\pi)+2\times Ln(\sigma_F)+1) \qquad (17)$$

For "observed" and expected recruitment for each year.

$$LL^R=\left(-\frac{n}{2}\right)\times(Ln\ (2\pi)+2\times Ln(\sigma_R)+1) \qquad (18)$$

For "observed" CPUE and estimated exploitable biomass for each year.

$$LL^{CPUE}=\left(-\frac{n}{2}\right)\times(Ln\ (2\pi)+2\times Ln(\sigma_{CPUE})+1) \qquad (19)$$

where LL is the likelihood logarithm, n is the number of observations, and σ is the standard deviation for the given function. The analytical solutions for the standard deviations (σ) were as follows: Eq. 6 for catch, Eq. 9 for effort, Eq. 11 for recruitment, and Eq. 14 for CPUE. A final fit to the model was performed by maximizing the total log-likelihood objective function; the total objective cell is the sum of the partial functions of catch at age, effort, recruitment, and CPUE (Megrey 1989, Haddon 2011):

$$LL^{total}=LL^C+LL^F+LL^R+LL^{CPUE} \qquad (20)$$

Once the model was adjusted, the annual stock biomass was estimated.

$$Bt=\sum N_{a,t}\times PT_{a,t} \qquad (21)$$

where $N_{a,t}$ is the number of organisms at age *a* and time *t*, $TW_{a,t}$ is the mean total weight at age *a* and time *t*, estimated by considering the mean size at age of the growth models and the weight-length relationship parameters (Enciso-Enciso, 2014).

Management quantities were estimated using the likeliest parameters corresponding to the Beverton-Holt (1957) S-R relationship structure, according to Hilborn & Walters (1992):

$$SSB_{MSY}=a\sqrt{\frac{\beta}{a}}-\beta \qquad (22)$$

$$MSY+S_{MSY}=\frac{\alpha SSB_{MSY}}{\beta+SSB_{MSY}} \qquad (23)$$

$$U_{MSY}=1-\sqrt{\frac{\beta}{a}} \qquad (24)$$

$$F_{MSY}=-\log(1-U_{MSY}) \qquad (25)$$

where α is the density-independent coefficient associated with mortality, β is the density-dependent coefficient associated with mortality, SSB_{MSY} is the estimated spawning biomass at which maximum sustainable yield is reached, U_{MSY} is the exploitation rate at MSY, and F_{MSY} is the fishing mortality at MSY.

We performed a sensibility analysis on the parameters with greatest uncertainty in the model (as main sources of error): natural mortality (M), catchability (q), and the α, β, and λ parameters of the S-R function in the modified Beverton-Holt model, concerning the control rule (quota). The analysis was performed using Crystal Ball software version 11.1.2.4 (Oracle® Crystal Ball), through which 10,000 iterations were run for each year's estimated abundances (Bt, BR, BE), as well as management quantities, thereby obtaining the confidence intervals (α = 0.05).

To validate the ACE model, the simulated catch was compared with the observed catch reported for the study period (2002-2023) with a Kolmogorov-Smirnov test.

Predicted exploitation level and stock status

According to what has been recommended for the management of other populations subject to exploitation, we suggest that the control rule (annual catch quota) be calculated with the following equation:

$$Quota_{t+1}=U_{MSY}\times SSB_t \qquad (26)$$

where U_{MSY} is the exploitation rate for maximum sustainable yield and SSB_t is the spawning stock biomass in year t. In this way, the annual quota will be designed to continually reduce the catch (exploitation rate) by as much as the biomass decreases, and the value of the exploitation rate will change as a function of biomass size.

A Kobe diagram was used to determine the state and trajectory of the GC population in a time series. Spawning stock biomass (SSB) was plotted on the x-axis and fishing mortality (F) on the y-axis, concerning the maximum sustainable yield (MSY). The graph is divided into four sections: in the upper left is an overfished and overexploited population; in the upper right is an overfished population; in the lower left is an underfished but overexploited population; and in the lower right is where a fishery typically develops, that is, underfished and underexploited (Maunder & Aires-da-Silva 2011).

A management scenario was projected until 2030 based on the breeding biomass obtained with the ACA model in 2023, considering different catch quotas. A scenario in which the catch quota was zero was included, i.e. the behavior of the population breeding biomass without fishing mortality. The catch was then increased until 6,000 t were reached.

RESULTS

Length composition

A total of 47,035 specimens were analyzed during 22 fishing seasons (2002-2023). Interannual variations in TL were observed, with an upward trend from the beginning until the 2009 season, when a median TL of 712 mm was recorded. This trend was followed by a downward trend until the 2023 season, when a median TL of 571 mm was recorded. The Kruskal-Wallis statistical test revealed significant differences between the study years ($H(21, 47035) = 30369$; $P < 0.05$ (Fig. 2).

Catch-at-age composition

Catches have not varied in weight during the past decade (Fig. 3a); however, catches doubled in terms of the number of individuals from 2010 to 2021 (Fig. 3b). There was a loss of individuals in age groups 7, 8, and 9 and an increase in small specimens in the catches (age group 3); the age groups 3 and 4 were the most abundant, with 92% of catches from 2021 to 2023; the age of recruitment to the fishery was 3 years of age.

Population size

The ACA model results indicated that total biomass has oscillated between 21,100 and 35,200 t, with a mean of 26,900 t. A population size of 25,700 t was estimated for the 2023 season, with a 95% confidence interval of between 21,900 and 30,200 t (Fig. 4a). The SSB presented a similar trend, oscillating between 10,000 and 25,600 t, with a positive trend between 2002 and 2006 and a negative trend after 2006, with a small recovery in 2020 (Fig. 4b). The estimated value in 2023 was 15,500 t, with a 95% confidence interval of between 12,400 and 19,250 t (Fig. 5).

Fishing mortality and exploitation rate

Annual fishing mortality and exploitation rates and their respective reference points are shown in Figure 6. The reference point for fishing mortality was estimated at $F_{MSY} = 0.250$ yr^{-1} (IC 0.240 and 0.260 yr^{-1}), and the reference point for the exploitation rate was estimated at $U_{MSY} = 0.221$ yr^{-1} (IC 0.213 and 0.229 yr^{-1}). Exploitation rate and exploitation rate for maximum sustainable yield (E/E_{MSY}) with its respective confidence intervals ($\alpha = 0.05$) estimated for the GC (*C. othonopterus*) stock in the UGC from 2002 to 2023.

Exploitation level

The validation of the ACA model, comparing the observed catch with the simulated catch through Pearson's correlation analysis, did not result in significant differences ($R^2 = 0.429$, $t = 3.88$, $P < 0.00093$; Fig. 7). Recorded catches did not exceed the catch quota during the first decade (2002-2012).

However, there has been high fishing pressure in later years (2013-2023), which has exceeded the control rule by up to 61.7%, as was the case in the 2023 season (Fig. 8).

The population status and exploitation level of the GC resource were expressed using a Kobe diagram, which indicated that there have been significant oscillations in terms of biomass from 2002 to 2022. However, both indicators have currently (2023) slightly exceeded their targets: $F_{2023}/F_{MSY} = 1.309$ and $SSB_{2023}/SSB_{MSY} = 0.986$. Therefore, the state of the resource is considered precautionary due to the risk of overfishing, as noted by Haddon (2011, Figs. 9-10).

Risk analysis

The risk analysis presented different biomass scenarios projected until 2030, considering various catch quotas as management strategies. As catches increased, the probability of having a breeding biomass above the objective reference point decreased (Fig. 11).

DISCUSSION

Length composition

The Gulf corvina is endemic to the UGC, and its fishery is the second most important in the region (Enciso-Enciso 2014). Its relevance led to permanent monitoring since 2002, which has provided information on size composition. Length showed an increasing trend from 2002 to 2009 and stayed above the MLS of 650 mm TL until 2016. This length is consistent with what has been reported in other studies undertaken in the UPG; for example, Erisman et al. (2014) reported a size interval of 614 to 730 mm TL from 1997 to 2012, with a mean size of 685 mm TL. Gherard et al. (2013) reported a wide size interval, ranging from 145 to 1,013 mm TL, in individuals collected from 2009 to 2011. However, they found a decrease in mean size (605 mm

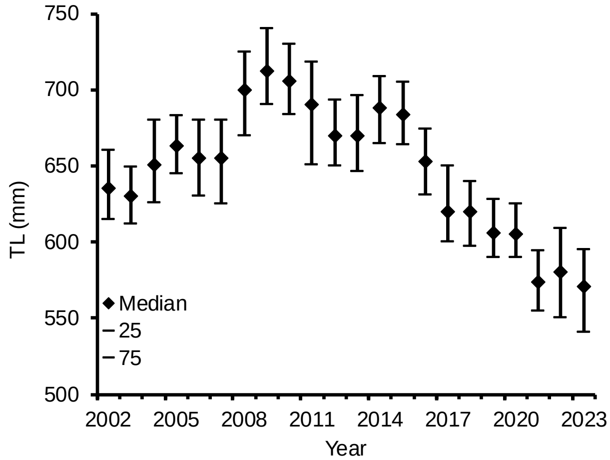

Figure 2. Median total length (TL) of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

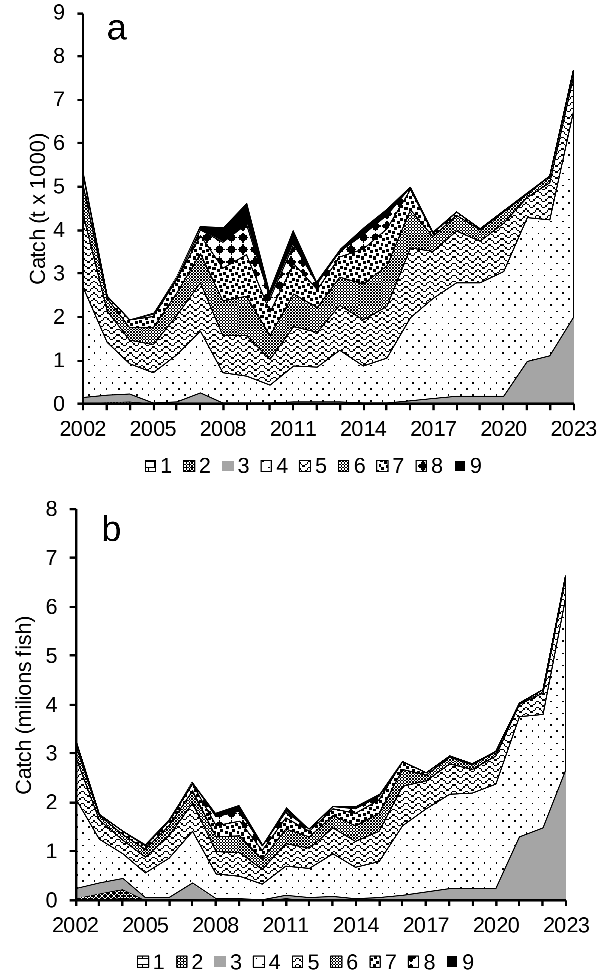

Figure 3. Catch-age a) weight (t) and b) number of individuals of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

TL), which was below the MLS. The wide range of lengths is explained by the fact that individuals included in that study were obtained from fisheries as well as from shrimp and marine scalefish fisheries bycatch, which resulted in smaller specimens, in contrast with the specimens analyzed in the present study. Over the past eight years, the mean size of GC caught in the UGC was below the MLS; this decrease in the mean size of specimens could lead to changes in breeding tactics and to natural variations in recruitment (Enciso-Enciso et al. 2018, Erisman et al. 2019). A linear relationship between size and fecundity has been found; larger females can spawn up to 1,700,000 oocytes, whereas smaller females spawn 355,000 oocytes (Cotero-Altamirano et al. 2018). Enciso-Enciso et al. (2018) reported that a decrease in size is an indicator of an increase in fishing pressure.

Catch-at-age composition

The age-length key by Román-Rodríguez (2000) was used to determine age groups in the GC catches. This author considered up to nine age groups for specimens caught between 1997 and 1999, with a size interval ranging from 145 to 920 mm TL. Based on this age-length key, we assigned an age to the organisms caught by the artisanal fleet from 2002 to 2023. Nine age groups were identified until 2016; after this year, there was a decrease in age groups 7, 8, and 9, and an increase in age groups 3 and 4, with mean lengths ranging from 537 to 615 mm TL. This result suggests that from 2017 to the current date the GC caught in the UGC are not only smaller but also younger, as until 2016 the most abundant age groups in the fishery were age groups 5 and 6, with a total length of 650 to 750 mm TL (Gherard et al. 2013, Cotero-Altamirano et al. 2018). Moreover, there is evidence that 5-year-old GC females have spawned during the past three years, resulting in only half of their potential length (Gherard et al. 2013), which has led to a low reproductive yield.

Population size

A total GC biomass ranging from 15,000 to 25,000 t has been estimated for the period 1995-2013 (Enciso-Enciso 2014) using the catch-MSY method (Martell & Froese 2012), whereas Schaefer's model found a system carrying capacity of 16,400 t for the 1993-2012 period (Ruelas-Peña et al. 2013). Recently, Urías-Sotomayor et al. (2024) employed a bioeconomic model based on linear regressions for the 1991-2019 period, determining a carrying capacity of between 19,465 and 20,814 t of fish. The results of these models differ from those

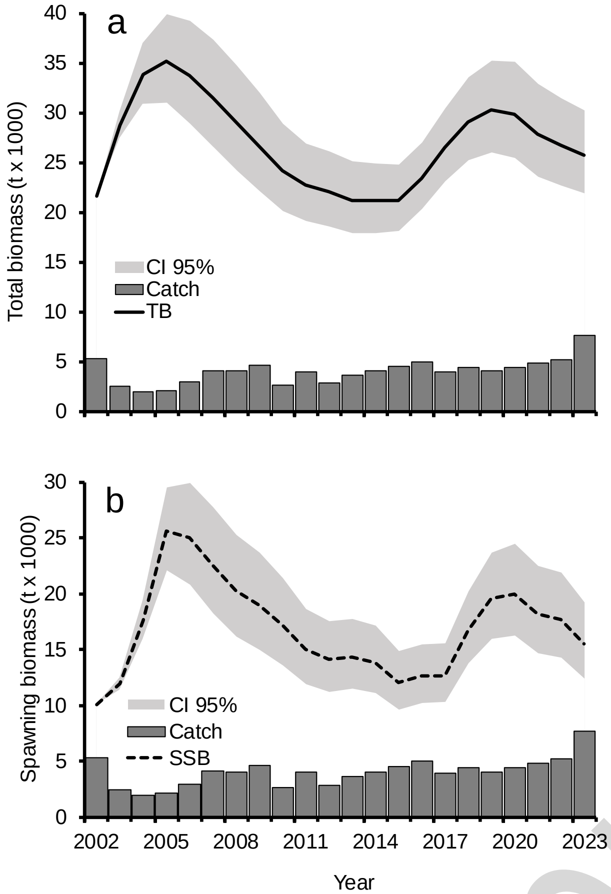

Figure 4. a) Total biomass (TB) and b) spawning biomass (SSB) (α = 0.05) of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

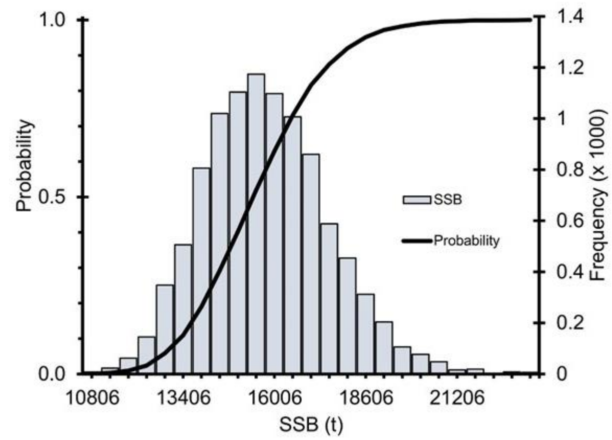

Figure 5. Spawning stock biomass (SSB) and confidence intervals (α = 0.05) of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

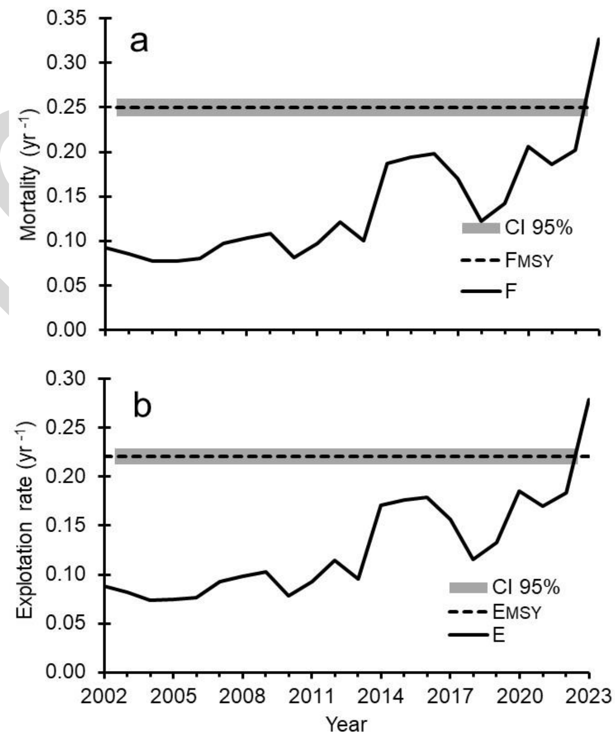

Figure 6. a) Fishing mortality (F) and mortality from maximum sustainable yield (F_{MSY}) and b) exploitation rate and exploitation rate from maximum sustainable yield (E_{MSY}), confidence intervals CI (α = 0.05), of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

found in the present study, suggesting that the differences in estimates may be due to the methods used. We considered fishery-dependent information based on the ACA model, which accounted for age, and estimated a biomass of between 21,100 and 35,200 t. Previous studies only used catches and CPUE, without considering biometric information of the GC population. In contrast, the present study incorporated age and size of the specimens in addition to catch information, which allowed us to follow the population dynamics of each age group (cohort) over time. Production models do not consider size, age, or sex, and stock biomass estimates are undifferentiated (Haddon 2011).

The biomass of fish populations is not constant; it fluctuates around a mean due to environmental conditions, interactions with other species (such as predation or competition), and fishing mortality (F) (Allen & Hightower 2010). There was an increasing trend in GC F during the study period, i.e. the F necessary to obtain the maximum sustainable yield (F_{MSY}) was exceeded. It has been shown that an increase in catches can have a negative effect on popu-

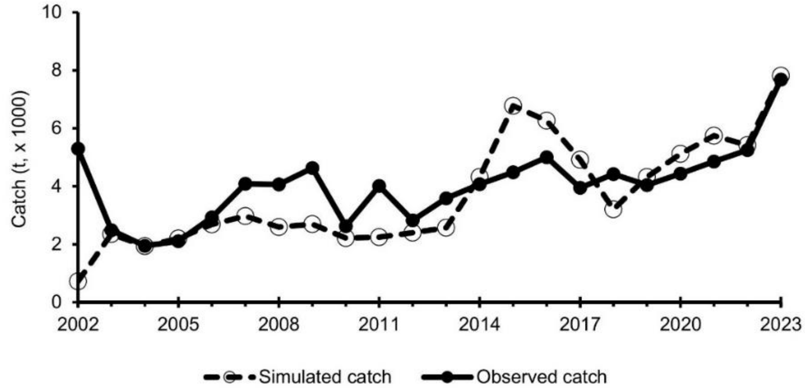

Figure 7. Comparison between simulated catch (dashed line) and observed catch (solid line) from the analysis model of catch-at-age of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

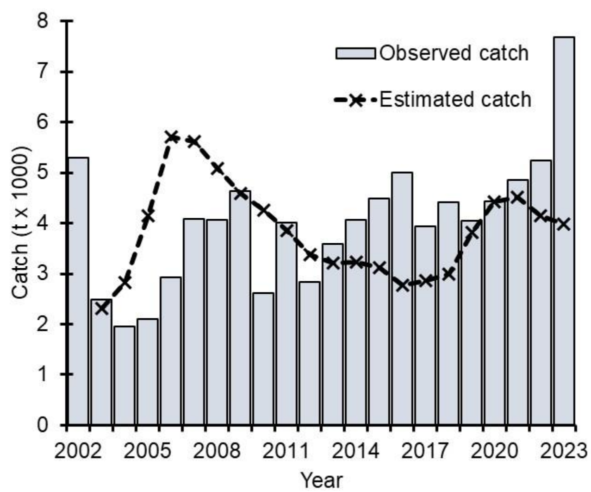

Figure 8. Observed catch and estimated catch of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

lation density, which can in turn influence population parameters (growth, recruitment) that can have repercussions even on the food chain of the population (predator-prey relationship) (Iserman & Paukert 2010).

Management strategy and exploitation level

Catch quotas constitute a management measure used worldwide by countries such as New Zealand, Iceland, Norway, the USA, Canada, Chile, and Peru, where approximately 90% of fisheries implement this strategy. It has proven to be efficient, as the status of the different resources is healthy; that is, they are maintained near the various reference points (Seijo et al. 1997). In Mexico, this management strategy has been

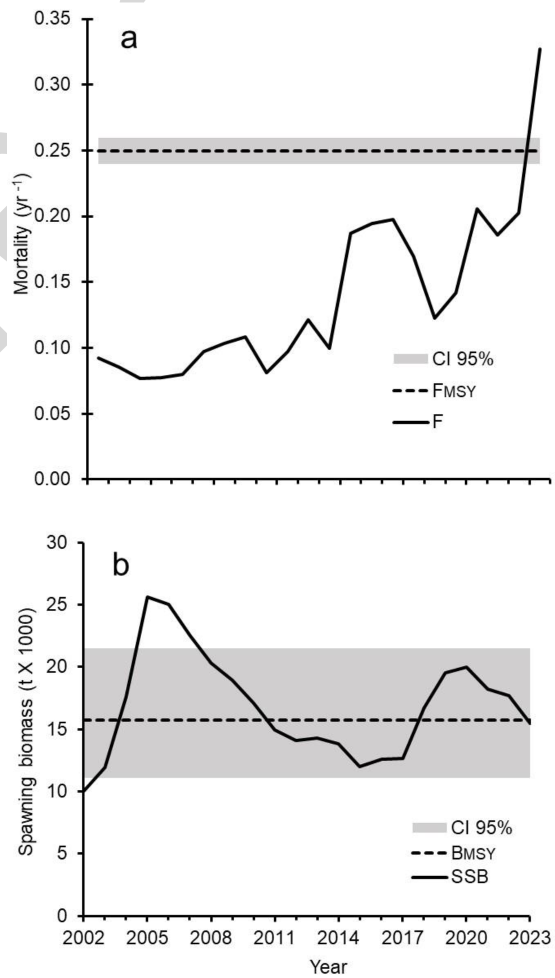

Figure 9. a) Interannual variation in fishing mortality (F) and b) spawning stock biomass (SSB), with reference points (F_{MSY} and B_{MSY}) and confidence intervals ($\alpha = 0.05$) of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

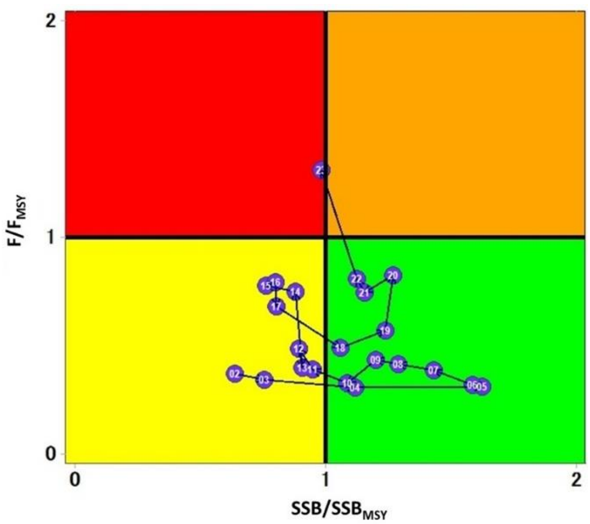

Figure 10. Kobe diagram of Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California, during the period from 2002 to 2023.

implemented since 1990, primarily for benthic resources such as abalone, sea urchin, lion's paw scallop, and certain fish species, including Pacific hake, grouper, and GC. For the latter, a catch quota was implemented in 2011 as a control rule, which is assigned annually according to the National Fishing Charter Sheet (DOF 2023b), based on fishery statistics. It has been observed that in 9 of the 11 years, the catch quotas recommended by the IMIPAS have been exceeded by 1.8 to 61.7%. The maximum was recorded in 2023, resulting in an increase in F and a decrease in population biomass. This finding aligns with the report by Mendivil-Mendoza et al. (2018), who found that total catches exceeded the quotas established by the National Fishing Institute during the 2012-2016 period.

A model structured by age resulted in F reference points of $F_{2023}/F_{MSY} = 1.309$, i.e. there was greater F than necessary to reach MSY. The biomass obtained was $SSB_{2023}/SSB_{MSY} = 0.986$. The published literature notes that overfishing occurs when the ratio of mortality (F) to fishing mortality to achieve the maximum sustainable yield (F_{MSY}) exceeds 1, and that underfishing occurs when this ratio is less than 1. When the ratio of SSB to spawning stock biomass required to reach maximum sustainable yield (SSB_{MSY}) is greater than 1 the population is underexploited. When this ratio is below 1 the population is overexploited (Cochrane 2005). Considering the results obtained in this study, the status of the GC endemic to the Gulf of California is overfished, according to Haddon (2011), which is consistent with reports from other evaluations that have recorded a significant decline in the GC population. The status of the population is not healthy; however, the degree to which populations are affected varies. Ruelas-Peña et al. (2013) and Urías-Sotomayor et al. (2024) reported a 75% decrease in size compared with the virgin biomass stock value. This result differs from that found in the present study, as the maximum biomass of the population was estimated in 2005, and an 18% decrease was observed compared to the biomass estimated in 2023.

The risk analysis revealed that the biomass of the population estimated using the ACA model exhibited significant fluctuations, with some years in which the biomass was below half the carrying capacity (k). However, when different catch quota scenarios were projected using the current management measure, it was found that maintaining a catch of approximately 4,000 t would be necessary to keep the population at healthy levels over the short term (6 years). In contrast, an increase of over 50% concerning the catch quota, as

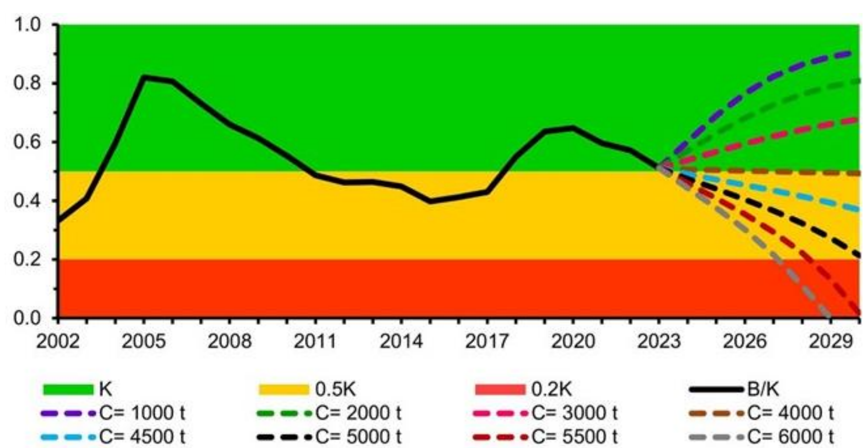

Figure 11. Risk analysis from 2030, considering different catch quotas as management measures from the Gulf corvina (*Cynoscion othonopterus*) in the Upper Gulf of California. K: carrying capacity, B/K: relative biomass and C: catch.

occurred during the 2023 season, could lead the corvine stock to a state that would put its recovery at risk. Previous studies have recommended that the MSY of the GC fishery should be 3,100, 3,215, or < 4,000 t, as a precautionary approach (Ruelas-Peña et al. 2013, Enciso-Enciso 2014, Urías-Sotomayor et al. 2024).

CONCLUSION

The Gulf corvina (GC) fishery has a comprehensive and current regulatory legal framework (regulation, management plan, and sheet in the NFC); however, the historical analysis of catch volumes suggests that the management strategy has not been adhered to. That is, the control rule (catch quota) has been exceeded by up to 61.7% in 2023, based on the exploitation level, $F_{2023}/F_{MSY} = 1.309$ and $B_{2023}/B_{MSY} = 0.986$, the population status of the GC should be considered precautionary, with increasing overfishing, causing to a decrease in mean size and the age composition of the breeding stock, negatively affecting the recruitment of the species by approximately 2.3 years.

The success of a fishery management strategy depends on various factors, including social, economic, political, and biological aspects; however, not all fish populations respond in the same manner or at the same speed. Therefore, in the case of the GC in the UGC, an awareness campaign regarding fishing regulation strategies should be conducted among users, which could guarantee resource sustainability.

Credit author contribution

C. Enciso-Enciso: project administration, methodology, formal analysis and writing-original draft and editing; E. Alvarez-Trasviña: conceptualization, methodology, formal analysis and writing-original draft and editing; D.I. Arizmendi-Rodríguez & M.S. Zuñiga-Flores: methodology, formal analysis, review and editing; M. Ruiz-Zuñiga: review and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest regarding this research article.

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