Assessment of the status of the black skipjack *(Euthynnus lineatus)* resource **in Oaxaca, Mexico, using the CMSY model.**

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Introduction

Depending on different criteria, reference points such as gross catch and productivity can be used to estimate biomass and maximum sustainable yield (Martell and Froese, 2013), since a catch time series can be viewed as a sequence of yields produced by the available biomass in relation to productivity (Hilborn and Stokes, 2010; Froese *et al.,* 2017). This is based on determining the relative biomass and the annual exploitation rate, and predicting maximum sustainable yield (MSY) data. The result can be important not only in terms of assessment, but also for promoting sustainable fisheries management.

Materials and methods

Annual data (2005-2023) on total landings of black skipjack *(Euthynnus lineatus)* in tonnes (t) were used, which were considered as catch (C). With these data, the CMSY model, using a Monte Carlo method, developed by Froese *et al.* (2017), was applied to evaluate the biomass and the exploitation level. The model generates population dynamics parameters, according to the relative size of the population, from the relationship between the current biomass (B) of the resource, and according to the biomass corresponding to a Maximum Sustainable Catch (Maximum Sustainable Yield) (B/BMSY), and the fishing mortality rate (F), exploitation, in relation to that necessary to maintain a Maximum Sustainable Yield MSY (F/FMSY). Both benchmarks, maximum sustainable yield (MSY) and maximum sustainable biomass (MSB) combine the production model with a simple stock recruitment model, taking into account the recruitment of reduced (severely depleted) stock.

The method used is based on an annual series of gross catches from the fishery and an estimate of the species' resilience, and allows for the determination of reference points (RPs) for its management. Estimates of the carrying capacity (K) and the intrinsic population growth rate (r) (resilience) were obtained, from which predictive results, limit reference points (MSY and BMSY) , and a precautionary 80% MSY, were determined for the management of the skipjack *(E.* lineatus) fishery .

The model provides a Kobe diagram (Maunder & Aires-da-Silva 2012), where the trajectories of F and B relative to the values corresponding to MSY are presented. According to the evaluative model, if the current biomass (B) is below the sustainable biomass (BMSY < 1), the resource is considered depleted. The model also provides information on overfishing in the case where fishing mortality (F), caused by fishing effort, is greater than the F corresponding to the maximum sustainable yield (F/FMSY > 1).

An 80% MSY was also estimated. MSY should be considered a limiting PR to prevent overfishing (Hillborn, 2007), while 80% MSY can be considered a precautionary PR to maintain an efficient and sustainable fishery (Hillborn, 2010). Average catch data by period are presented with standard deviation (±).

Results

The assessed fishery shows a period of growth until 2013, with an average annual catch (2005-2013) of 511.4±198.2 t. Subsequently, a period of maximum exploitation occurs from 2014 to 2019; the catch in 2014 (1482.96 t) increased by 812.9 t, more than double the catch in 2013, and by 971.6 t compared to the average annual catch of the period 2005-2013, indicating a significant increase in fishing effort. This situation of maximum exploitation continues until 2019 (1090.2 t), with a maximum catch in 2015 (2096.9 t). After 2019 and until 2023, the catch decreases, with an annual average of 689.9±90.8 t.

According to the model outputs, the interannual variability of the catch (Catch) and its relationship with the catch for maximum sustainable yield (Fig. 1a), corroborates that in the period 2014-2019 the catch was not sustainable. From 2017 onwards, the population biomass was lower than the biomass required for maximum sustainable yield (B/BMSY), the horizontal line at 0.5 indicates half of the biomass corresponding to the biomass for maximum sustainable yield (BMSY), a limit below which recruitment is reduced to levels of serious population depletion (Fig. 1b). According to the model, there has been no exploitation compatible with the maximum sustainable yield (FMSY) since 2015, with peak overexploitation between 2017 and 2019 (Fig. 1c). The relationship and development between biomass and exploitation are shown, denoting that stock recruitment is relatively reduced (Fig. 1d).

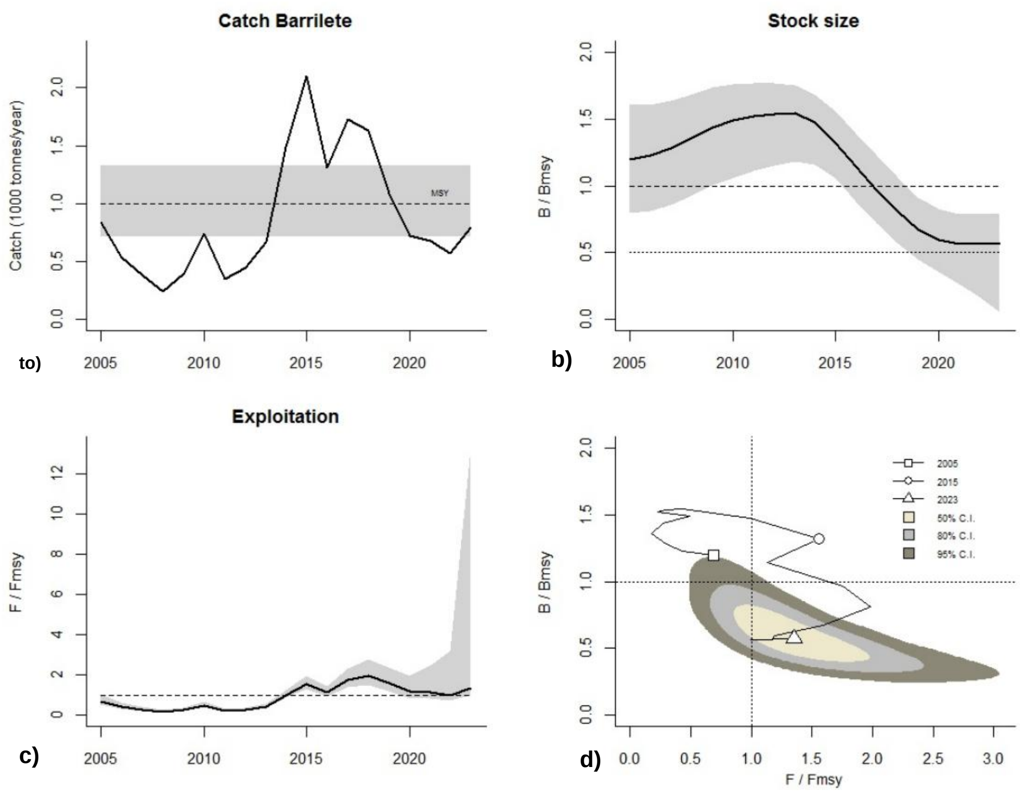

Figure 1. Reference points for the black skipjack *(Euthynnus lineatus)* fishery assessment . The dashed lines represent the maximum sustainable value for both catch and biomass, as well as exploitation (F).

According to the evaluated reference points, all indicators of stock status and predictions for reaching maximum sustainable yield (MSY) indicate that there is carrying capacity (k) to sustain a population (biomass) of over 8,700 t; however, the current biomass for a sustainable fishery (BMSY) was estimated at 4,389.5 t. According to the population growth rate (r), the model suggests that the population is still resilient. The maximum annual catch for maximum sustainable yield (MSY) is 1,002 t, but because there are signs of population depletion and overfishing since 2015, a precautionary approach is recommended, and it is proposed to maintain an annual maximum catch of 80% of MSY, which would be 802 t (Table 1). The average annual catch (C) for the period (2005-2023) has been 879 t.

Table 1. Status of the black skipjack oyster resource in Oaxaca, Mexico according to the CMSY model, stock indicators: carrying capacity (K), population growth rate

(r), average catch (C) for the period 2005-2023, and predictive results of limit reference points (MSY and BMSY) and precautionary 80% of MSY, for management.

Indicators	Values
K (t)	8779
r	0.464
MSY (t)	1002.5
80%MSY (t)	802
BMSY (t)	4389.5
Average C (t)	879

The Kobe diagram (Fig. 2), which describes the trajectory of the fishery according to the relationship between biomass and fishing exploitation, shows that the fishery remained in a favorable state from 2005 to 2014 without stock depletion or overfishing (F/FMSY < 1 and B/BMSY > 1). During 2015 and 2016, there were no serious signs of depletion (B/BMSY > 1), but there were signs of maximum fishing exploitation and overfishing (F/FMSY > 1). Since 2016, the state of the fishery has been unfavorable, with indicators of overfishing (F/FMSY > 1) and biomass depletion (B/BMSY < 1).

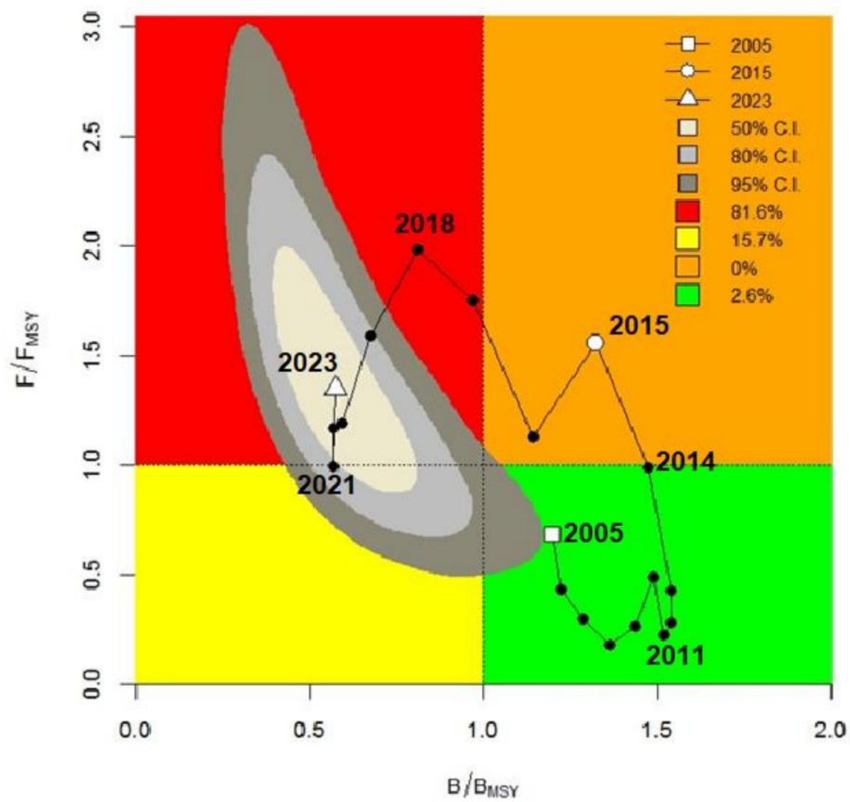

Figure 2. Status of the *Euthynnus lineatus* resource according to the CMSY model output. Kobe diagram, with 2005–2023 trajectories of fishing mortality (F) and biomass (B) corresponding to MSY (green quadrant = favorable, yellow quadrants = need for precautionary measures with effort reduction, red quadrant = unfavorable).

Considerations

According to the CMSY model applied, the status of the assessed black skipjack fishery in Oaxaca can be classified as unfavorable, as there are signs of stock depletion due primarily to overfishing. However, it can be managed favorably by keeping total annual catches below 800 t. This could involve implementing quota-based management.

In the applied model, a more or less similar annual fishing effort is assumed, it is recommended to carry out other analyses, such as determining the interannual variability of fishing effort, according to the number of vessels and fishing time, and other variables that allow explaining what was the cause of such a significant increase in annual catches from 2014 to 2019, and whether the subsequent reduction in landings is due to a reduction in effort or a decrease in the abundance of the resource, to corroborate the causes explained by the model.

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