INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

15TH MEETING

La Jolla, California (USA)
10 - 14 June 2024

DOCUMENT SAC-15 INF-L

YELLOWFIN AND SKIPJACK CATCH TRENDS RELATIVE TO ENSO EVENTS

Dan Crear, Dan Ovando, Carolina Minte-Vera and Jon Lopez

CONTENTS

EXECUTIVE SUMMARY

Recent relatively high catches of yellowfin tuna in 2022 and skipjack tuna in 2023 and 2024 in the purse-seine floating-object (OBJ) fishery prompted a request from the Scientific Advisory Committee (SAC) (SAC-14-16) for the IATTC staff to investigate potential causes of these fluctuations, including environmental factors. In this document, changes in yellowfin and skipjack tuna catch in the purse-seine OBJ fishery were assessed relative to El Niño Southern Oscillation (ENSO) events to better understand the effect of long-term environmental processes on tuna catches. The analysis suggests that there is likely some lag effect of ENSO events on catch (i.e., CPUE) of both species. Specifically, yellowfin tuna CPUE 4-6 months and 16 months after La Niña events are higher compared to neutral and El Niño events, suggesting the positive impact La Niña events may have on yellowfin recruitment into the fishery. In addition to increases in effort, this relationship may have attributed to increases in yellowfin catches in the OBJ fishery in 2022. For skipjack, CPUE just over two years after El Niño events are higher compared to neutral and La Niña events. Two years prior to the increase in skipjack CPUE and catch in 2023, a La Niña event was weakening towards a neutral phase, which may be a contributing factor for higher catches, despite a slight decrease in effort in 2023. This work would benefit from additional analyses to further investigate these impacts and could potentially be used to help predict catch fluctuations in the future based on ENSO values.

1. BACKGROUND

Over the last couple years yellowfin and skipjack tuna catch in the purse-seine floating-object (OBJ) fishery has significantly increased relative to recent historical trends. Specifically, starting in early 2022 small and medium yellowfin tuna catch from purse-seine OBJ sets increased to above 6,000 metric tons (t) /month and peaked at almost 10,000 t/month by October 2022. Catches dropped in subsequent months but were consistently high throughout 2023. However, once catch was corrected for the number of purse seine OBJ sets, the trend diminished substantially, but remained higher than CPUE trends observed since 2017. On the other hand, skipjack tuna catch has recently increased throughout 2023 and has continued to increase into 2024. Similar to yellowfin, once corrected for the number of OBJ sets that trend was reduced but CPUE has consistently increased since the beginning of 2023. Based on these shifts in trends the Scientific Advisory Committee (SAC) requested the IATTC staff to investigate potential causes for these fluctuations, including environmental factors (see recommendation 3.3 in SAC-14-16).

The El Niño Southern Oscillation (ENSO) is a long-term climate phenomenon that influences water temperatures in the central and eastern tropical Pacific Ocean. The irregular pattern switches back and forth from the warm phases, or El Niño and the cool phases, La Niña every two to seven years (SAC-04-11, SAC-06 INF-C). When a warm or cool phase is not occurring, a neutral phase is present. During neutral or average conditions, westward trade winds push the surface waters west causing an upwelling of cooler waters and a shoaling of the thermocline in the eastern Pacific Ocean (EPO). During a La Niña event, which usually lasts 1 to 3 years, normal conditions are intensified, meaning the westward trade winds strengthens causing stronger upwelling, cooler waters, and increased productivity. During an El Niño event, which can last from nine to 12 months, the westward trade winds weaken or switch direction leading to warmer waters, a deepening of the thermocline, and often decreased productivity in the EPO. It is important to mention that the effect of an El Niño or La Niña event varies in intensity, duration and spatial extent (typically extend across the central and eastern Pacific), therefore, each event is unique. There are multiple metrics used to quantify the magnitude of ENSO. The Oceanic Niño Index (ONI) is a common index produced by the National Oceanic and Atmospheric Administration (NOAA) and is calculated as the three-month running mean of sea surface temperature anomalies in the Niño 3.4 region (defined as the area within 5°N to 5°S and 120° to 170°W). Index values of 0.5 or greater indicate El Niño phases, while values of -0.5 or less indicate La Niña phases.

Because ENSO impacts the temperature variability and productivity of the water on a large scale, it is expected to influence the habitat, distribution, and biomass of tunas (Domokos 2023). It is generally thought that during neutral and La Niña phases, when the thermocline is shallow, tunas are compressed towards the surface and catches in the purse-seine fishery increase, while during El Niño phases, the thermocline deepens, expanding tuna preferred habitat and potentially reducing catch (SAC-14-11, SAC-06 INF-C). Further, it is known that fishing effort responds to shifts in oceanographic conditions (SAC-06 INF-C). The Annual Reports of the IATTC in 1983 and 1989 showed that tuna catch rates in the EPO were low during the El Niño of 1982-1983. This caused a shift in fishing effort from the eastern to western Pacific. Later in the decade, a stronger La Niña event occurred and tuna catches were high. It was also reported that from 1983 to 1989 yellowfin recruitment was the highest on record for a 7-year long period and that typically the effect of El Niño events is not seen in the fishery until about two years after the event (Annual Report of the IATTC 1989). At the entrance of the Gulf of California, the Mexican tuna purse seine fleet experienced peaks in yellowfin tuna catches two to four months following strong El Niño events in 1991 and 1997. These trends were supported in a cross-correlation analysis (Torres-Orozco et al. 2006), which suggested that recruitment was the main cause of yellowfin tuna catch fluctuations, with the peak in catches occurring 12 to 14 months after those El Niño events. Yen et al. (2017) found that using data from Taiwanese purse seiners and South Pacific Commission, El Niño events had a variable but negative effect on skipjack tuna relative abundance and habitat suitability indices and that typically spatial factors (central vs eastern Pacific El Niño) had more of an influence than temporal factors on relative abundance. Understanding tuna environmental preferences and limitations of long-term oceanographic features like ENSO can improve conservation and management measures for target species (SAC-06 INF-C).

Based on this information, the objective of this study is to determine the potential effect of ENSO on the historical and recent yellowfin and skipjack tuna CPUE fluctuations in the purse-seine floating-object fishery.

2. METHODS

We used data collected by observers in Class-6 (>363 mt) purse-seine vessels from 1995 to 2023 to investigate the potential influence ENSO events may have had on yellowfin and skipjack tuna catches in the OBJ fishery. To capture the most recent impacts, the 1995-2023 time series was complemented with the observer's daily reports from the sea (i.e., daily activity report) for January to March 2024. For yellowfin tuna, only small individuals (<2.5 kg) were used because it is the most commonly occurring yellowfin tuna size class in the purse-seine OBJ fishery. Catch per set (CPUE) in the purse-seine OBJ fishery was calculated monthly for small yellowfin tuna and all sizes combined of skipjack tuna.

To represent ENSO events, ONI values were used over the same timeframe. The ONI was extracted monthly from the NOAA Climate Prediction center (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). As mentioned above, ONI values of 0.5 or greater indicate El Niño phases, while values of -0.5 or less indicate La Niña phases.

The monthly CPUE data for each species were decomposed into three components: trend, seasonal, and random (Kendall and Stuart 1983). To capture the trend potentially attributed to ENSO events the seasonal and random components were removed from the observed data. Therefore, only the trend time series data were used for all analyses described below. As an initial exploratory measure, cross-correlations (Torres-Orozco et al. 2006) were run between the trended CPUE time series and ONI time series to determine if various lags of ONI correlated best with the CPUE time series. For example, if peak CPUE occurred 12 months after high ONI values (i.e., El Niño event) that may imply that certain conditions during that El Niño event may have improved the species biological or ecological processes, such as recruitment success. ONI lags from 0 to 40 months were examined. Lags were limited to 40 months because it would likely be difficult to biologically explain relationships beyond that timeframe, increase potential noise, and because individuals in the small yellowfin tuna size class are less than two years old.

Once the most correlated lags were determined, a series of generalized additive mixed models (GAMM) were developed where a separate model was run for each lag. GAMMs were selected because they are flexible enough to handle nonlinear relationships using smoothing functions (Hastie and Tibshirani 1990, Wood 2017). Based on the cross-correlation analysis, a series of lagged models were run for each species from no lag to around a two-year lag, while making sure to expand into greater lags if correlations peaked just beyond two years. Larger lags were used for skipjack based on the cross-correlation analysis because there was no age class limitation compared to yellowfin. This was done to further examine the correlation between CPUE and ONI because although the cross-correlation analysis may show a relationship this may be attributed to other variables like effort, fishing strategy changes, or other environmental processes at finer and larger scale. Further, we were particularly interested in recent trends for both species. The response variable for the GAMMs was the trended CPUE data (Hastie and Tibshirani 1990, Wood 2017). The covariates were the ONI time series at time equal to 0 to represent catchability, lagged ONI time series corresponding to appropriate lagged model (for the no-lag model, there was no lagged ONI to include), and annual total sets to account for changes in effort over the time series. Lagged ONI was investigated to determine which ENSO events may influence the trended CPUE. A smoothing function of thin plated regression splines was put around all covariates. To account for the non-independence of the data (Gillies et al. 2006), year was included in each model as a random effect. The base equation for the lagged models is below:

$$CPUEtrend_{t=0} \sim s(ONI_{t=0}) + s(ONI_{t-L}) + s(annual\ set\ \#) + random(Year)$$

where, L is the lag of interest. Model diagnostics were done through plotting residuals. All lagged models were compared to each other using Akaike information criterion (AIC) and the top models were examined further. Specifically, CPUE predictions were made over the lagged ONI time series using marginal means (Searle et al. 1980). These predictions provided a relationship between CPUE and ONI lagged. Estimates of uncertainty around the predictions were calculated from 500 bootstrapped samples (Efron and Tibshirani 1993).

To examine recent fluctuations in catch of both species, trended CPUE was predicted for the recent periods with increases in CPUE; January to October 2022 for yellowfin and July to September 2023. Predictions were particularly made using the top lag models and lagged ONI values were manipulated. All other covariates (ONI at t=0, annual total sets) were averaged over the time period of CPUE changes. Predictions of CPUE were calculated when lagged ONI values were its actual value, during neutral conditions (-0.2 to 0.2), regular El Niño conditions (1.0 to 1.5), strong El Niño conditions (1.7 to 2.2), and strong La Niña conditions (-1.7 to -1.1). Regular La Niña conditions were not predicted because the actual lagged conditions for both species were during an average La Niña events. It would be assumed that if actual lagged conditions were during a La Niña and CPUE was positively correlated to lagged La Niña events, then predicted CPUE would be greater when lagged conditions were La Niña, compared to if they were neutral or El Niño conditions.

The analyses above were complemented with an analysis focused on assessing, in a simple manner, how much of the annual changes in catch can be attributed to changes in CPUE versus changes in effort. The assumption is that effort is exogenous to the system and that CPUE is where the environment can come in. In this case, the environment encompasses effects that are confounded and that are difficult to tease apart, such as, recruitment (abundance), availability or catchability, and the processes and mechanisms driving these. If we want to better understand the potential role of the environment in explaining recent trends in yellowfin and skipjack catch, it can be helpful to determine how much of the change in tuna catch is from effort versus from CPUE, and by extension how much of the change is possibly explained by the environment (i.e., CPUE). Specifically, year-to-year changes in catch were decomposed into constituent parts of CPUE and effort. Taking the catch equation of,

$$catch_t = cpue_t E_t$$

The proportional change in catch was calculated as,

$$\frac{catch_t}{catch_{t-1}} = \frac{cpue_t E_t}{cpue_{t-1} E_{t-1}}$$

Log-transforming then gives,

$$log(catch_t) - log(catch_{t-1}) = log(cpue_t) + log(E_t) - \big(log(cpue_{t-1}) + log(E_{t-1})\big)$$

The right-hand part of the equation can be re-arranged into

$$log(cpue_t) - log(cpue_{t-1}) + log(E_t) - log(E_{t-1})$$

And then aggregated into

$$\Delta_{cpue_t} = log(cpue_t) - log(cpue_{t-1})$$

and

$$\Delta_{E_t} = log(E_t) - log(E_{t-1})$$

Δ_{cpue} and Δ_E were plotted together for yellowfin and skipjack to visualize the relative contribution of effort and CPUE to changes in catch, particularly during the recent years when catches increased.

3. RESULTS

3.1. Yellowfin tuna

Once the seasonal and random components were removed from the observer monthly small yellowfin tuna OBJ CPUE data (Fig. 1a), a much smoother trend was evident (Fig. 2a). The highest trended small yellowfish tuna CPUE in the purse-seine OBJ fishery occurred from the second half of 1999 to the first half in 2000. Smaller peaks occurred in 2015-2016 and in 2022. Drops in CPUE occurred after the large peak in 2000, once in 2008-2009, and in 2012-2013. Cross-correlation showed that trended small yellowfin tuna had the strongest correlations during the current ONI and when ONI was lagged 23 to 26 months. Specifically, low small yellowfin tuna CPUE occurred when the current ONI was comparable to an El Niño, whereas high CPUE occurred approximately 23 to 26 months after El Niño (Fig. 3a). The opposite trend occurs for CPUE when looking at the ONI from a La Niña perspective.

In total, 27 models were run for yellowfin tuna including the no lag model and models representing lags from one to 26. Due to time constraints models' autocorrelation diagnostics were not fully met for this analysis. Using model selection, seven of the 27 models were further analyzed. Marginal mean plots for all lagged models are in the Appendix. The top model occurred at a 16 month lag of ONI, followed by the lags of 5, 6, 4, and 11. CPUE appeared to be greatest 16 months after ONI values that were less than -1.5 (strong La Niña) and between 1 and 1.5 (moderate to strong El Nino) (Fig. 4). Whereas CPUE was estimated to be the lowest 16 months after ONI values between 2 and 2.5 (strong El Nino). Based on the other top models, CPUE was estimated to be greater 4-6 months after ONI values that were less than -0.5 (moderate La Niña).

Predictions of small yellowfin CPUE were conducted for the top two lagged models, 16 and 5 months. For the 16-month lagged model, predictions during actual (moderate La Niña) conditions and neutral conditions were similar (1.28/1.29 catch/set), whereas during moderate El Niño conditions, predictions increased to 1.44 (Table 1). During strong El Niño events predictions drop to 1.22. During strong La Niña events predictions increased to 1.33. For the 5-month lagged model, predictions of catch per set were high (1.27) during actual conditions (weak La Niña), compared to moderate and strong El Niño conditions (1.24/1.25) and neutral conditions (1.23) (Table 2). However, predictions were the highest (1.35) 5 months after strong La Niña events.

Lastly, when examining the annual changes in yellowfin catch, CPUE, and effort, all three increased in 2022 (Fig. 6a). In 2022 the catch approximately increased 45% and this was attributed to a 19% increase in CPUE (i.e., environment, confounded with other effects like availability, catchability, or recruitment/abundance) and a 26% increase effort (Fig. 6b).

3.2. Skipjack tuna

Similar to yellowfin tuna, once the seasonal and random components were removed (Fig. 1b) the monthly skipjack tuna CPUE trend smoothed out (Fig. 2b). The highest trended skipjack tuna CPUE occurred between 1999 and 2000, like for yellowfin. From 2003 to 2007 the trend bounced up and down at higher levels relative to average. Beyond 2007 the trend remained low, while reaching its lowest level in the time series in 2018. Starting in 2023, trended CPUE has increased to its highest levels since 2007. Cross-correlation indicated that trended CPUE and ONI had the strongest correlations when ONI was lagged between 2 and 5 months and 19 and 24 months. Therefore, low skipjack CPUE occurred 2 to 5 months after an El Niño, whereas greater CPUE occurred 19 to 24 months after an El Niño (Fig. 3b). The relationship between CPUE and ONI flips during lower ONI values or La Niña events.

For skipjack tuna, the 31 models were run, including the no lag model and models representing lags from one to 30. Of the 31 models, the top models had lags of 27, 26, 28, 25, 29, and 30 months. Marginal mean plots for all lagged models are in the Appendix. CPUE appeared to be the greatest 27 months after higher (~2) ONI values (strong El Niño events) (Fig. 5). Whereas low CPUE is correlated with low (~-1) ONI values 27 months earlier (moderate La Nina events). Similar correlations existed for the other top lagged models.

Predictions of skipjack CPUE were conducted for the top lagged model, 27 months. For the 27-month lagged model, the catch per set predictions for the actual conditions (weak La Niña) and strong La Niña conditions were smallest (19.2) and then increased for neutral (19.9), moderate El Niño (20.6), and strong El Niño (21.6) conditions (Table 3).

Annual changes in skipjack catch and CPUE increased in the year 2023 while effort decreased (Fig. 7a). In 2023 skipjack catch approximately increased 17% and this was attributed to a 23% increase in CPUE (i.e., environment) and a 6% decrease in effort (Fig. 6b).

4. DISCUSSION

When combining the results from all analyses, it appears that there is some effect of the lagged environment (ENSO, as measured by the ONI index) on the CPUE of both yellowfin and skipjack tuna. For yellowfin the effects differ based on the lagged ONI value, but according to the top lagged models, CPUE is positively correlated with La Niña events (especially strong La Niñas), while lower CPUE values are associated more with neutral and El Niño events. These relationships particularly occurred when catch occurs 4-6 months after the ENSO event. When focusing on the recent increases in small yellowfin CPUE in 2022 it appears that the recent weak La Niña events that occurred 4-6 months prior had a positive effect on the CPUE. This indicates that La Niña events may improve small yellowfin recruitment success into the purse seine object fishery since small yellowfin size class represents individuals that are less than two years old. Although an El Niño event did not occur within the last 40 months since 2022, it is interesting to highlight the stronger influence moderate El Niño events may have on positive small yellowfin CPUE 16 months later. This association suggests that individuals that are over a year old may prefer warmer conditions compared to individuals less than one year old which may increase the CPUE in the fishery. The equal contribution of effort and CPUE on catch also indicates that although increased effort contributed to increase catch, CPUE which takes into account change in the environment, also influenced the increase in catch. However, the specific mechanisms relating ONI and yellowfin tuna recruitment, availability or catchability need to be better understood.

Similar to yellowfin, the effect of lagged ONI on skipjack CPUE varied based on the number of months that were lagged. The top lagged models suggest that skipjack CPUE (all size classes combined) is positively correlated with El Niño events and negatively correlated with La Niña events. These relationships occurred particularly when catch occurs 25 to 30 months after the ENSO event. When examining the cause of the recent increase in skipjack catches and CPUE in 2023, predicted CPUE may have risen partially due to La Niña conditions improving towards a neutral phase over two years prior. The impact of the environment is further supported by the fact that although effort decreased in 2023, CPUE, which may include the effect of the environment, increased and thus lead to an increase in catch of skipjack tuna.

This analysis adds support to previous works indicating that there is likely an environment effect on the catch of small yellowfin and skipjack tuna in the purse-seine floating-object fishery in the EPO (Annual Report of the IATTC 1983 and 1989, SAC-06-INF-C). This analysis would benefit further with a deeper analysis into the impacts of various fishing behavior, strategy and technology changes through time as well as assessing the duration, severity, and cumulative impact of ENSO events on catch, availability or catchability, and species' biology and ecology in general. These additional variables could further explain historic and recent trends observed in catch overtime. Lastly, if these models' predictive skill is high, ENSO conditions could be used to predict potential catch and CPUE fluctuations in the future, which could help management prepare and anticipate changes in fishing resources.

5. REFERENCES

Domokos, R. 2023. Influence of El Niño-Southern Oscillation on bigeye and yellowfin tuna longline catch per unit effort in the equatorial Pacific. Fisheries Oceanography **32**:527-540.

Efron, B., and R. J. Tibshirani. 1993. An introduction to the bootstrap. CRC press, New York, NY.

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology **75**:887-898.

Hastie, T. J., and R. J. Tibshirani. 1990. Generalized Additive Models. CRC Press.

Kendall, M., and A. Stuart. 1983. The Advanced Theory of Statistics, Vol.3, Griffin. pp. 410–414.

Searle, S. R., F. M. Speed, and G. A. Milliken. 1980. Population marginal means in the linear model: an alternative to least squares means. The American Statistician **34**:216-221.

Torres-Orozco, E., A. Muhlia-Melo, A. Trasviña, and S. Ortega-García. 2006. Variation in yellowfin tuna (Thunnus albacares) catches related to El Niño-Southern Oscillation events at the entrance to the Gulf of California.

Wood, S. N. 2017. Generalized Additive Models: An Introduction with R, Second Edition. Chapman & Hall/CRC, Boca Raton, FL.

Yen, K.-W., G. Wang, and H.-J. Lu. 2017. Evaluating habitat suitability and relative abundance of skipjack (Katsuwonus pelamis) in the Western and Central Pacific during various El Niño events. Ocean & coastal management **139**:153-160.

6. TABLES

TABLE 1. Predictions of CPUE for yellowfin tuna using the 16 month lagged model for actual and various hypothetical ONI conditions during the January to October 2022 period when CPUE increased. ONI values are provided for the 16 month lagged for each condition that were used in the predictions. The actual conditions at the 16 month lag was a moderate La Niña. The other covariates in the model were held constant for the predictions including the mean number of sets in the purse seine object fishery and the mean ONI value during the time period.

TABLA 1. Predicciones de CPUE para el atún aleta amarilla utilizando el modelo con retardo de 16 meses para condiciones de ONI reales y varias condiciones hipotéticas durante el periodo de enero a octubre de 2022, cuando aumentó la CPUE. Se proporcionan los valores del ONI para el retardo de 16 meses para cada condición que se utilizaron en las predicciones. Las condiciones reales en el retardo de 16 meses eran condiciones moderadas de La Niña. Las demás covariables del modelo se mantuvieron constantes para las predicciones, incluido el número promedio de lances en la pesquería cerquera sobre objetos flotantes y el valor promedio del ONI durante el periodo.

Condition	Lag	Mean # of sets	ONI t_0	ONI t_{16}	CPUE predictions
Actual	16	15918	-0.95	-1.3 to -0.7	1.28
Neutral	16	15918	-0.95	-0.2 to 0.2	1.29
Moderate El Niño	16	15918	-0.95	1.0 to 1.5	1.44
Strong El Niño	16	15918	-0.95	1.7 to 2.2	1.22
Strong La Niña	16	15918	-0.95	-1.7 to -1.1	1.33

TABLE 2. Predictions of CPUE for yellowfin tuna using the 5 month lagged model for actual and various hypothetical ONI conditions during the January to October 2022 period when CPUE increased. ONI values are provided for the 5 month lagged for each condition that were used in the predictions. The actual conditions at the 5 month lag was a weak La Niña. The other covariates in the model were held constant for the predictions including the mean number of sets in the purse seine object fishery and the mean ONI value during the time period.

TABLA 2. Predicciones de CPUE para el atún aleta amarilla utilizando el modelo con retardo de cinco meses para condiciones de ONI reales y varias condiciones hipotéticas durante el periodo de enero a octubre de 2022, cuando aumentó la CPUE. Se proporcionan los valores del ONI para el retardo de cinco meses para cada condición que se utilizaron en las predicciones. Las condiciones reales en el retardo de cinco meses eran condiciones débiles de La Niña. Las demás covariables del modelo se mantuvieron constantes para las predicciones, incluido el número promedio de lances en la pesquería cerquera sobre objetos flotantes y el valor promedio del ONI durante el periodo.

Condition	Lag	Mean # of sets	ONI t_0	ONI t_5	CPUE predictions
Actual	5	15918	-0.95	-1.0 to -0.5	1.27
Neutral	5	15918	-0.95	-0.2 to 0.2	1.23
Moderate El Niño	5	15918	-0.95	1.0 to 1.5	1.25
Strong El Niño	5	15918	-0.95	1.7 to 2.2	1.24
Strong La Niña	5	15918	-0.95	-1.7 to -1.1	1.35

TABLE 3. Predictions of CPUE for skipjack tuna using the 27 month lagged model for actual and various hypothetical ONI conditions during the July to September 2023 period when CPUE increased. ONI values are provided for the 27 month lagged for each condition that were used in the predictions. The actual conditions at the 27 month lag was a weak La Niña. The other covariates in the model were held constant for the predictions including the mean number of sets in the purse seine object fishery and the mean ONI value during the time period.

TABLA 3. Predicciones de CPUE para el atún barrilete utilizando el modelo con retardo de 27 meses para condiciones de ONI reales y varias condiciones hipotéticas durante el periodo de julio a septiembre de 2023, cuando aumentó la CPUE. Se proporcionan los valores del ONI para el retardo de 27 meses para cada condición que se utilizaron en las predicciones. Las condiciones reales en el retardo de 27 meses eran condiciones débiles de La Niña. Las demás covariables del modelo se mantuvieron constantes para las predicciones, incluido el número promedio de lances en la pesquería cerquera sobre objetos flotantes y el valor promedio del ONI durante el periodo.

Condition	Lag	Mean # of sets	ONI t_0	ONI t_{27}	CPUE predictions
Actual	27	14923	1.3	-0.4 to -0.7	19.2
Neutral	27	14923	1.3	-0.2 to 0.2	19.9
Moderate El Niño	27	14923	1.3	1.0 to 1.5	20.6
Strong El Niño	27	14923	1.3	1.7 to 2.2	21.6
Strong La Niña	27	14923	1.3	-1.7 to -1.1	19.2

7. FIGURES

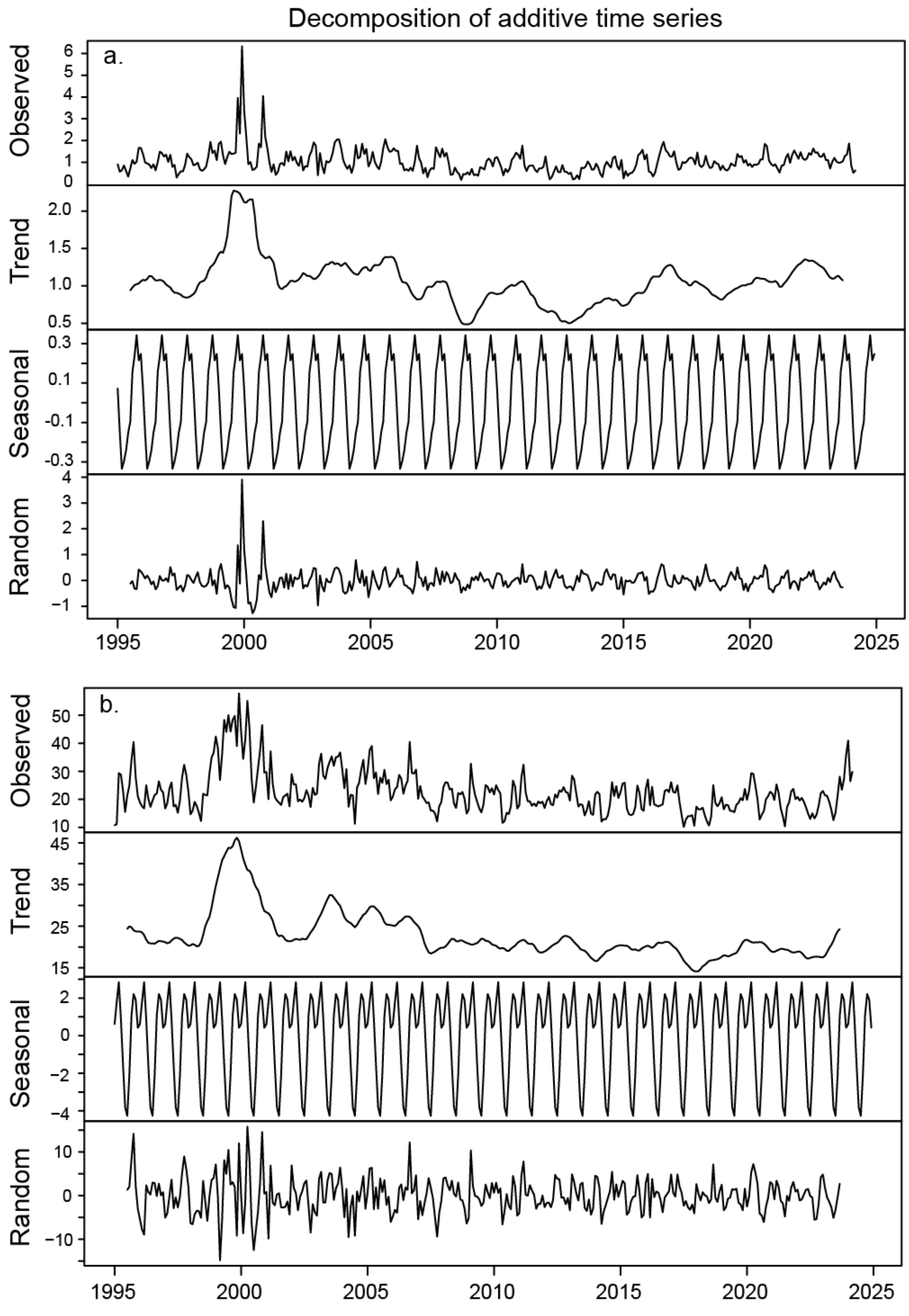

FIGURE 1. Decomposed CPUE timeseries data into trend, seasonal, and random components for small yellowfin tuna (a) and skipjack tuna (b).

FIGURA 1. Descomposición de los datos de la serie de tiempo de la CPUE en componentes de tendencia, estacionales y aleatorios para el atún aleta amarilla pequeño (a) y el atún barrilete (b).

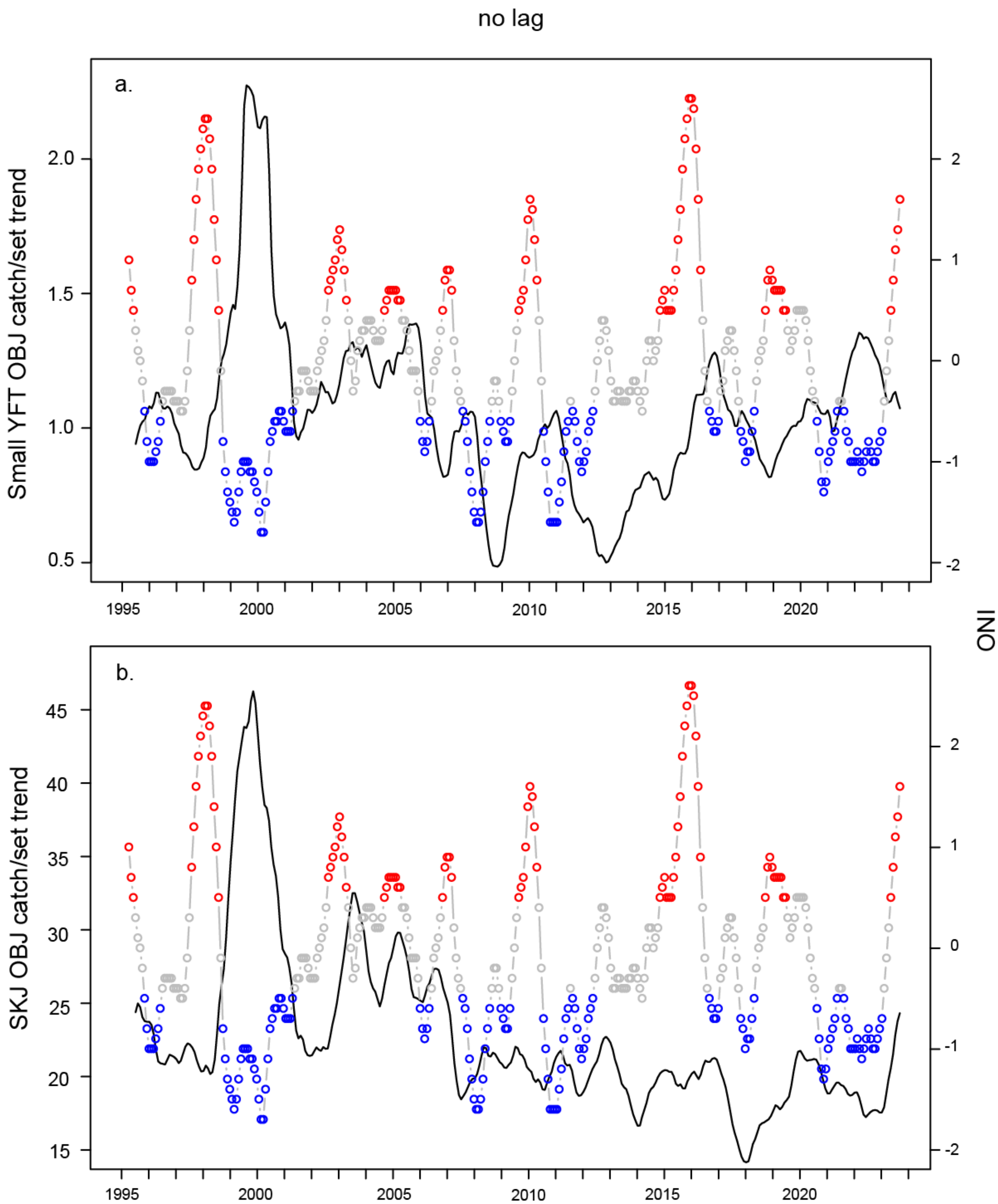

FIGURE 2. Small yellowfin tuna (a) and skipjack tuna (b) CPUE trend data overlaid with ONI. The colors of the points of ONI correspond to the El Niño (red), La Niña (blue), or Neutral (grey) phase.

FIGURA 2. Datos de tendencia de la CPUE del atún aleta amarilla pequeño (a) y del atún barrilete (b) superpuestos con el índice ONI. Los colores de los puntos del ONI corresponden a las fases de El Niño (rojo), La Niña (azul) o neutras (gris).

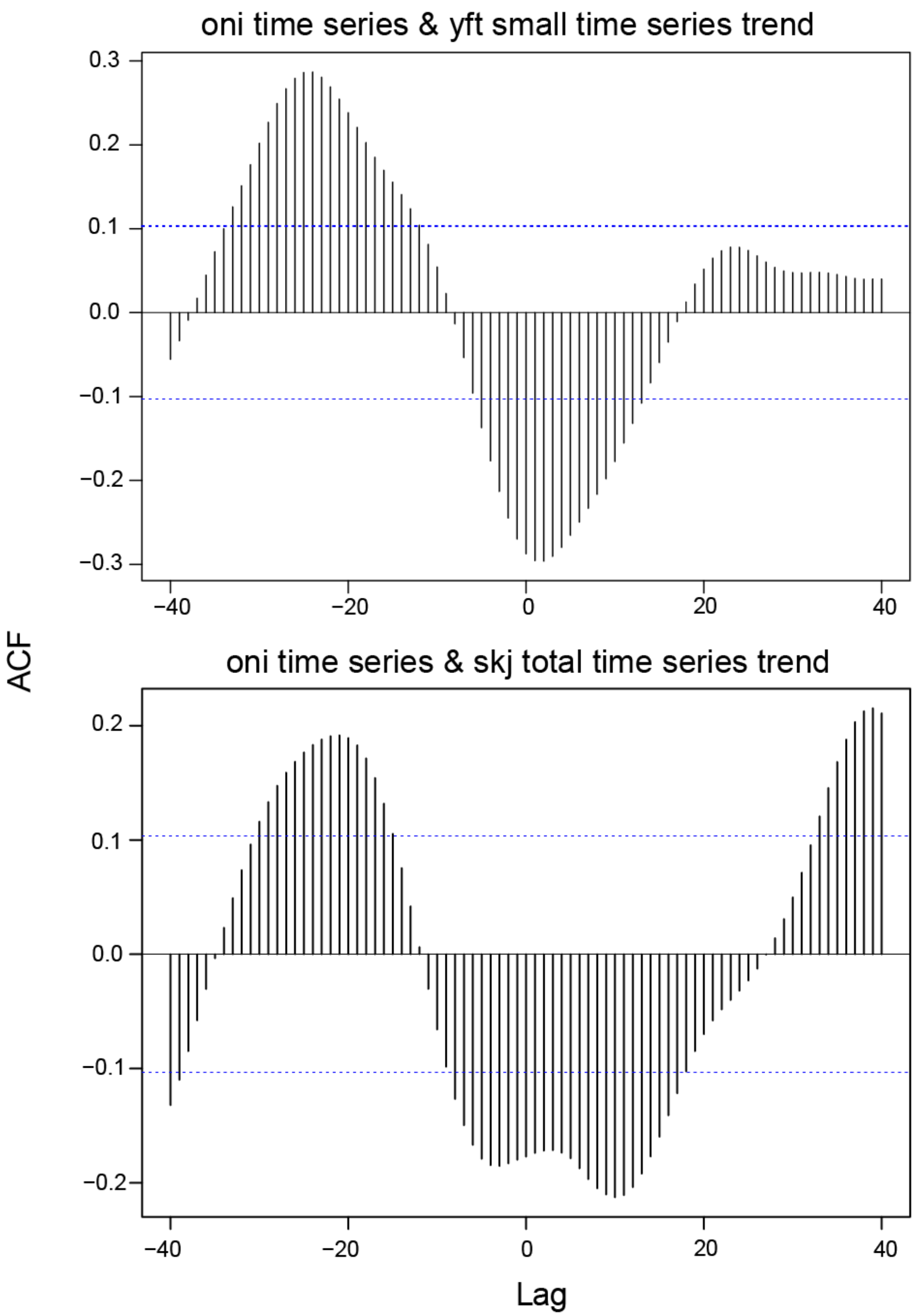

FIGURE 3. Cross-correlations between small yellowfin (a) and skipjack (b) trended CPUE data against the ONI timeseries from -40 to 40 month lags. Lags less than 0 indicate that catches correlate with prior ONI values. If the correlations extend beyond the blue dashed line the correlations are significantly different from 0.

FIGURA 3. Correlaciones cruzadas entre los datos de tendencia de la CPUE del atún aleta amarilla pequeño (a) y del atún barrilete (b) y la serie de tiempo del ONI con retardos de -40 a 40 meses. Los retardos inferiores a 0 indican que las capturas están correlacionadas con valores anteriores del ONI. Si las correlaciones se extienden más allá de la línea discontinua azul, las correlaciones son significativamente diferentes de 0.

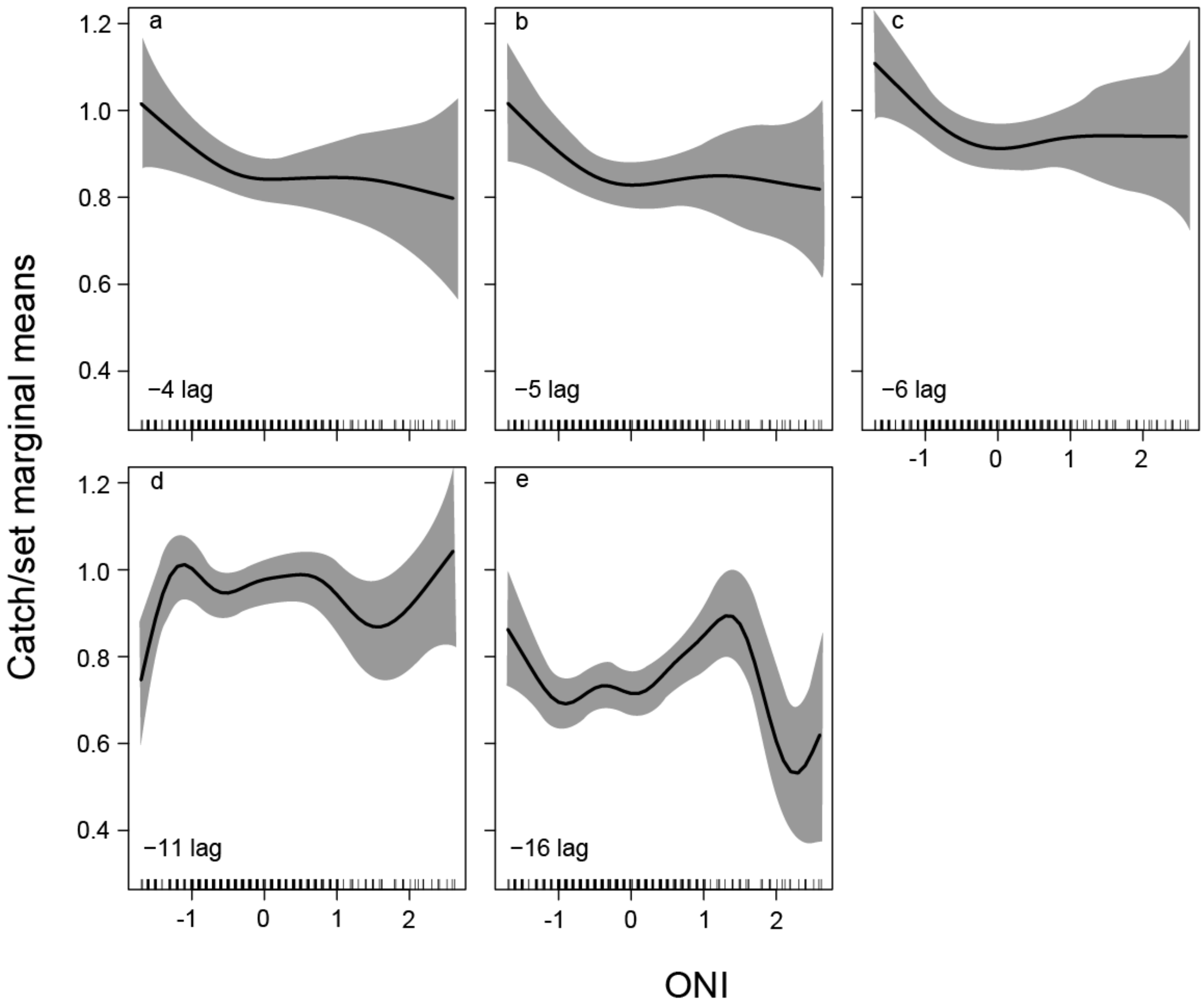

FIGURE 4. Marginal mean predictions of small yellowfin CPUE in the purse seine object fishery for ONI for the top lagged models (-4, -5, -6, -11, -16). The black line shows the actual marginal mean for ONI for each lagged model, while the grey area indicates the confidence intervals generated through bootstrapping. The black tick marks on the bottom of the plots show the monthly ONI values under which sets occurred.
FIGURA 4. Predicciones de medias marginales de la CPUE del atún aleta amarilla pequeño en la pesquería cerquera sobre objetos flotantes para el ONI para los mejores modelos con retardo (-4, -5, -6, -11, -16). La línea negra muestra la media marginal real del ONI para cada modelo con retardo, mientras que el área gris indica los intervalos de confianza generados mediante *bootstrapping*. Las marcas negras de la parte inferior de las gráficas muestran los valores mensuales del ONI bajo los que se produjeron los lances.

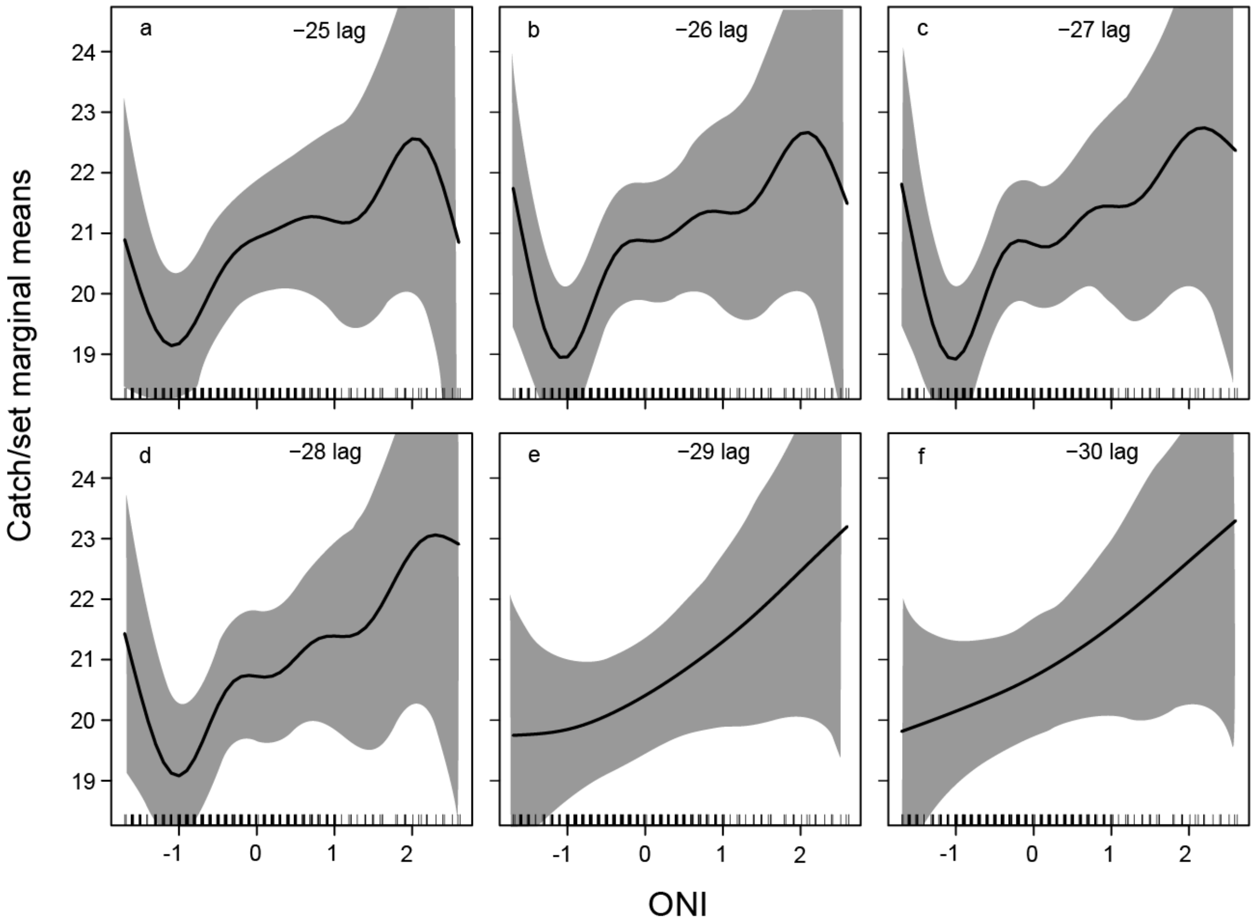

FIGURE 5. Marginal mean predictions of skipjack CPUE in the purse seine object fishery for ONI for the top lagged models (-25, -26, -27, -28, -29, -30). The black line shows the actual marginal mean for ONI for each lagged model, while the grey area indicates the confidence intervals generated through bootstrapping. The black tick marks on the bottom of the plots show the monthly ONI values under which sets occurred.

FIGURA 5. Predicciones de medias marginales de la CPUE del atún barrilete en la pesquería cerquera sobre objetos flotantes para el ONI para los mejores modelos con retardo (-25, -26, -27, -28, -29, -30). La línea negra muestra la media marginal real del ONI para cada modelo con retardo, mientras que el área gris indica los intervalos de confianza generados mediante *bootstrapping*. Las marcas negras de la parte inferior de las gráficas muestran los valores mensuales del ONI bajo los que se produjeron los lances.

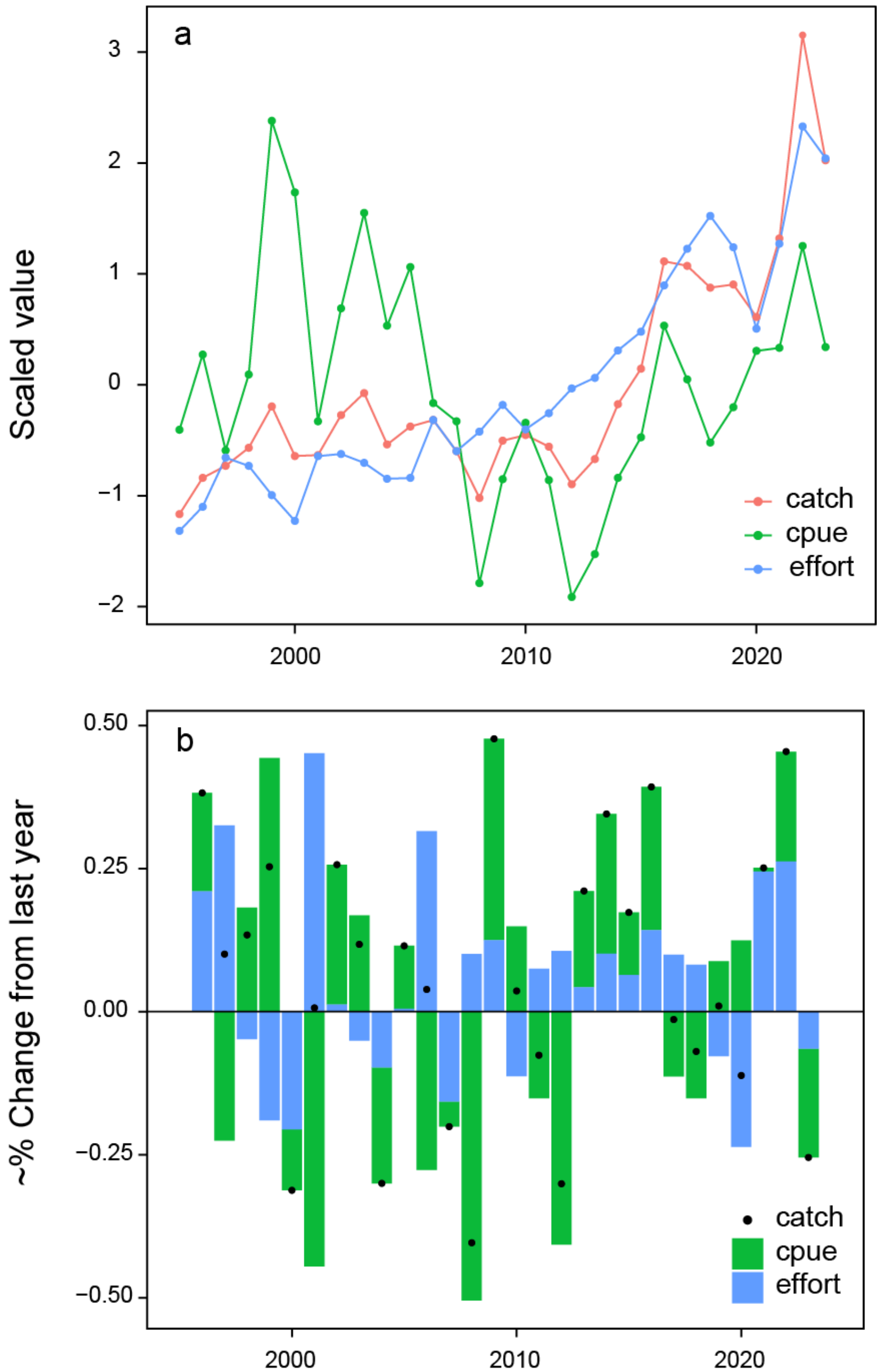

FIGURE 6. Centered and scaled trends in catch, effort, and CPUE for small yellowfin tuna in the purse seine object fishery (a). Decomposition of changes in catch into contributions of CPUE and effort. Values are roughly analogous to percent effects (b).

FIGURA 6. Tendencias centradas y escaladas de captura, esfuerzo y CPUE para el atún aleta amarilla pequeño en la pesquería cerquera sobre objetos flotantes (a). Descomposición de los cambios en las capturas en contribuciones de CPUE y esfuerzo. Los valores son más o menos análogos a los efectos porcentuales (b).

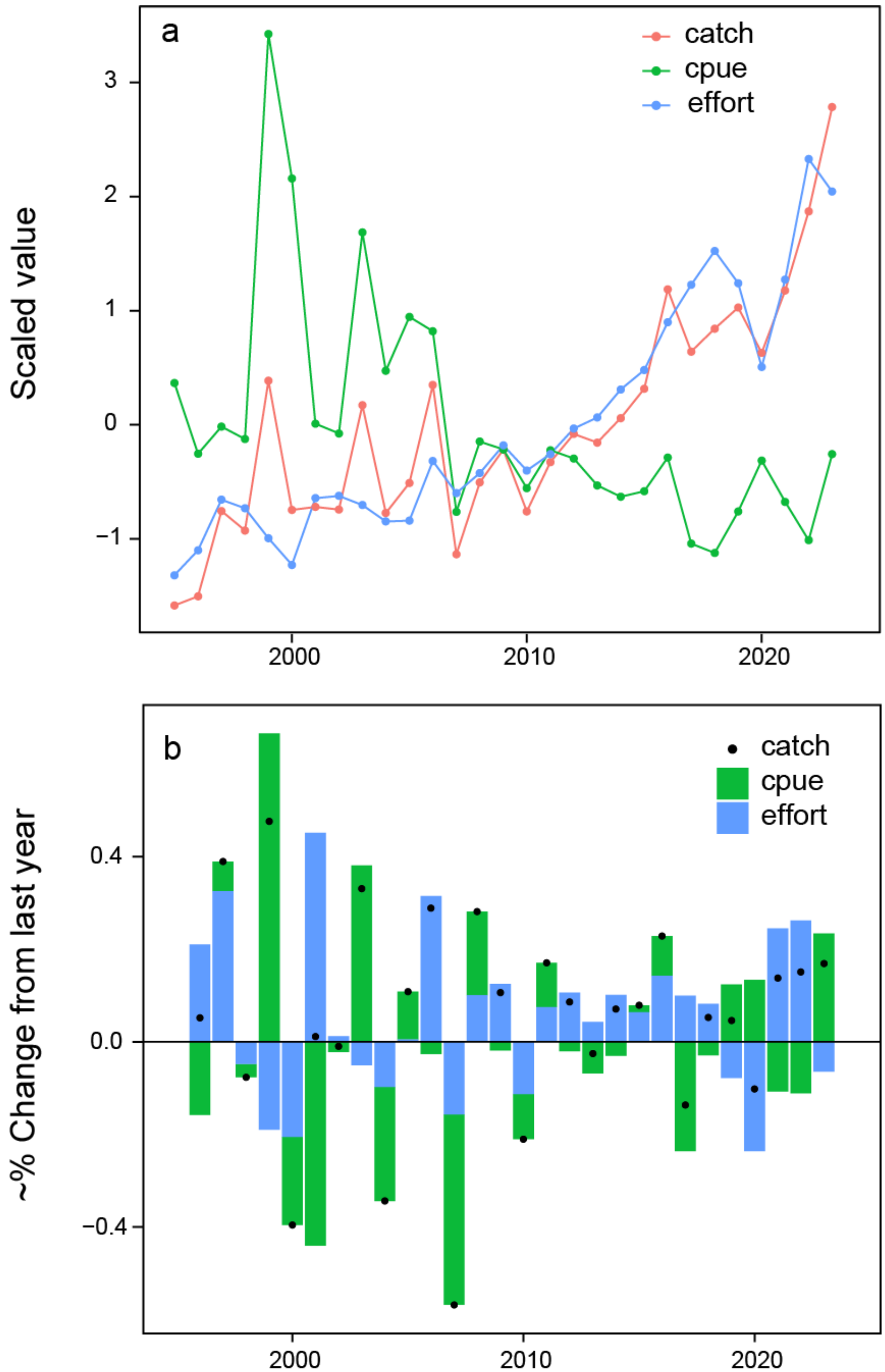

FIGURE 7. Centered and scaled trends in catch, effort, and CPUE for skipjack tuna in the purse seine object fishery (a). Decomposition of changes in catch into contributions of CPUE and effort. Values are roughly analogous to percent effects (b).

FIGURA 7. Tendencias centradas y escaladas de captura, esfuerzo y CPUE para el atún barrilete en la pesquería cerquera sobre objetos flotantes (a). Descomposición de los cambios en las capturas en contribuciones de CPUE y esfuerzo. Los valores son más o menos análogos a los efectos porcentuales (b).

8. APPENDIX

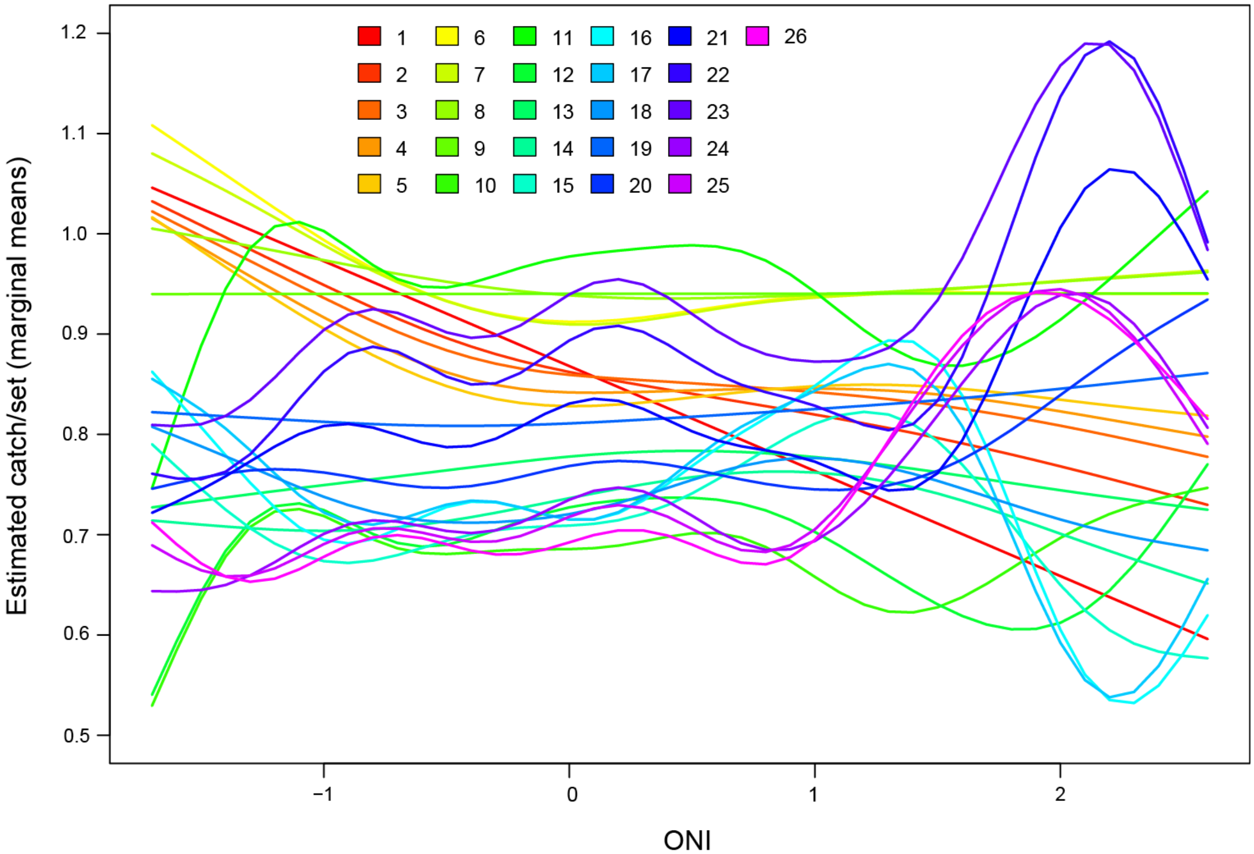

FIGURE A1. Marginal mean predictions of small yellowfin CPUE in the purse seine object fishery for ONI for all lagged models.

FIGURA A1. Predicciones de medias marginales de la CPUE del atún aleta amarilla pequeño en la pesquería cerquera sobre objetos flotantes para el ONI, para todos los modelos con retardo.

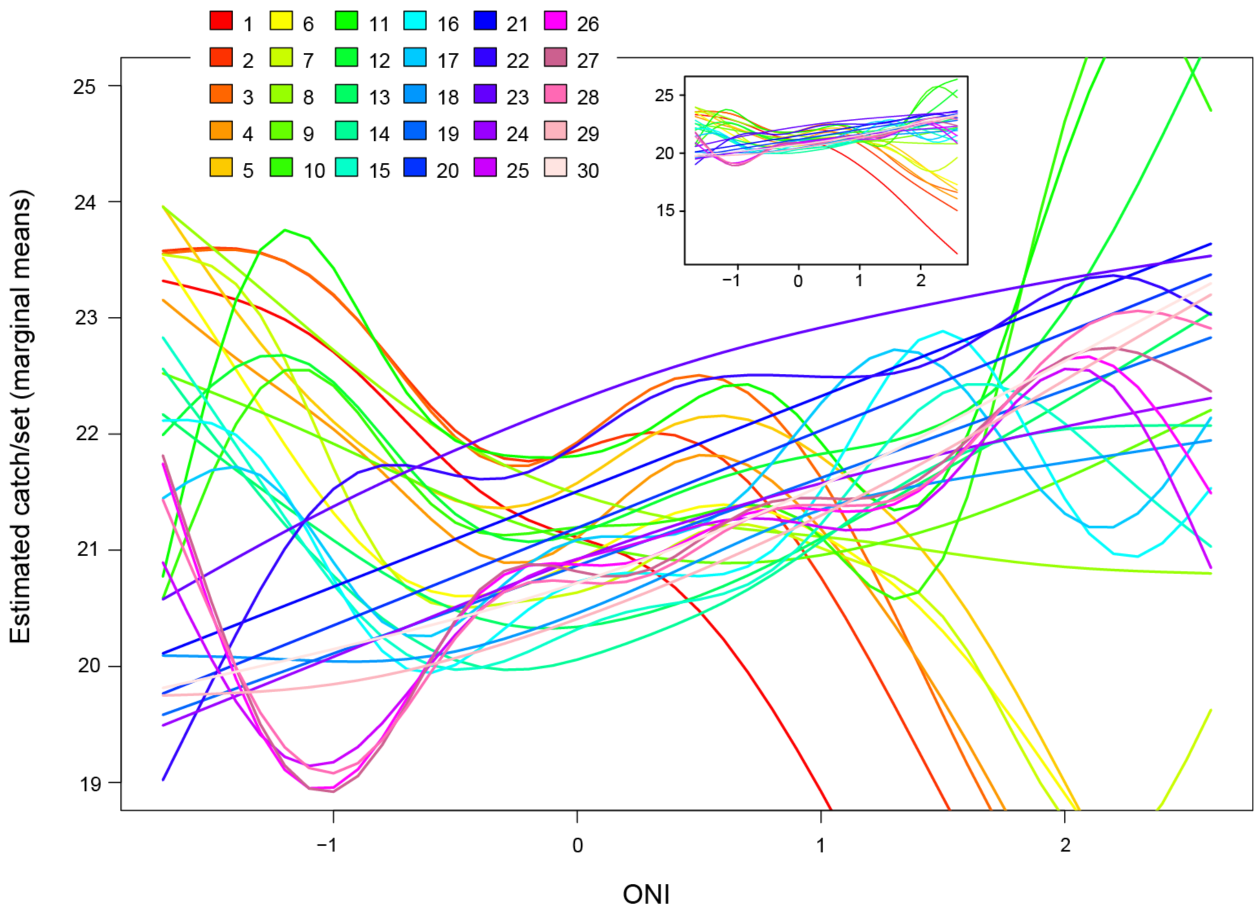

FIGURE A2. Marginal mean predictions of skipjack tuna CPUE in the purse seine object fishery for ONI for all lagged models. The inset map shows the entire extent of all marginal mean predictions.

FIGURA A2. Predicciones de medias marginales de la CPUE del atún barrilete en la pesquería cerquera sobre objetos flotantes para el ONI, para todos los modelos con retardo. El mapa del recuadro muestra la extensión completa de todas las predicciones de medias marginales.