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# IMPACTS OF THE CORRALITO ON THE TUNA FISHERIES AND ECOSYSTEMS OF THE EASTERN PACIFIC OCEAN

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## EXECUTIVE SUMMARY

The IATTC has utilized a spatio-temporal closure known as "the corralito" as part of its conservation and management measures package for many years (Table 1, Figure 1). The corralito has been in the same location since 2009, but the exact dates of the closure have varied slightly, from Sep 29 to Oct 29 (2009 through 2016), to Oct 9 to Nov 8 (2017 through 2024). In response to a request from Resolution C-21-04, the IATTC staff assessed evidence for the effects of the spatio-temporal closure known as "the corralito" on a range of outcomes of the purse-seine fishery in the eastern Pacific Ocean (EPO), with a focus on the structure of the corralito defined in C-21-04.

This study ran a "predictive" analysis similar to the methods reported in IATTC-77-04 REV (Section 3.1) using data from 1996 to 2008, excluding 2003, (years in which the corralito was not active) to predict what change in catch might have happened had the corralito been applied in those years, based on the catch, effort, and CPUE inside and in areas outside of the corralito. This predictive analysis estimated that, based on assumptions and conditions these non-corralito years, that the corralito would generally reduce annual catches of bigeye (BET) and skipjack (SKJ), respectively, while having variable to slightly positive impacts on catches of yellowfin (YFT). The average change in total annual catch attributed to the corralito by this predictive analysis was consistently between $\pm$ 2.5%. This predictive analysis found similar results to SAC-

05-16, with the corralito projected to be the equivalent of on average approximately 3 days of closure for BET, 1 day for SKJ, and 0 days for YFT. However, there was substantial year-to-year variation in these numbers, ranging from over 10 days of closure for BET in some years to an additional three days of fishing in others (Figure 3).

Data from 1996 to 2023 was used to attempt to estimate the empirical effects of the corralito during the years and periods in which it was active (Section 3.2). We examined potential impacts to catch, effort, CPUE, mean length of tropical tunas, and catches of sharks and other vulnerable non-target taxa. This analysis found no clear or consistent positive or negative signals of the corralito on any of these metrics. The lack of a clear empirical signal from the corralito is consistent with the finding that based on historic data we would predict the corralito to have small and highly variable outcomes, making any effect hard to detect in a dynamic social-ecological system such as the EPO. IATTC-77-04 REV also predicted that the corralito would have a small effect. The lack of a clear empirical signal within the data then is consistent with the expected performance of this management measure. Future work should complement the predictive and empirical analyses presented here with structural modeling that simulates the dynamics of fish and fishing fleets in space and time in reaction to management measures such as the corralito.

## 1. BACKGROUND

The IATTC has utilized a spatio-temporal closure known as "the corralito" as part of its conservation and management measures package for many years (Table 1, Figure 1). Noting that an early spatial "closure zone" was established by Resolution C-03-12 in 2003, the corralito as it is known today has been in the same location since 2009, but the exact dates of the closure have varied slightly, from Sep 29 to Oct 29 (2009 through 2016), to Oct 9 to Nov 8 (2017 through 2024).

The language of Resolution, C-21-04, specifically under paragraph 12 states that:

*"The fishery for yellowfin, bigeye, and skipjack tuna by purse-seine vessels within the area of 96° and 110°W and between 4°N and 3°S, known as the 'corralito'… shall be closed from 00:00 hours on 9 October to 24:00 hours on 8 November."*

Paragraph 1 of C-21-04 states that:

*"These measures are applicable to all CPCs' purse-seine vessels of IATTC capacity classes 4 to 6 (more than 182 metric tons carrying capacity), and to all their longline vessels over 24 meters length overall, that fish for yellowfin, bigeye and skipjack tunas in the Convention Area."*

With Resolution C-21-04 set to expire in late 2024, the Commission will be considering the adoption of a new package of conservation and management measures for tropical tuna at its 102nd annual meeting, in September 2024. If adopted, the new Resolution is expected to come into effect at the start of 2025. As a contribution to the upcoming discussions on the new conservation and management measures, and as requested by C-21-04, this document provides an evaluation by the IATTC scientific staff on evidence for impacts of the corralito on various metrics related to the catch and population of tropical tunas and other non-target species, including sharks and other vulnerable taxa, within the IATTC Convention Area (CA). This work builds off of, and expands on, previous analyses conducted by the staff of the role of spatial closures in tropical tuna management described in SAC-12 INF-B.

### 1.1. Theory of The Corralito Impacts

Spatial closures can affect fish and fisheries in a variety of direct and indirect ways (Hilborn et al. 2004; Gaines et al. 2010; Ovando et al. 2023). The clearest impact of a fully enforced spatial closure is the loss of the fishery catches that would have occurred within the closure had it been open to fishing. These immediate losses may be offset to some degree by redistribution of fishing effort from inside the closed area to outside, with the net impact on total catch being a function of the amount of catch lost within the closure relative to the catch gained resulting from redistributed effort outside the closure. The net effect on catch and the fished population may also be affected by differences in population selectivity (the cumulative effect of species availability and gear contact selectivity) in space and time, for example if effort is displaced from an area with smaller fish to an area with larger fish.

The reduction in catch inside the closure can result in an increase of biomass inside the closure, either through somatic growth or local recruitment, with the degree to which this occurs being a function of the size and duration of the closure relative to the biology and the movement dynamics of the species in question. The closure could also affect fish populations outside the closure through spillover of fish at various life stages from inside the closure to outside, as well through the displacement of fishing effort into the remaining fishing grounds (Gaines et al. 2010). In summary, the most immediate impacts expected from a spatial closure such as the corralito are a change in attributes of the catch during the periods of the closure. Those catch changes could have both short- and long-term impacts on the population over time, both inside and outside the closed area.

### 1.2. Objectives

The objectives of this study are to:

1. Update the predicted impacts of the corralito on tropical tuna catches first generated by IATTC-77-04 REV (Section 3.1).
2. Assess empirical evidence for the impacts of the corralito on catches of tropical tunas (Section 3.2).
3. Evaluate potential impacts of the corralito on other species of interest such as sharks, rays, and sea turtles (Section 3.3).

## 2. METHODS

This analysis used a range of methods to determine what if any effects of the corralito are evident in data from the EPO. Results are focused on impacts on the tropical tuna species skipjack (*Katsuwonus pelamis*, SKJ), yellowfin (*Thunnus albacares*, YFT), and bigeye (*Thunnus obesus*, BET). Evaluating the impacts of a policy like the corralito is challenging as numerous environmental, economic, and policy changes have overlapped with its implementation. Therefore, we need to consider to what extent changes observed when the corralito is in effect reflect the impacts of the policy itself or some other confounding factor such as broader environmental shifts, exogenous changes in fishing strategy or other domestic and international regulations.

We conducted two quantitative analyses in this study: i) predictive and ii) empirical. For the predictive section (Section 3.1), we generated a prediction of the magnitude and direction of catch impacts of the corralito based on patterns of catch and effort during years in which the corralito was inactive, similar to the approach applied by the staff in IATTC-77-04 REV. For the empirical approach (Section 3.2), we used a range of quasi-experimental methods to explore evidence for impacts of the corralito during the years in which it has been active. These include comparing various indices during the corralito period to their values in appropriately matched periods in which the corralito was not active (i.e., catches during October in years with the corralito relative to catches in October in years without the corralito), controlling to the extent possible for broader temporal trends.

In addition to the these two quantitative analyses, we also conducted a series of more qualitative and visual analyses of factors including identification of potential BET conservation hotspots in space and time, the effects of the corralito on mean length of BET caught in the purse-seine fishery, evidence for buildup of biomass inside the corralito and spillover of that biomass outside the corralito, and contributions of the corralito area to catches of sharks and other vulnerable taxa of interest.

### 2.1. Data

The primary database used here is the Daily Activity Records (DAR) database. The DAR provides records of catches per set of the three tropical tuna species, skipjack, yellowfin, and bigeye, as well as metadata related to the fishing operations (e.g., date and location of the fishing set) provided by on-board observers and complemented with logbooks where not. The DAR data are not a complete record of all the catch occurring in the region (omitting, for example, data from longline fisheries), but do provide good coverage of the class 4-6 purse-seine vessels directly affected by the corralito. Information on the spatio-temporal distribution of the lengths of tropical tunas were obtained from the Best Scientific Estimate (BSE) data, which reports numbers and weight caught by species, fishing method, year, month, broad location (5 x 5 degree grid cell), and size bin. BSE data for large purse-seine vessels fishing on floating objects was used, and the average length of fish caught by species, year, month was calculated. Each year was then classified based on whether the corralito was active in that particular year. Spatio-temporal data on non-tuna catches was obtained from data collected by observers on class 6 purse-seine vessels.

### 2.2. Predictive Analyses

IATTC-77-04 REV describes the original methods used to predict the potential impacts of the corralito on catches of tropical tunas, with the modified equation from that report being:

$$C_R = C_{total} - C_{inside} + CPUE_{outside} E_{inside} \qquad (1)$$

Where $C_R$ is the new predicted total catch with the corralito, $C_{total}$ is the observed catch in a given year, $C_{inside}$ is the observed catch within the corralito, $CPUE_{outside}$ is the CPUE outside of the corralito but south of 10°N (under the assumption that displaced effort would not move to the dolphin fishery area further north), and $E_{inside}$ is the observed purse-seine effort inside the corralito during the proposed closure period.

We modified the methods behind Equation 1 slightly to provide an updated prediction of the impacts of the modern corralito (2009-2023) on catches of tropical tunas based on years in which the corralito was never active (1996-2002 and 2004-2008, noting that an alternative closure to the corralito was used in 2004), a set of years we denote as $\iota$. In this report, for all years in $\iota$ we assumed that:

1. All catch within the most recent corralito time period (Oct 9 to Nov 8) and area is lost each year.
2. Effort of each set type $j$ (one of floating object, unassociated, and dolphin sets) that occurred within the corralito is displaced outside the corralito in proportion to the number of sets of gear type $j$ of vessels that historically used the corralito area, restricting this redistribution to areas south of 10°N.
3. The catch per unit effort (CPUE) in the displaced areas is unaffected by the displaced effort or biological spillover from the corralito.

For $y \in \iota$, these assumptions can be expressed as:

$$E^*_{y,j} = \sum_{l \in \theta} E_{y,j,l} \qquad (2)$$

$$P_{y,j,l} = \frac{E_{y,j,l}}{\sum_{l \notin \theta} E_{y,j,l}}, l \notin \theta \qquad (3)$$

$$C^{*}_{s,y,j} = \sum_{l \notin \theta} \left( C_{s,y,j,l} + CPUE_{s,y,j,l} P_{y,j,l} E^{*}_{y,j} \right) \qquad (4)$$

$$\Delta C_{s,y} = \sum_{j}^{J} C^{*}_{s,y,j} - C_{s,y,j} \qquad (5)$$

Where $C$ is catch of species $s$ in year $y$ for set type $j$ at location $l$, CPUE is catch per unit effort, $P$ is the proportion of effort of set type $j$ in location $l$ outside of the corralito for vessels that historically used the corralito, $E^{*}$ is the total effort of set type $j$ that occurred inside the corralito in a given year and $\theta$ are the locations covered by the corralito. $C^{*}$ is the updated prediction of total catch for a given species in a year outside the corralito. The net change in catch can then be calculated by subtracting the observed catch for a given species (which includes the catches inside the corralito area) from this updated catch prediction (Equation 5).

We next calculated the percent change in catch both during the corralito periods (i.e., how different do we expect catch to be during the time in which the corralito is active) and during the whole year (i.e., how much would we predict annual catch to change in years with the corralito). This approach provides a distribution of expected impacts of the corralito during each of the non-corralito years included in our analysis. We then applied these predicted impacts to the years in which the corralito did occur to generate a prediction of what the catches of each species would have been in the absence of the corralito. We generated these predictions by making the simplifying assumption that the corralito effects estimated for each year are independent, bootstrapping those values and applying the randomly sampled corralito effect based on this historic data to the corralito years.

Previous analyses suggested that the corralito could be expected to result in the equivalent of approximately three days of complete closure of the purse-seine fishery (SAC-05-16). This analysis can be approximately converted into equivalent units by calculating $\kappa$, the average catch per day $d$ per species per year over the years without the corralito ($\iota$), then converting the net change in catch predicted by Equation 5 into average equivalent days of closure per year per species ($\delta$):

$$\kappa_{s,y} = \frac{\sum_{d}^{D_y} C_{s,y,d}}{D_y} \qquad (6)$$

$$\delta_{s,y} = \frac{\Delta C_{s,y}}{\kappa_{s,y}} \qquad (7)$$

### 2.3. Empirical Analyses

The predictive analyses make a prediction of what would have happened in the years with the corralito based solely on data from years without the corralito. The empirical approach takes data from both years with and without the corralito, and attempts to empirically estimate the effect of the corralito on outcomes observed during periods in which the corralito was active.

#### 2.3.1. Non-Parametric Estimation of Corralito Effects on Catch

One challenge to estimating the effect of the corralito on catches is that the closure has been in effect in approximately the same days of the year, largely covering the month of October, since 2009. This means that we cannot easily separate out the effects of the corralito from the overall trends in catches in October. However, Figure 5 suggests that while there are no obvious changes in catch coinciding with the corralito, there are also clear seasonal trends that seem to be overall maintained between the corralito and non-corralito years. These seasonal trends are at least partially associated with the two seasonal closure periods of the purse-seine fishery.

Taking advantage of this, a non-parametric empirical approach was developed to estimate changes in catches of the tropical tuna species during the corralito. We trained a random forest model to predict catch as a function of year, month, and fishing effort using data from months in which the corralito was not active. The trained model was then used to predict the catch of each species during periods in which the corralito was active (which were held out from the model training). This model provides a counterfactual prediction of what catches would have been during periods that the corralito was active based on the trends in catches in the dates surrounding the corralito closure. This approach makes the assumption that there are short- (i.e., seasonal) and long-term (i.e., yearly to decadal) trends in catches around these closure periods that can be used to interpolate the expected catches in the closure period. Using this approach, we can examine whether observed catches were systemically lower in corralito months than expected based on the broader trends in the data.

We quantified the discrepancy between the observed and predicted values by first defining residuals *r* in year *y*, month *m* for species *s* as:

$$r_{y,m,s} = c_{y,m,s} - \widehat{c_{y,m,s}} \qquad (8)$$

where *c* is observed catch and $\hat{c}$ is the catch predicted by the non-parametric model. Under this framing, if the corralito resulted in a reduction in catch relative to the trend, the residuals would be *negative*, whereas the residuals would be *positive* if catches were higher than expected.

We quantified this difference by fitting a Bayesian generalized additive model (GAM) for each species of the general form:

$$residuals_{y,m,s} \sim \beta_0 + \beta_1 corralito_{y,m} + s(year_y) + s(month_m) \qquad (9)$$

The *corralito* in this equation is the proportion of days in that month in which the corralito was active. The $\beta_1$ term describes the extent to which the residuals deviate from the expected residuals for that species in that year and month. Therefore, if the corralito was reducing catches in a systemic way relative to the trend predicted by the model, the $\beta_1$ coefficient would be meaningfully less than zero.

### 2.3.2. Regression-Based Estimation of Corralito Effects on Catch

The advantage of the non-parametric approach is that it avoids potential confounding between the effect of the corralito and general seasonal trends in the approximate the closure month (October) after 2009. The disadvantage is that it requires an assumption that the trends around the corralito closure can be reliably used to interpolate the catches during the corralito month. An alternative approach is to fit a GAM of the general form:

$$log(catch_t) \sim \beta_0 + \beta_1 corralito_{y,m} + s(year_y) + s(month_m) \qquad (10)$$

In this model, $\beta_1$ is the estimated deviation in log-scale monthly catches (which is approximately equal to the percent change in the catch) when the corralito is active relative to long-term and seasonal trends without the corralito. This method assumes that trends in catches in October in the years without the corralito are indicative of what we would have observed in October in the corralito years had the corralito not been in place. A positive value of $\beta_1$ would indicate that catches when the corralito was active were systemically higher than the seasonal and yearly trend, a negative value would indicate lower catches.

### 2.3.3. Additional Analyses

Additional analyses on factors beyond the impacts of the corralito on catches of tropical tunas were conducted primarily using visual methods. We plotted various metrics including mean length of the catch, estimated biomass densities, and catch per set, as a function of either time and/or distance from the corralito and looked for evident breakpoints in the data that might be consistent with effects of the corralito. We also analyzed the spatio-temporal distribution of BET catches and estimated abundance on their own and relative to all tropical tunas to identify areas and times of concentrated BET importance.

In order to evaluate evidence of "spillover" of biomass from the corralito to surrounding waters, we fit a GAM to the VAST-estimated biomass densities of BET of the general form:

$$log\left(biomass_{y,m,l}\right) \sim s(lon_l, lat_l) + s\left(k_l \times corralito_{y,m}\right) + s\left(year_y\right) \qquad (11)$$

Where *lon* and *lat* are the longitude and latitude at location *l*, *k* is the distance from the nearest edge of the corralito at location *l*, *corralito* is a dummy variable indicating whether the corralito is in effect in that month *m* and year *y*. We then plotted the effect of distance from the corralito on log biomass as a function of whether the corralito was in effect, to see if there was evidence of a change in the biomass gradient with distance from the corralito border in years in which the corralito was in effect.

While this report is focused on the impacts of the corralito on tropical tunas, we also considered the role that the corralito might play in the conservation of other species of interest, such as sharks and sea turtles. Using data from 2000-2002 and 2004-2008, we calculated the proportion of annual catch for species of interest that were caught within the borders of the current corralito structure during the periods of the current corralito closure.

## 3. RESULTS

### 3.1. Predictive Analyses

Based on the patterns in the non-corralito years, Equation 5 predicted a range of catch effects for the three species, generally negative for skipjack and bigeye and positive for yellowfin. Bigeye had the largest estimated effect sizes, up to an approximately 20% predicted reduction in catch during the corralito window in some years, and as high as a 10% predicted increase in others. In terms of annual catch, effect sizes for all species were generally between $\pm$ 2.5% (Figure 2).

This study found similar results to SAC-05-16, with the corralito projected to be the equivalent of on average 2.63 days of closure for BET, 1.32 days for SKJ, and -0.18 days for YFT. However, there was substantial year-to-year variation in these numbers, ranging from over 14 additional days of closure for BET in some years to an additional 4 days of fishing in others (Figure 3).

Bootstrapping the impacts of the distribution of predicted corralito effects on catch by species shown in Figure 2 and applying them to the observed catches during years in which the corralito was active provided a prediction of the distribution of catches that might have expected based on Equation 4. Based on these predictions we would expect higher catches for BET and SKJ had the corralito not existed, and variable effects on YFT. However, both higher and lower catches were predicted to be possible for all species during the study period (Figure 4).

This process suggests that, based on historic data, variable effect sizes on total catch from the corralito are to be expected. Both positive and negative effects were possible for all species, but some species were predicted to be more likely to have reduced catches due to the corralito (BET, SKJ). Figure 4 also suggests, though, that we are likely to be searching for a small and variable signal from the corralito, ignoring all other forms of variation that might mask potential impacts.

### 3.2. Empirical Analyses

The predictions resulting from Equation 4 provide a framework for predicting the kinds of effects that might be expected from the corralito (Figure 4), based on the methods described in IATTC-77-04 REV. We then explored the data during the periods in which the corralito was active to see if we could detect any empirical effects of the corralito during its implementation.

Given that the corralito goes into effect for a defined period at a defined date, we examined the data to see whether there are visually obvious changes in total catch, effort, or CPUE coinciding with activation of the corralito, relative to what would be expected given recent or relevant historical trends. The assumptions behind Equation 4 require no changes in total effort coinciding with the corralito periods beyond seasonal trends independent of the corralito. The results shown in Figure 4 suggest that we might expect to see a small reduction in catch, resulting from a net decrease in CPUE (taking into account the loss of the corralito fishing grounds and the effort displacement outside).

There were no obvious changes in the EPO total catch in the months before, during, or after the corralito during years in which the corralito was active relative to trends in the non-corralito years (Figure 5). In general, in many corralito and non-corralito years October was a seasonal peak in catches for purse-seine vessels covered by this analysis. Effort was systemically higher during the later corralito years (2009-2023) than in the earlier non-corralito years (pre-2009, excluding 2003 as another spatial closure similar to the corralito was in effect that year).

This visual analysis did not reveal any clear breakpoints related to the different metrics analyzed for the corralito. However, we also did not observe a dramatic reduction in fishing effort during the corralito months, which would indicate a violation the assumptions of Equation 4 that assumes that effort is redistributed, not reduced, by the corralito.

#### 3.2.1. Non-Parametric Estimation of Corralito Effects on Catch

Figure 7 through Figure 9 show the results of the non-parametric modeling approach for BET, SKJ, and YFT. The model was able to capture the longer-term and seasonal trends in monthly catch. This non-parametric approach did not find systemic deviations in the observed catches during the corralito periods relative to the catch predicted by the model. Instead, for BET the model estimated an unclear but potentially positive corralito coefficient, while for both SKJ and YFT the model estimated meaningfully positive residuals, indicating that catches during the corralito periods held out from the model were actually systemically higher than predicted by the model for those species (Figure 10).

However, there are many reasons that we should interpret these results with caution. Seasonal trends shifted between the early 2000s and the later years when the corralito was active, meaning that the trends picked up by the model may be partially constructed of data from the earlier years that may be less applicable now. However, by only including later years the model might be biased due to only observing seasonal trends in the presence of the corralito, which may exert impacts outside of the months it is active, either through fleet dynamics or biological responses, and prevent us from isolating the background trend of catches in October from the effects of the corralito.

#### 3.2.2. Regression-Based Estimation of Corralito Effects on Catch

The results of the regression-based approach outlined in Equation 10 are generally in line with those estimated by the non-parametric method (Figure 11), finding evidence of equal or higher catches in corralito periods relative to non-corralito periods. However, the regression-based approach may be confounded with non-corralito driven shifts in catches in October since 2009 (Figure 11).

### 3.3. Additional Analyses

#### 3.3.1. Effects of the Corralito on Mean Length

Purse-seine fishing primarily targeting skipjack tuna has increasingly depended on fish-aggregating devices (FADS) in the EPO (FAD-07-01). An associated concern to FAD fishing is that it results in higher levels of catch of juvenile bigeye tuna. Therefore, a possible mechanism of action for the corralito is that if juvenile bigeye tuna are concentrated within the period and border of the corralito, shifting fishing pressure outside of that area might reduce catch on these smaller BET, potentially increasing the mean length of fish in the purse-seine catch.

If the corralito reduces fishing pressure on smaller individuals, higher mean length in October (the approximate month of the corralito) in years with the corralito than years without it, and/or a change in the seasonal trend of mean length in years with the corralito relative to years without should be expected. However, these patterns were not observed. According to the BSE data, mean length of the catch of large purse-seine vessels fishing on FADs was lower in October in corralito years than in non-corralito years. Mean length appears to increase between September and October in non-corralito years, whereas the mean lengths are largely similar between September and October during the corralito years (Figure 12). Based on this analysis, no direct evidence is observed in support of the hypothesis that the corralito reduces fishing on smaller BET resulting in increases in mean length of the catch.

### 3.3.2. Evidence For Biomass Buildup Inside the Corralito

Given that fishing normally occurs within the corralito when the closure is not in effect, the removal of that fishing effort should increase the biomass of fish within the corralito to some degree. The exact magnitude of this biomass increase depends on how heavy fishing would have been without the corralito, and the size and duration of the closure relative to the biology and movement dynamics of the species in question. Importantly, an increase of biomass inside the corralito should be expected, even if no impact of the corralito on total catch is observed, due to, for example, lost catch from inside the borders of the corralito being made up for by displaced fishing effort outside of the corralito.

However, this buildup in biomass inside the corralito is challenging to detect as the corralito directly affects purse-seine vessels, and CPUE data from purse-seine vessels is rarely proportional to abundance due to the schooling nature of the fish and changes in fishing efficiency driven by technological advancements, such as satellite linked echo-sounder buoys attached to FADs (Lopez et al. 2014). As such, the VAST (Thorson and Barnett 2017) standardized spatio-temporal estimates of biomass used in the stock assessments for the tropical tunas were used as our measure of biomass in space and time (Figure 13).

To examine the potential biomass increase within the corralito during and following periods of closure, the VAST estimated biomass densities within the borders of the corralito was summed by month and year. The seasonal trends between the years with and without the corralito were then compared (Figure 14). No clear changes in the seasonal biomass trends between the two groups were observed. In general, during years in which the corralito was in effect biomass densities were lower for BET, approximately the same for SKJ, and higher for YFT (Figure 14). However, no clear evidence of an increase in biomass was observed in the months following the approximate corralito month (Oct) relative to the seasonal trend observed in the non-corralito years.

We also examined catch-per-set (CPUE) calculated from the DAR database, acknowledging that interpreting purse-seine CPUE as an index of abundance is challenging. The same lack of clear difference in trends between the years with and without the corralito was found (Figure 15).

### 3.3.3. Evidence for Spillover from the Corralito

We also considered whether there is evidence for a “spillover” effect, where biomass is higher closer to the corralito in corralito years than in non-corralito years, relative to the average baseline distribution of tunas in space and time. We restricted this analysis to the month of November (which is mostly post-corralito).

We found no clear difference in the marginal effect of distance from the corralito border between years with and without the corralito, though there is perhaps slight evidence for a decrease in biomass near the border in the corralito years which could correspond to a "fishing the line" effect, but the results are not clear enough to make a definitive conclusion at this time (Figure 16).

### 3.3.4. Other Vulnerable Taxa in the Corralito

In addition to the tropical tuna species, we examined the role that the corralito might play in conservation of various non-tuna species caught in the EPO. For this analysis, data collected from observers on large purse-seine vessels (class 6) was used, and the proportion of annual catch from 2004 to 2008 (years that had no corralito) that occurred within the corralito "window" was calculated for both groups of shark species and broader groups of vulnerable species.

The area and time window of the C-21-04 configuration of the corralito between 2004 and 2008 generally accounted for less than 2.5% of the annual catch of plotted shark species (Figure 17). We find similar results when examining other vulnerable taxa, with no group having consistently disproportionately large catches within the corralito area and time window (Figure 18).

### 3.3.5. BET Conservation Hotspots

Outside of the corralito itself, regions and months that appear to have the highest relative concentrations of BET were explored to identify potential hotspots areas for BET conservation. Comparing the relative VAST estimated biomass densities of BET to all tropical tunas, the models identified a consistent hotspot of BET relative to all tropical tunas along the south-eastern border of the primary purse-seine fishing grounds between 10 and 15 degrees South 110 and 120 degrees West, and along the equator generally west of 110 degrees. These VAST estimates though are based on the purse-seine CPUE and so should be interpreted with caution as a reliable index of the true overall distribution of tropical tuna species. There is also a more seasonal hotspot along the equator from February to July (Figure 19). The raw fishery-dependent catch-per-set (i.e., CPUE) of BET shows a similar pattern (Figure 20). Interestingly, both the BET to tropical tuna ratios and the CPUE are low during the closure period (i.e., Oct) and higher during the boreal spring (i.e., March to June).

High levels of seasonal variability in total BET catch by space were found, with hotspots of catch appearing along the equator from April to July, followed by another spike in October (Figure 21). Hotspots of BET catch relative to the total catch of all tropical tunas consistently occurred in the southeast corner of the EPO tropical tuna fishing grounds (Figure 22).

## 4. DISCUSSION

The modern form of the corralito has been a part of the IATTC tropical tuna management measures since from 2009 to 2024. The version implemented in resolution C-21-04 closes approximately 1.2^{6} $KM^2$, a region approximately 1.5 times the area of the US state of Texas, for approximately one month per year. Previous efforts (SAC-05-16, IATTC-77-04 REV) estimated that the corralito would serve as the equivalent of three days of closure of the EPO purse-seine fishery. This updated predictive analysis estimated a very similar number to the previous report, despite using more data and slightly modified methods, although with substantial year-to-year variability in predicted impacts for each of the tropical tuna species (Figure 3).

The predictive analysis suggests that the effects of the corralito are likely to be relatively small (a few percentage points, or fishing days, annually) and variable, making them inherently challenging to measure and detect empirically due to all the other factors that could result in year-to-year and seasonal changes in fishery metrics in the EPO, such as biological, environmental and socio-economic processes. As such, it is unsurprising that the empirical approaches used here did not reveal a clear signal of the corralito on any of the evaluated metrics. That being said, the predictive model projected that the corralito might be equivalent to on average 2.63 days of closure for BET, 1.32 days for SKJ, and -0.18 days for YFT (rounded to the nearest whole day). However, there was substantial year-to-year variation in these numbers (Figure 3). The fishery also interacted with other vulnerable taxa such as sharks and turtles within the corralito area in years that the corralito was not in effect, but we found little evidence that the corralito area consistently contributed a disproportionate amount of interactions with vulnerable species in years in which the area and time window of the corralito was open to fishing. However, species of conservation concern were interacted with by the fishery in the corralito area, which could be taken into account when considering the role of the corralito in the future context of the Biodiversity Beyond National Jurisdiction Treaty (Blasiak and Jouffray 2024).

That this report did not find clear empirical effects of the corralito on the evaluated metrics is not surprising, given the expected effect sizes of the corralito predicted by IATTC-77-04 REV and confirmed here. As such, while we cannot point to clear empirical evidence confirming the predicted impacts of the corralito, this is entirely consistent with the predicted levels of impact, on average 3 days of closure for BET but with substantial year-to-year variation, on which the original decision to implement the corralito was based. This report then should not be considered to substantially change our evaluation of the potential role of the corralito as a tropical tuna management measure.

Given the highly variable nature of the processes at play here, and the lack of a clear dedicated natural experiment to take advantage of the data, it is unlikely that the addition of more data will allow empirical methods to provide greater clarity on the effects corralito than achieved here. Instead, future work should explore complementing the types of analyses presented here with more structural modeling methods such as those presented in Ovando et al. (2023) and Bailey et al. (2019) that can help ground the expected outcomes of policies like the corralito for various social and ecological objectives.

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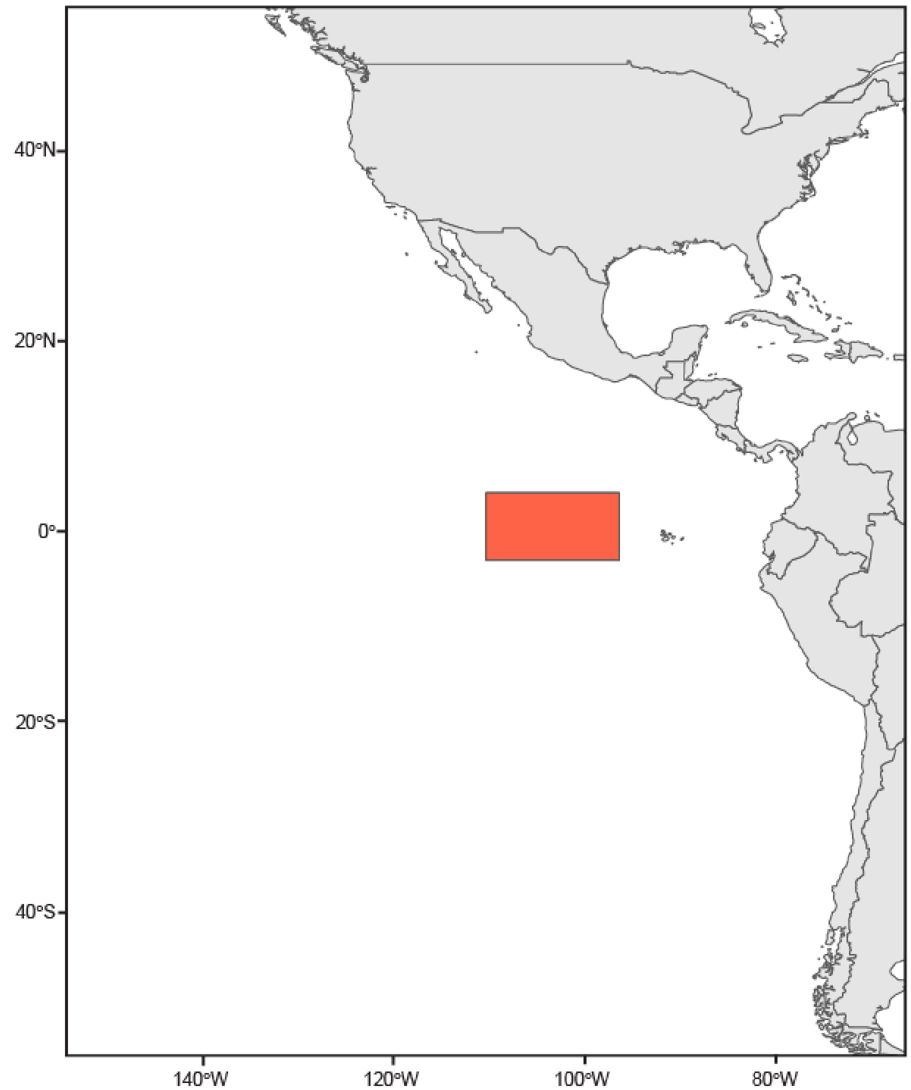


**FIGURE 1.** Location of the corralito as of Resolution C-21-04.
**FIGURA 1.** Ubicación del corralito según la resolución C-21-04.

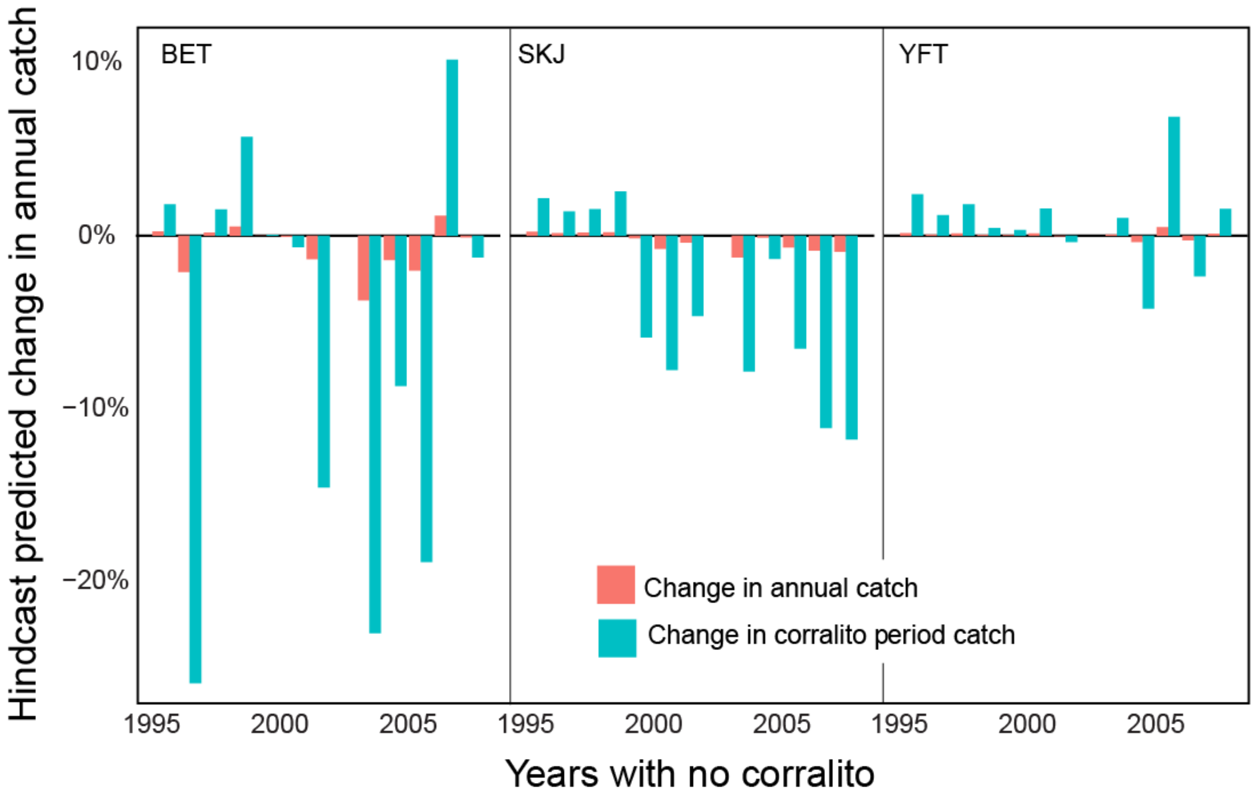


**FIGURE 2.** Predicted percent change in catch by species resulting from application of the corralito assumptions to historic years in which the corralito was never applied. Blue bars indicate the predicted percent change in catch during the portions of the year in which the modern corralito would be active (Oct 9 to Nov 8), red bars show the predicted percent change in annual catch.

**FIGURA 2.** Cambio porcentual predicho en la captura, por especie, resultante de la aplicación de los supuestos del corralito a los años históricos en los que nunca se aplicó el corralito. Las barras azules indican el cambio porcentual predicho en la captura durante las partes del año en las que el corralito moderno estaría activo (9 de octubre a 8 de noviembre); las barras rojas muestran el cambio porcentual predicho en la captura anual.

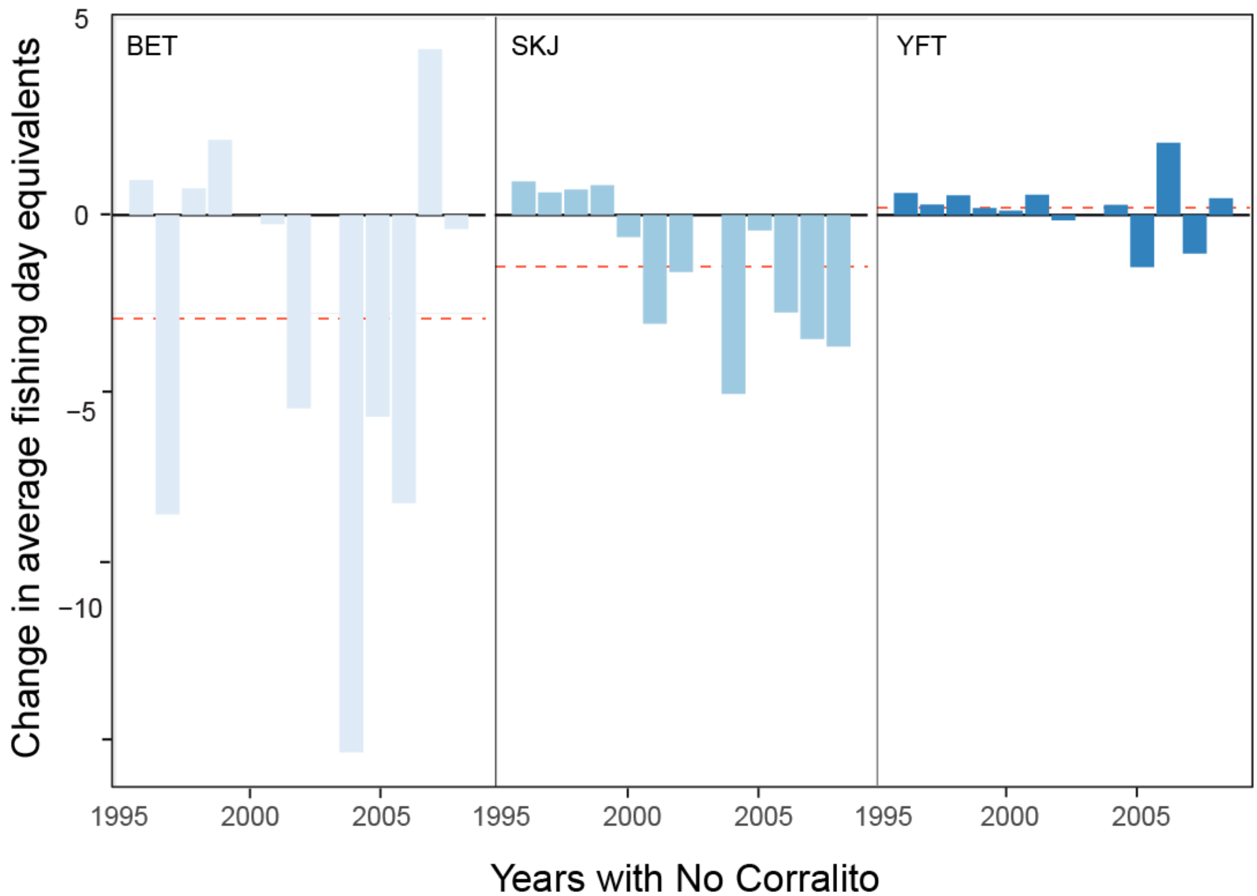


**FIGURE 3.** Predicted change in average fishing day equivalents by species resulting from application of the corralito assumptions to historic years in which the corralito was never applied. Red dashed line shows mean values over the evaluated years.

**FIGURA 3.** Cambio predicho en los equivalentes de días de pesca promedio por especie resultante de la aplicación de los supuestos del corralito a los años históricos en los que nunca se aplicó el corralito. La línea discontinua roja muestra los valores promedio a lo largo de los años evaluados.

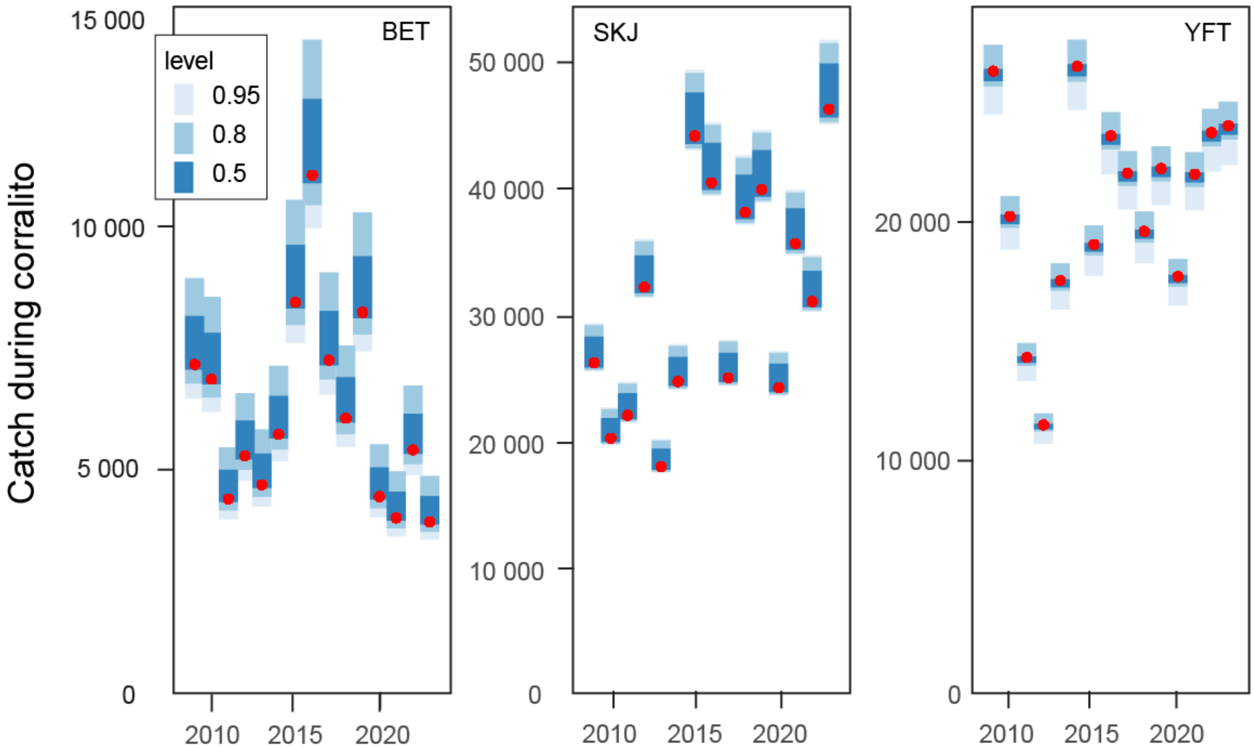


**FIGURE 4.** Observed (red dots) and predicted distribution (color bars) catches of BET, SKJ, and YFT during the modern corralito window (Oct 9 to Nov 8) during years in which the corralito was active. Color of distributions shows the ranges contained by various quantiles of the predictions.

**FIGURA 4.** Distribución observada (puntos rojos) y predicha (barras) de las capturas de BET, SJK y YFT durante la ventana del corralito moderno (9 de octubre a 8 de noviembre) en los años en los que el corralito estuvo activo. El color de las distribuciones muestra los rangos contenidos por varios cuantiles de las predicciones.

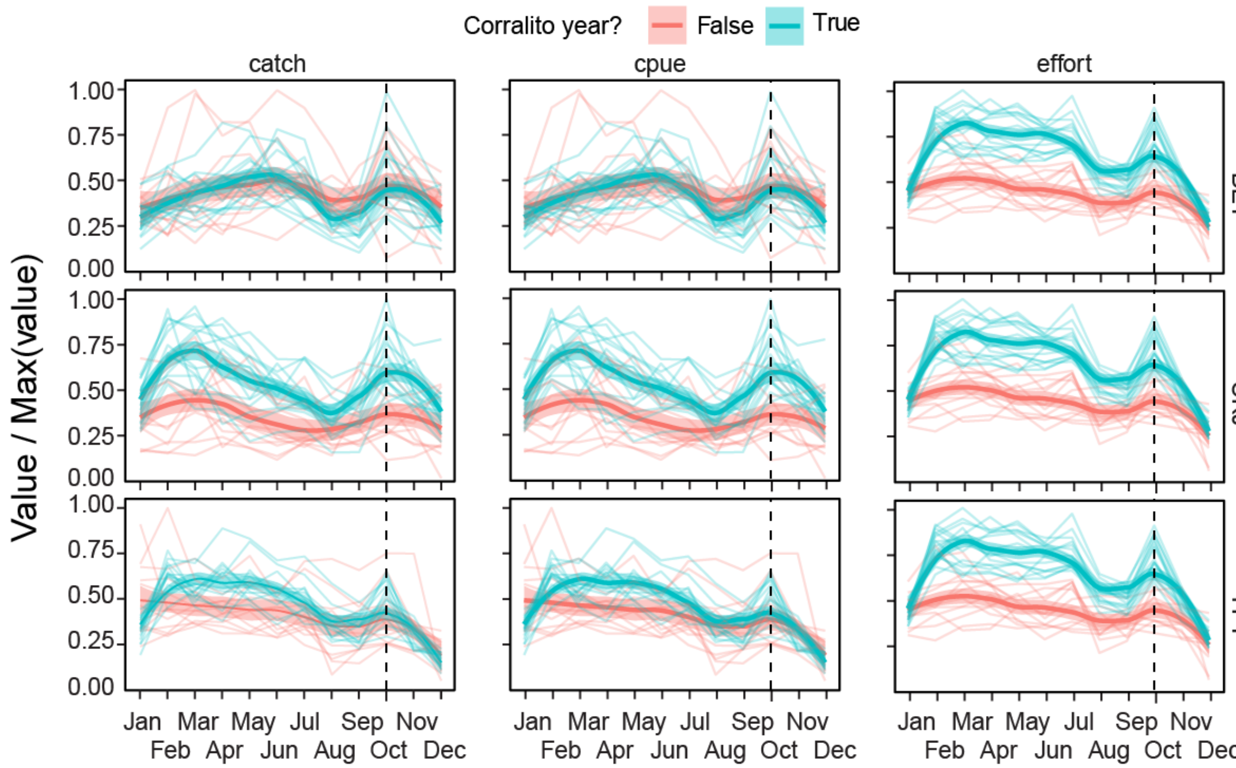


**FIGURE 5.** Trends EPO catch, effort, and CPUE for skipjack (SKJ), bigeye (BET), and yellowfin (YFT) by class 4-6 purse-seine vessels. Each thinner line represents a year, with the thicker line showing the smoothed seasonal trend across all years within the appropriate group. Corralito year indicates whether the corralito was in effect in that year, with the approximate month of the corralito (October) indicated with a vertical dashed line.

**FIGURA 5.** Tendencias de captura, esfuerzo, y CPUE en el OPO para el barrilete (SJK), el patudo (BET) y el aleta amarilla (YFT) por buques cerqueros de clases 4-6. Cada línea delgada representa un año, mientras que la línea gruesa muestra la tendencia estacional suavizada a lo largo de todos los años dentro del grupo correspondiente. El año con el corralito indica si el corralito estuvo activo ese año, y el mes aproximado del corralito (octubre) se indica con una línea discontinua vertical.

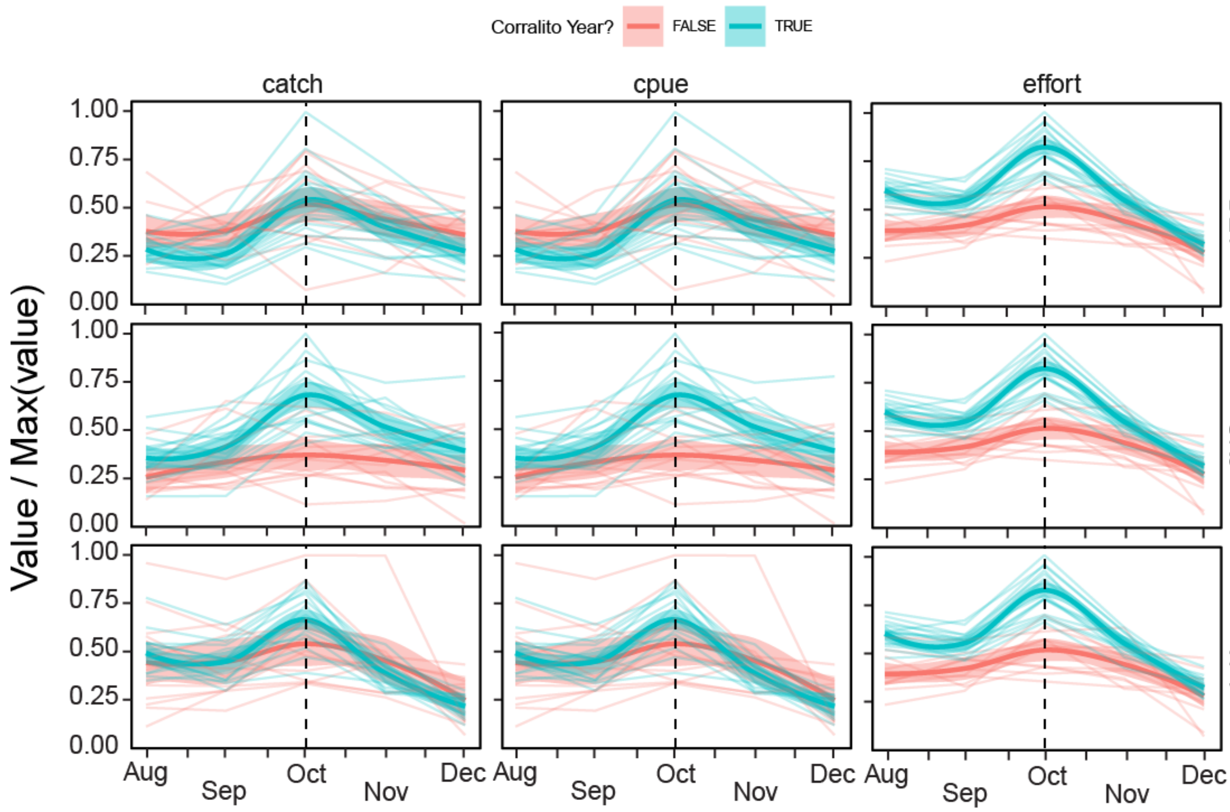


**FIGURE 6.** Zoomed in trends EPO catch, effort, and CPUE for skipjack (SKJ), bigeye (BET), and yellowfin (YFT) by class 4-6 purse-seine vessels. Each thinner line represents a year, with the thicker line showing the smoothed seasonal trend across all years within the appropriate group. Corralito year indicates whether the corralito was in effect in that year, with the approximate month of the corralito (October) indicated with a vertical dashed line.

**FIGURA 6.** Ampliación de las tendencias de captura, esfuerzo, y CPUE en el OPO para el barrilete (SJK), el patudo (BET) y el aleta amarilla (YFT) por buques cerqueros de clases 4-6. Cada línea delgada representa un año, mientras que la línea gruesa muestra la tendencia estacional suavizada a lo largo de todos los años dentro del grupo correspondiente. El año con el corralito indica si el corralito estuvo activo ese año, y el mes aproximado del corralito (octubre) se indica con una línea discontinua vertical.

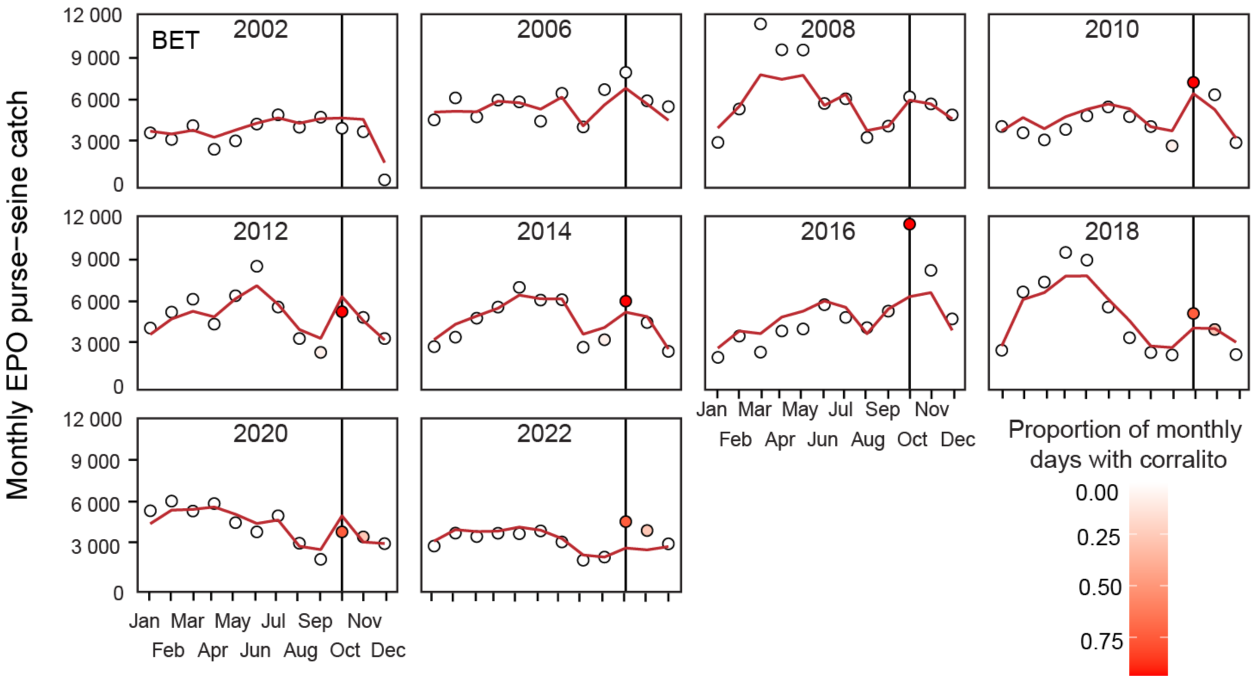


**FIGURE 7.** Observed (points) and predicted (lines) catches of BET by applicable purse-seine vessels by month. Color of points indicates the proportion of days in that month in which the corralito was in effect. Predicted catches (lines) generated by a random forest model fit only to months in which the corralito was never in effect.

**FIGURA 7.** Capturas observadas (puntos) y predichas (líneas) de BET por buques cerqueros aplicables, por mes. El color de los puntos indica la proporción de días de ese mes en que el corralito estuvo activo. Las capturas predichas (líneas) se generaron mediante un modelo de bosques aleatorios ajustado solo a los meses en los que el corralito nunca estuvo activo.

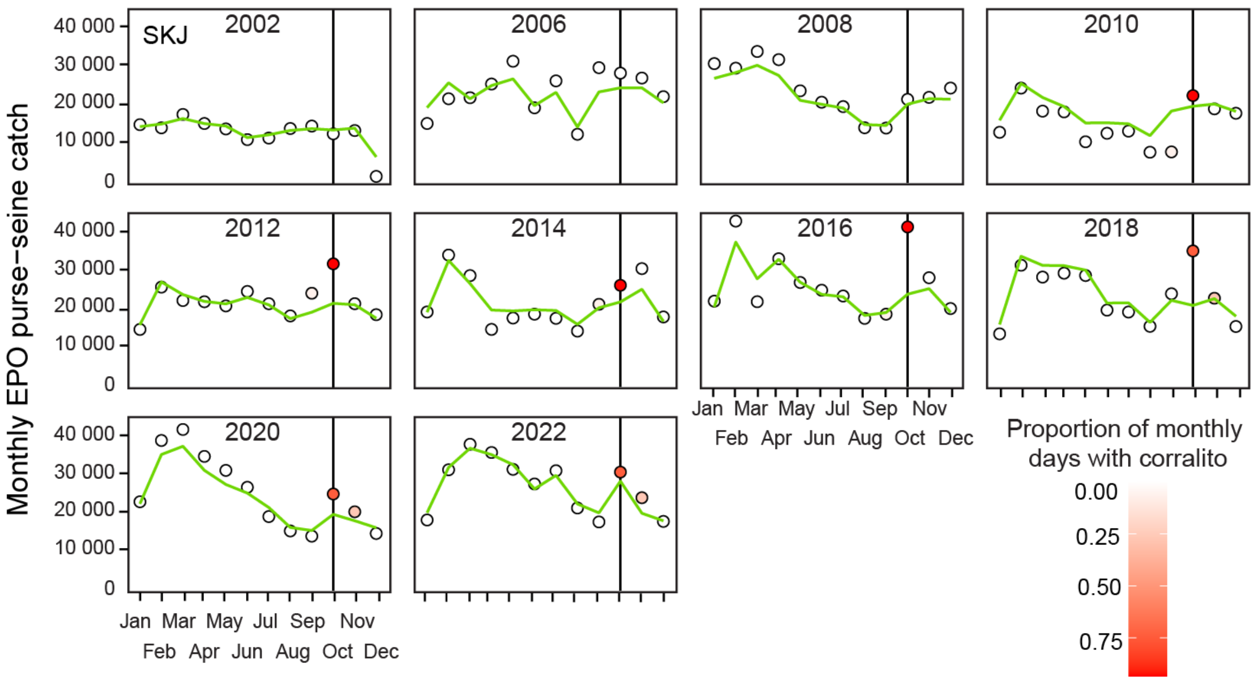


**FIGURE 8.** Observed (points) and predicted (lines) catches of SKJ by applicable purse-seine vessels by month. Color of points indicates the proportion of days in that month in which the corralito was in effect. Predicted catches (lines) generated by a random forest model fit only to months in which the corralito was never in effect. Only even years plotted for visual clarity.

**FIGURA 8.** Capturas observadas (puntos) y predichas (líneas) de SKJ por buques cerqueros aplicables, por mes. El color de los puntos indica la proporción de días de ese mes en que el corralito estuvo activo. Las capturas predichas (líneas) se generaron mediante un modelo de bosques aleatorios ajustado solo a los meses en los que el corralito nunca estuvo activo. Solo se graficaron los años pares para mayor claridad visual.

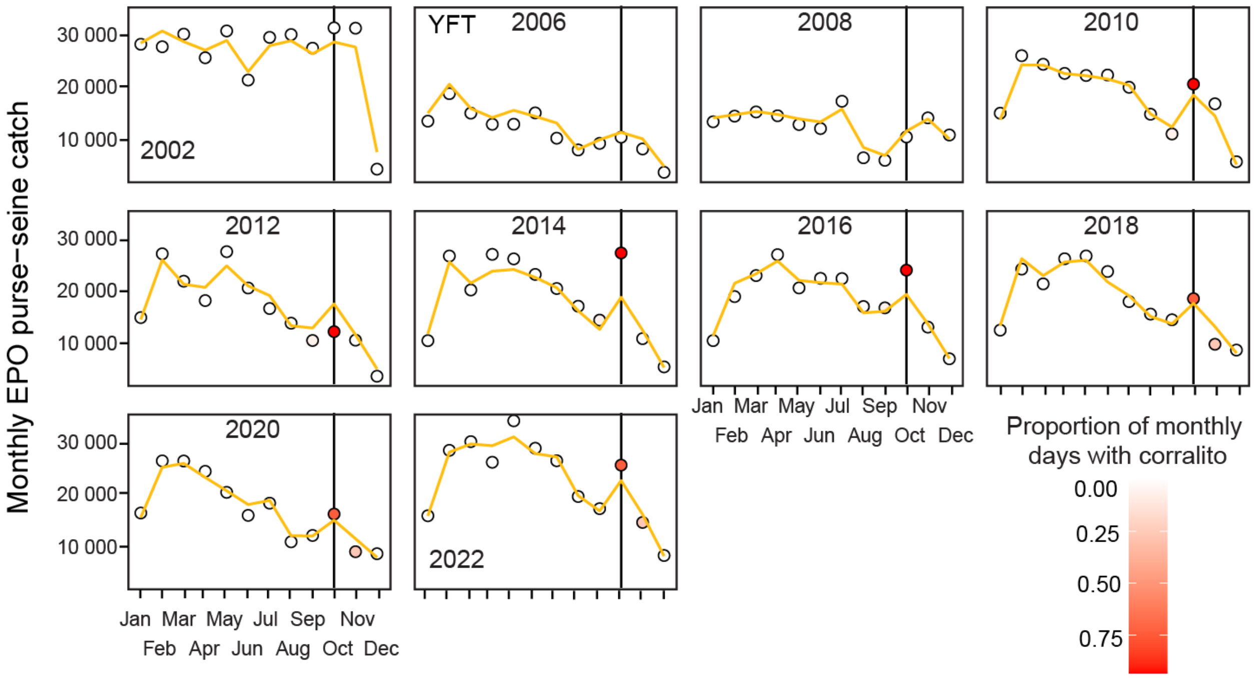


**FIGURE 9.** Observed (points) and predicted (lines) catches of YFT by applicable purse-seine vessels by month. Color of points indicates the proportion of days in that month in which the corralito was in effect. Predicted catches (lines) generated by a random forest model fit only to months in which the corralito was never in effect. Only even years plotted for visual clarity.

**FIGURA 9.** Capturas observadas (puntos) y predichas (líneas) de YFT por buques cerqueros aplicables, por mes. El color de los puntos indica la proporción de días de ese mes en que el corralito estuvo activo. Las capturas predichas (líneas) se generaron mediante un modelo de bosques aleatorios ajustado solo a los meses en los que el corralito nunca estuvo activo. Solo se graficaron los años pares para mayor claridad visual.

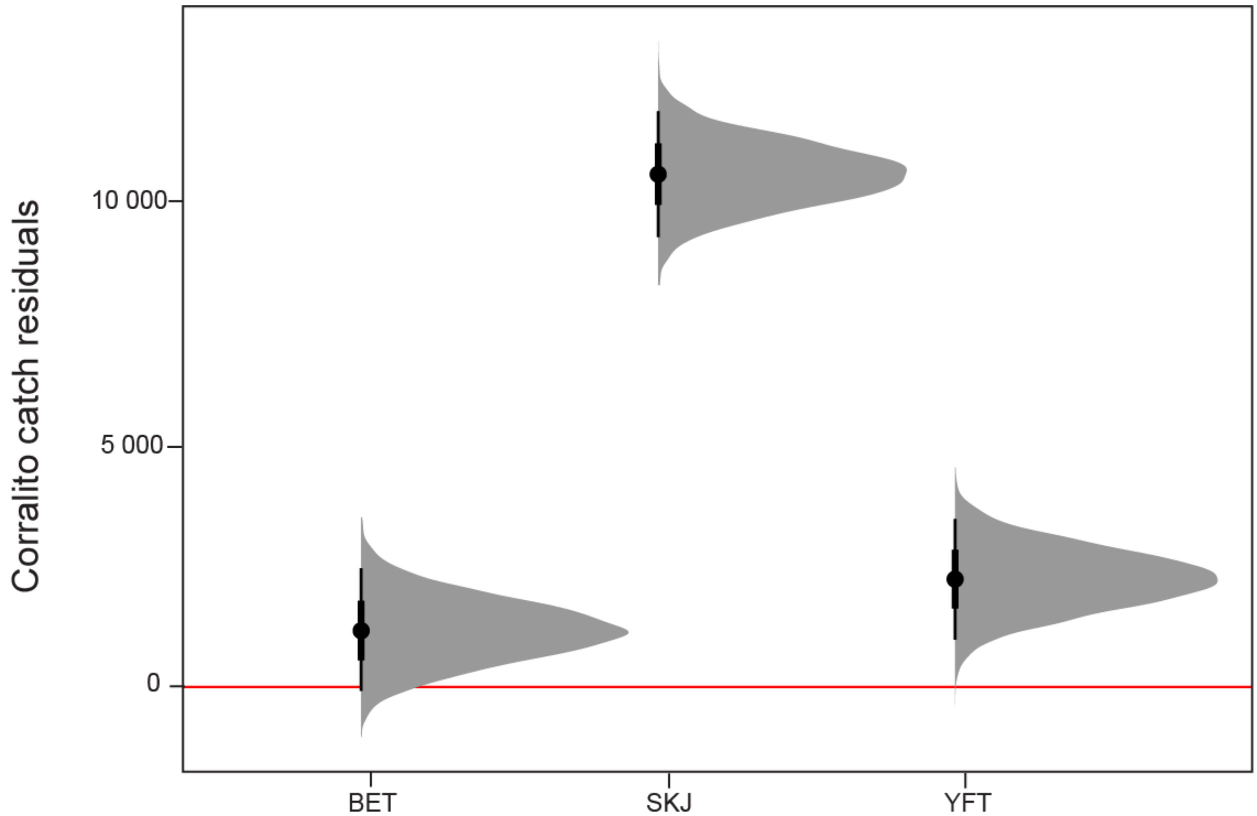


**FIGURE 10.** Mean residuals of monthly catch by species when corralito fully in effect, controlling for long-term and seasonal trends in residuals. Positive values indicate catches being systemically higher than model predictions when corralito is in effect, negative meaning catches are systemically lower than model predictions when corralito is in effect. Point shows mean with 66$^{th}$ and 95$^{th}$ probability interval, distribution is full posterior. Only even years plotted for visual clarity.

**FIGURA 10.** Residuales promedio de la captura mensual, por especie, cuando el corralito está plenamente activo, controlando las tendencias a largo plazo y estacionales en los residuales. Los valores positivos indican que las capturas son sistemáticamente superiores a las predicciones del modelo cuando el corralito está activo, mientras que los negativos indican que las capturas son sistemáticamente inferiores a las predicciones del modelo cuando el corralito está activo. Los puntos muestran el promedio con intervalos de probabilidad de 66 y 95, la distribución es posterior completa. Solo se graficaron los años pares para mayor claridad visual.

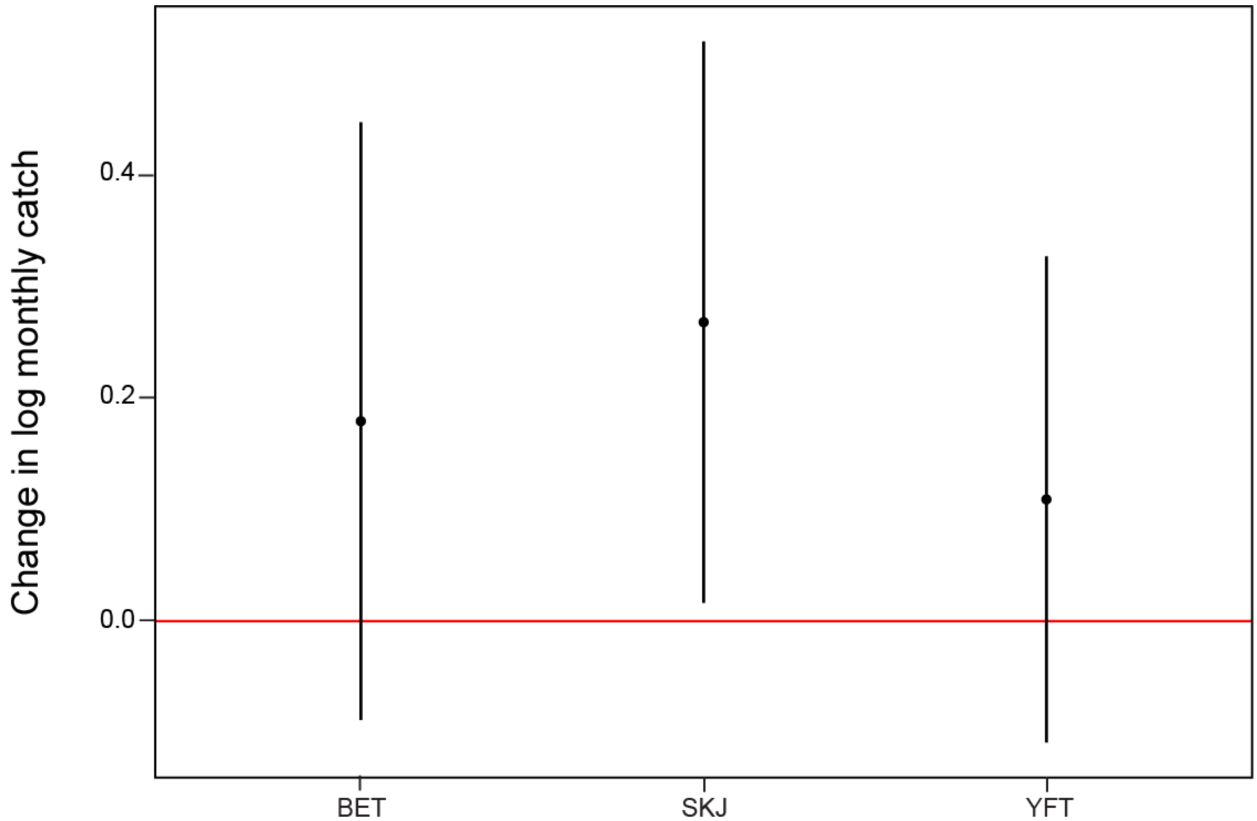


**FIGURE 11.** Estimated marginal effect of the corralito on log monthly catch by species when corralito fully in effect, controlling for long-term and seasonal trends in log catches. Positive values indicate catches being systemically higher when corralito is in effect, negative meaning catches are systemically lower. Point shows mean with 95% confidence intervals.

**FIGURA 11.** Efecto marginal estimado del corralito sobre la captura mensual logarítmica, por especie, cuando el corralito está plenamente activo, controlando las tendencias a largo plazo y estacionales en las capturas logarítmicas. Los valores positivos indican que las capturas son sistemáticamente mayores cuando el corralito está activo, mientras que los negativos indican que las capturas son sistemáticamente menores. Los puntos muestran el promedio con intervalos de confianza de 95%.

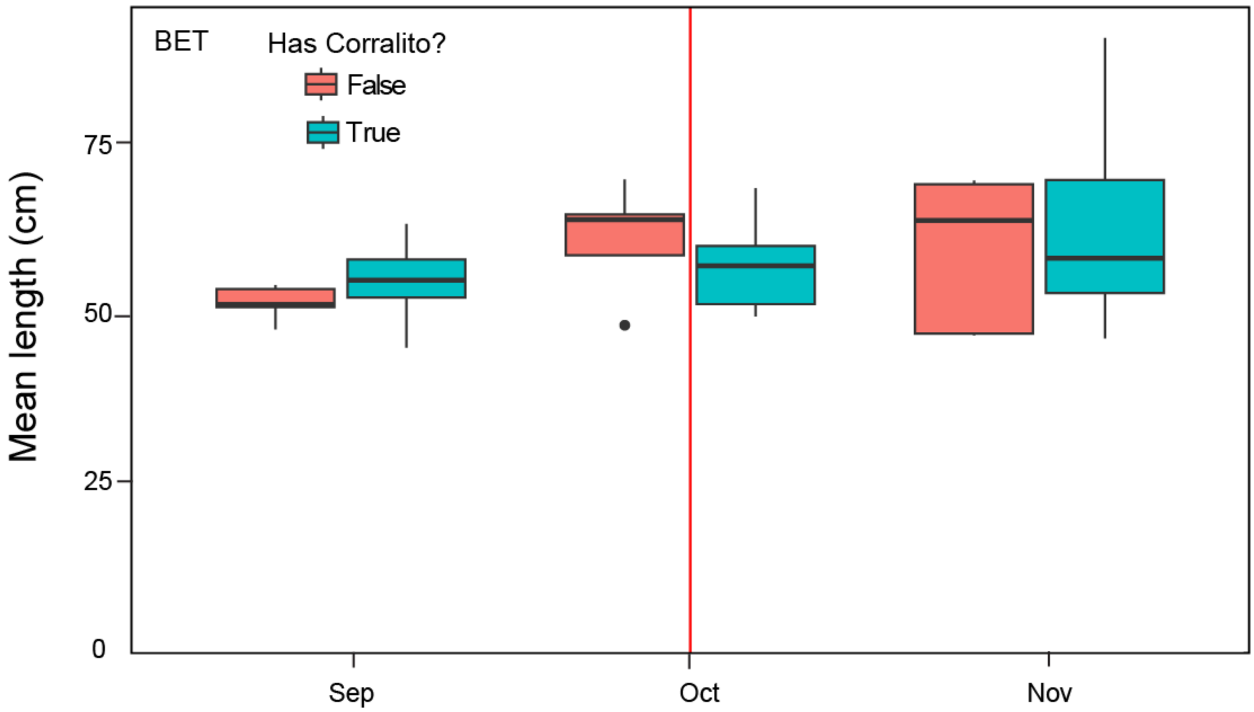


**FIGURE 12.** Distribution of mean length of the catch of BET in associated fishing by large purse-seine vessels (classes 4-6) by month, broken out by years with and without the corralito.

**FIGURA 12.** Distribución de la talla promedio de la captura de BET en pesca asociada por buques cerqueros grandes (clases 4-6), por mes, desglosada por años con y sin el corralito.

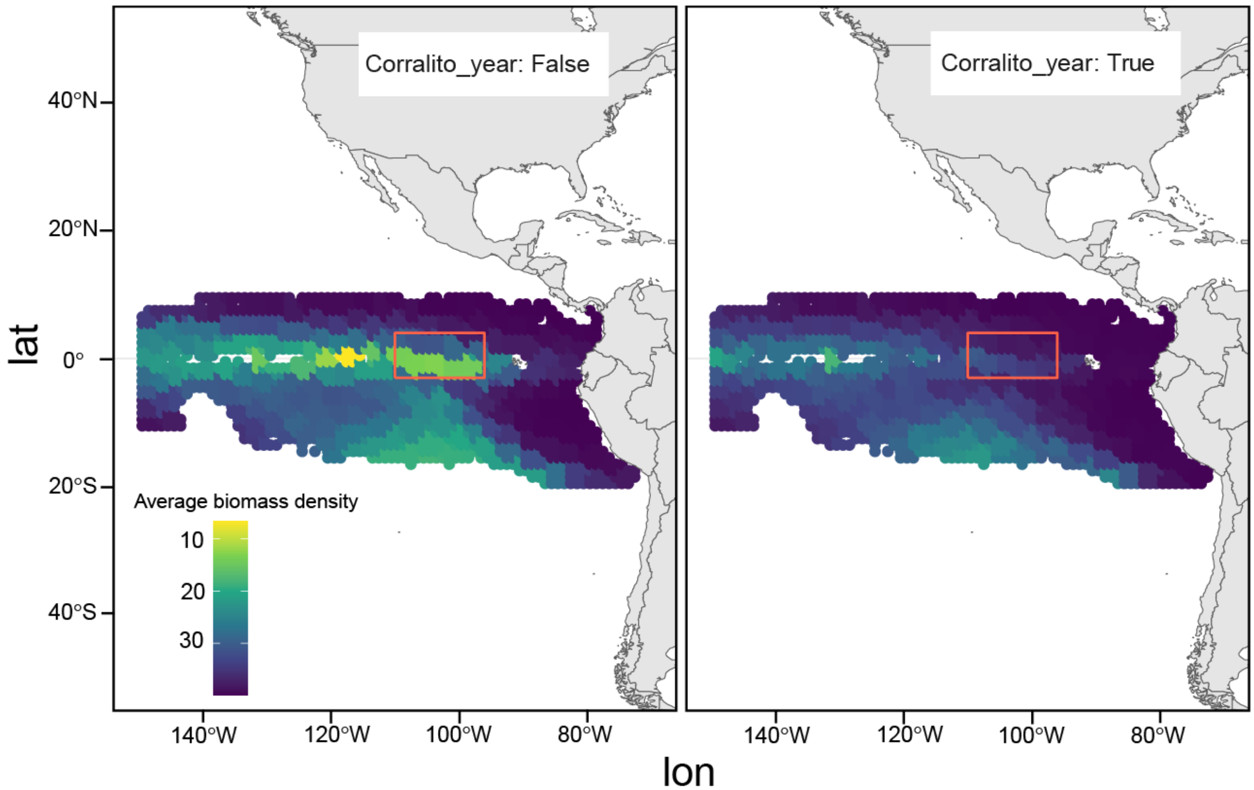


**FIGURE 13.** Mean VAST estimated biomass densities of BET in years with and without the corralito. Borders of the corralito shown in red.

**FIGURA 13.** Densidades promedio de biomasa de BET estimadas por VAST en años con y sin el corralito. Los límites del corralito se muestran en rojo.

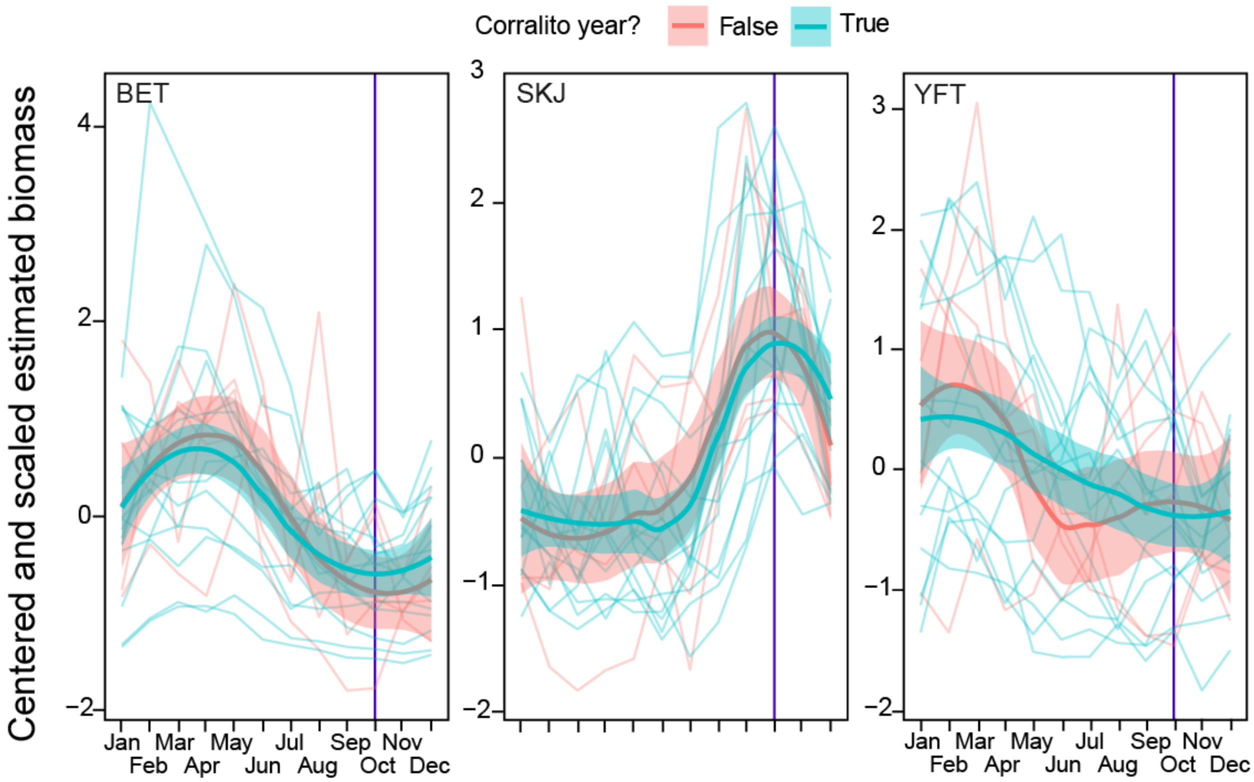


**FIGURE 14.** Centered and scaled total estimated biomass of tuna by month and year within the borders of the corralito. Centering and scaling grouped by year with and without the corralito to highlight seasonal trends. Each line represents one year. Color indicates whether the corralito was active in that calendar year. Panels represent the three tropical tuna species.

**FIGURA 14.** Biomasa total estimada de atunes centrada y escalada, por mes y año, dentro de los límites del corralito. El centro y la escala se agrupan por año con y sin el corralito para resaltar las tendencias estacionales. Cada línea representa un año. El color indica si el corralito estuvo activo en ese año. Los paneles representan las tres especies de atunes tropicales.

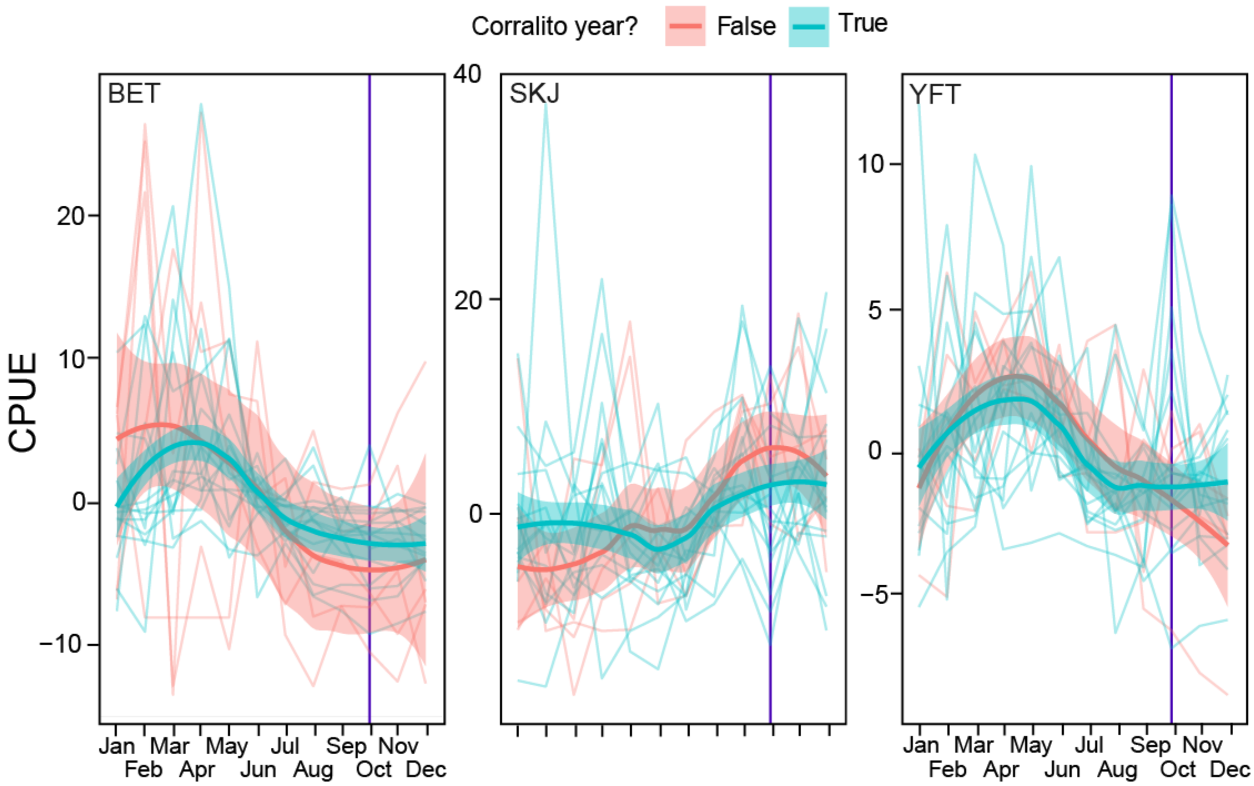


**FIGURE 15.** Mean CPUE (MT per set) by month and year within the borders of the corralito. Centering and scaling grouped by year with and without the corralito to highlight seasonal trends. Each line represents one year. Color indicates whether the corralito was active in that calendar year. Panels represent the three tropical tuna species.

**FIGURA 15.** CPUE promedio (MT por lance), por mes y año, dentro de los límites del corralito. El centro y la escala se agrupan por año con y sin el corralito para resaltar las tendencias estacionales. Cada línea representa un año. El color indica si el corralito estuvo activo en ese año. Los paneles representan las tres especies de atunes tropicales.

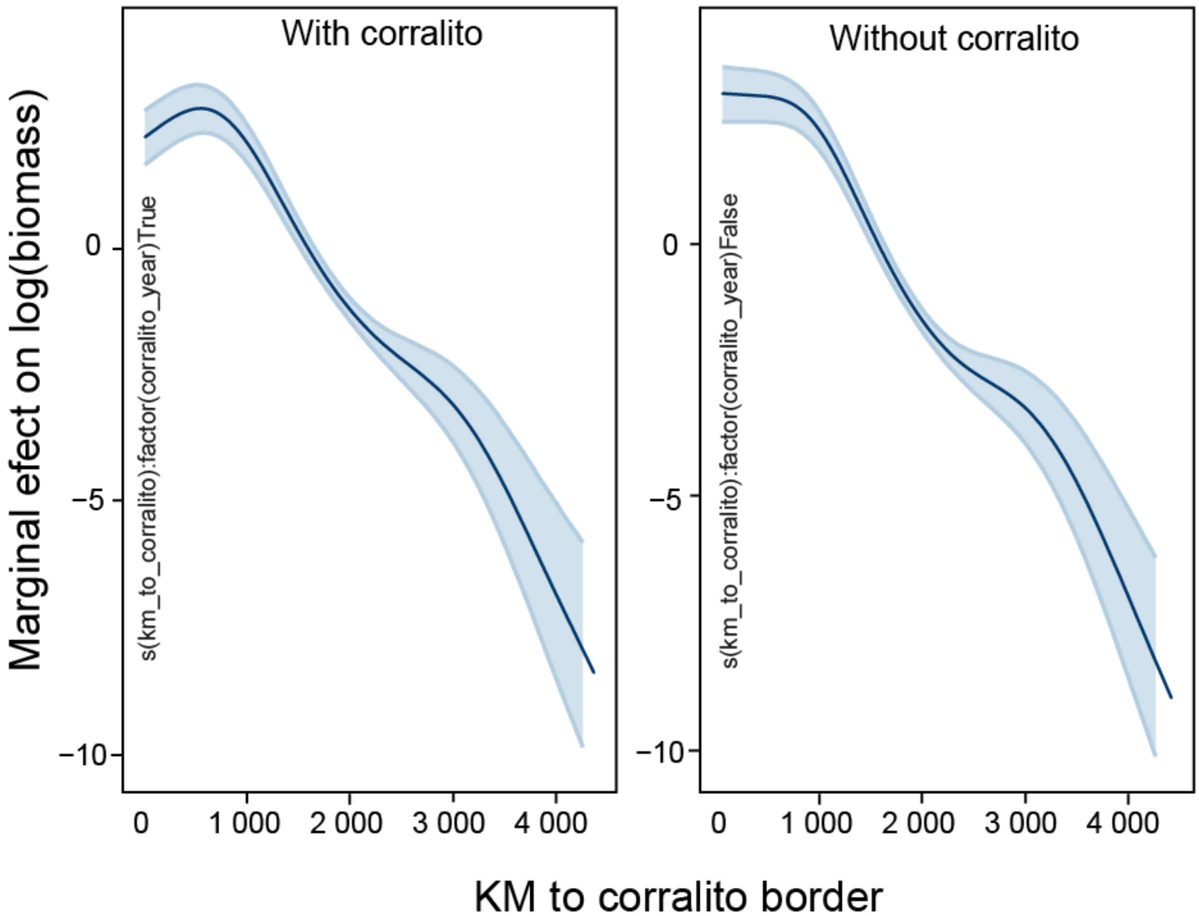


**FIGURE 16.** Marginal effect of distance from the corralito border on estimated biomass of BET during the month of November during years with and without the corralito.
**FIGURA 16.** Efecto marginal de la distancia del límite del corralito sobre la biomasa estimada de BET durante el mes de noviembre en años con y sin el corralito.

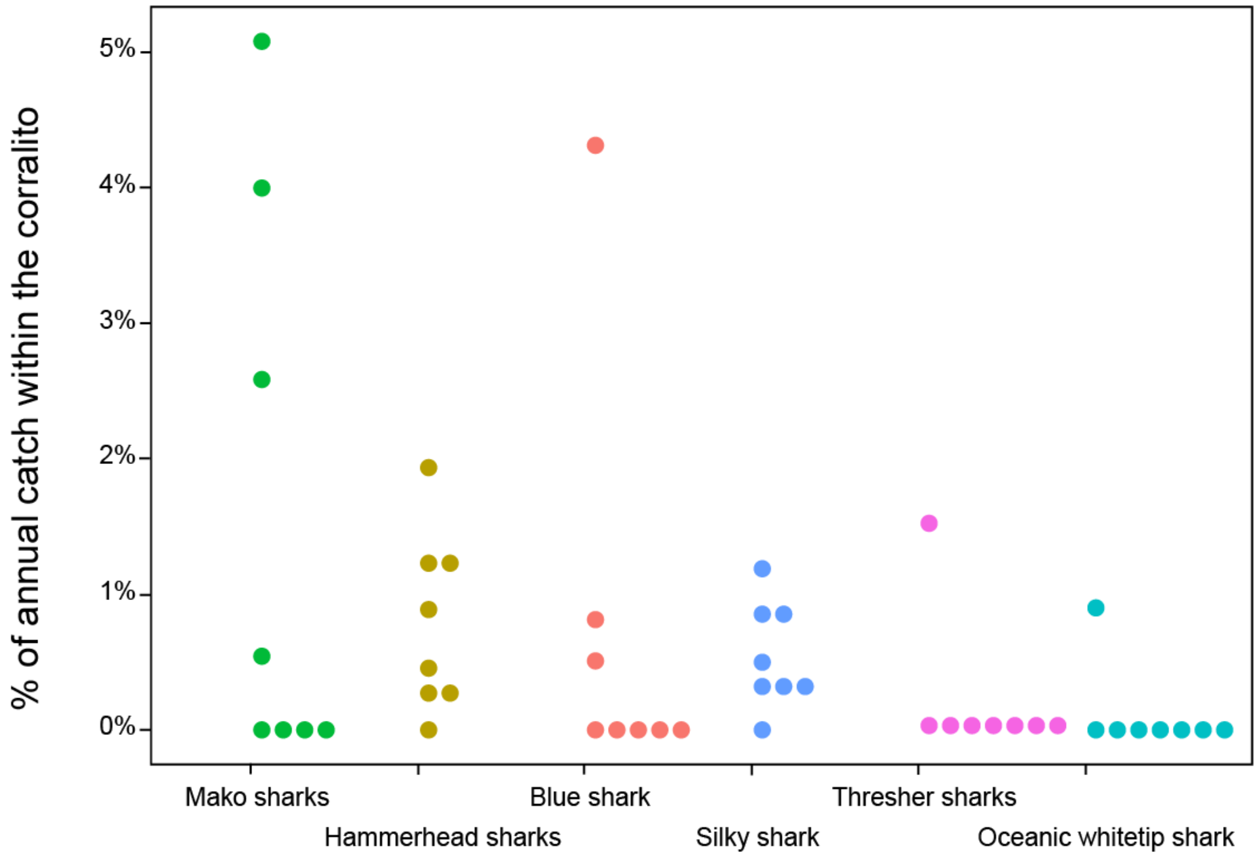


**FIGURE 17.** Proportion of annual catches of individual shark species coming from inside the corralito window during years without the corralito (2000-2002, 2004-2008). Each point is one year.
**FIGURA 17.** Proporción de capturas anuales de especies individuales de tiburones procedentes de la ventana del corralito durante los años sin el corralito (2000-2002, 2004-2008). Cada punto corresponde a un año.

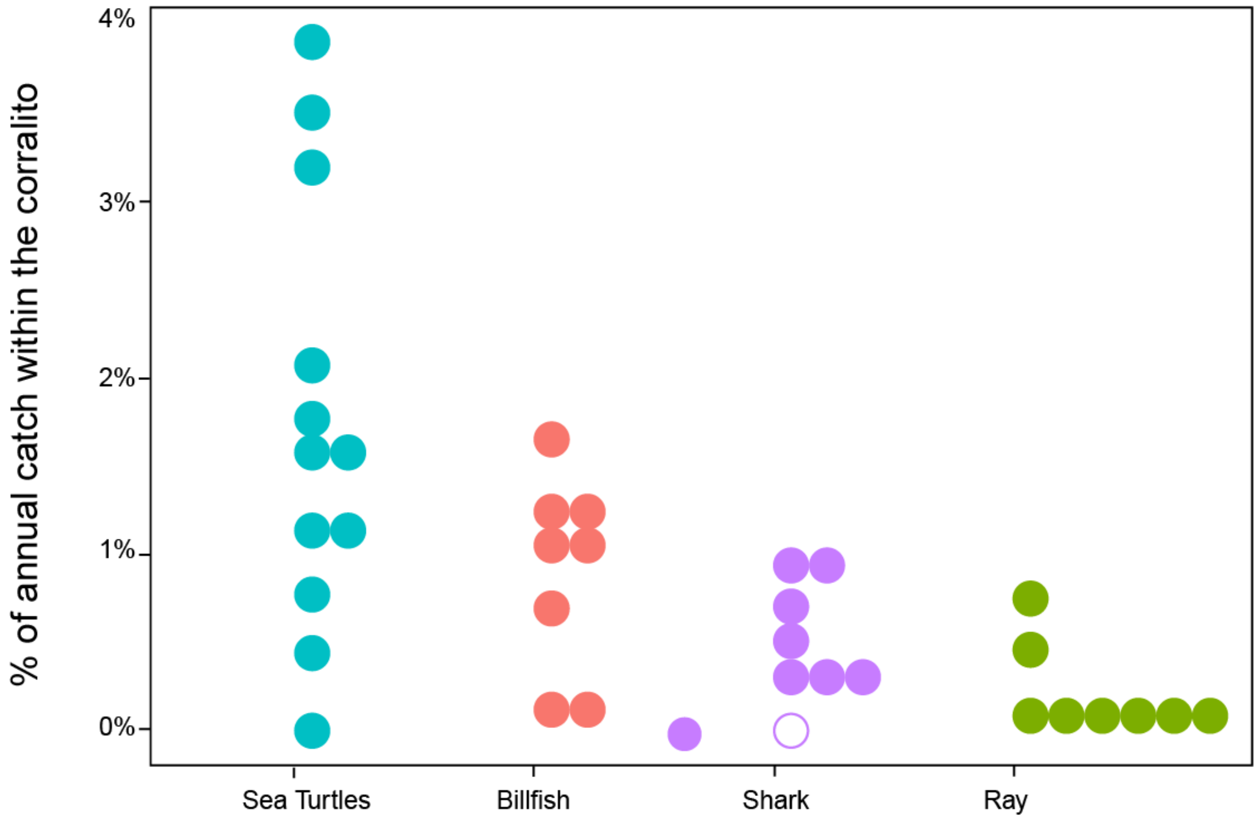


**FIGURE 18.** Proportion of annual catches of additional species groups coming from inside the corralito window during years without the corralito (2000-2002, 2004-2008). Each point is one year. Sea turtles include all interactions (both lethal and non-lethal) with fishing gear.

**FIGURA 18.** Proporción de capturas anuales de grupos de especies adicionales procedentes de la ventana del corralito durante los años sin el corralito (2000-2002, 2004-2008). Cada punto corresponde a un año. Para las tortugas marinas se incluyen todas las interacciones (tanto letales como no letales) con artes de pesca.

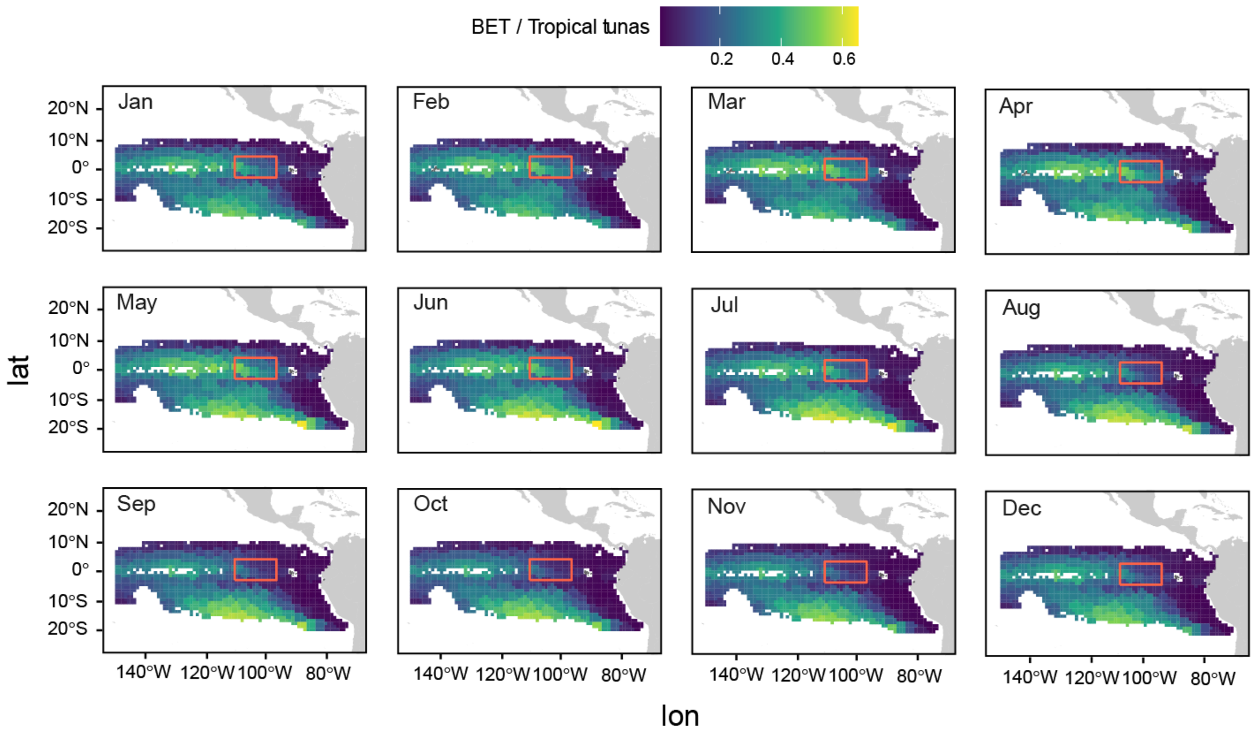


**FIGURE 19.** Mean ratio of estimated biomass density of BET relative to all tropical tunas since from 2009 through 2022. Red rectangle shows the location of the corralito as specified in resolution C-21-04.
**FIGURA 19.** Proporción promedio de la densidad de biomasa estimada de BET en relación con todos los atunes tropicales desde 2009 hasta 2022. El rectángulo rojo muestra la ubicación del corralito especificada en la resolución C-21-04.

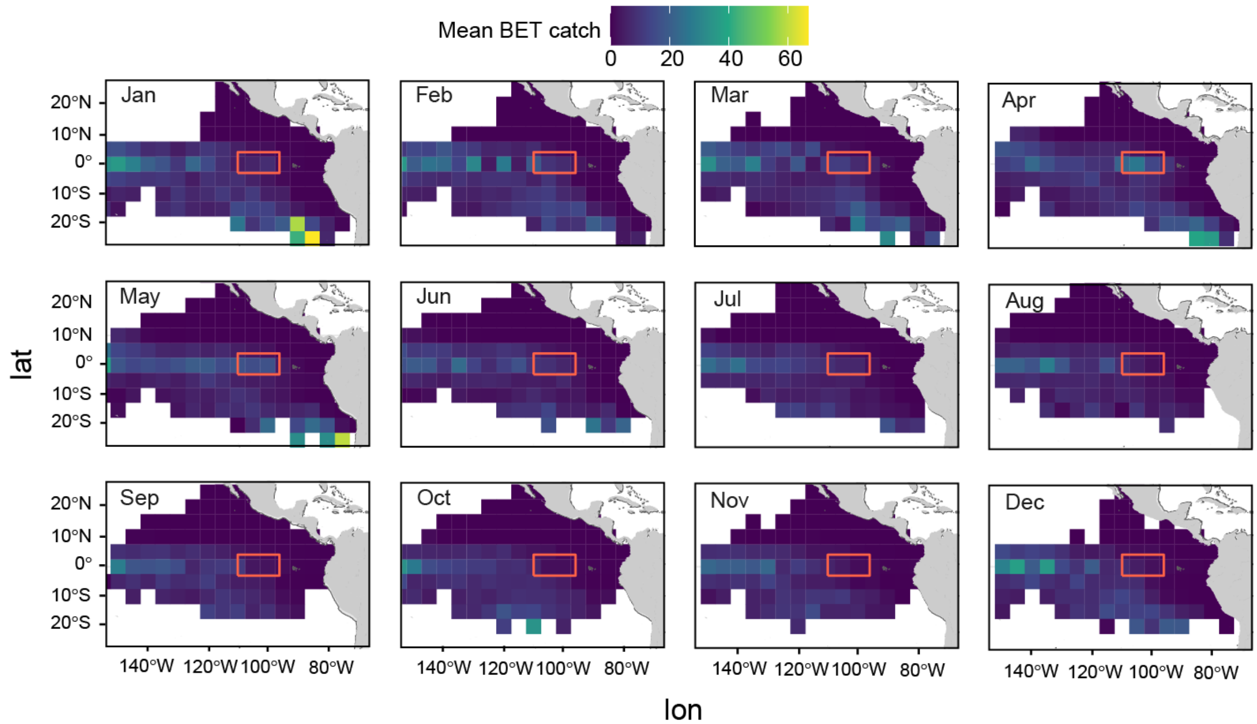


**FIGURE 20.** Mean CPUE (catch per set) of BET by month and location from 2009 through 2023. Red rectangle shows the location of the corralito as specified in resolution C-21-04.

**FIGURA 20.** CPUE (captura por lance) promedio de BET, por mes y ubicación, desde 2009 hasta 2023. El rectángulo rojo muestra la ubicación del corralito especificada en la resolución C-21-04.

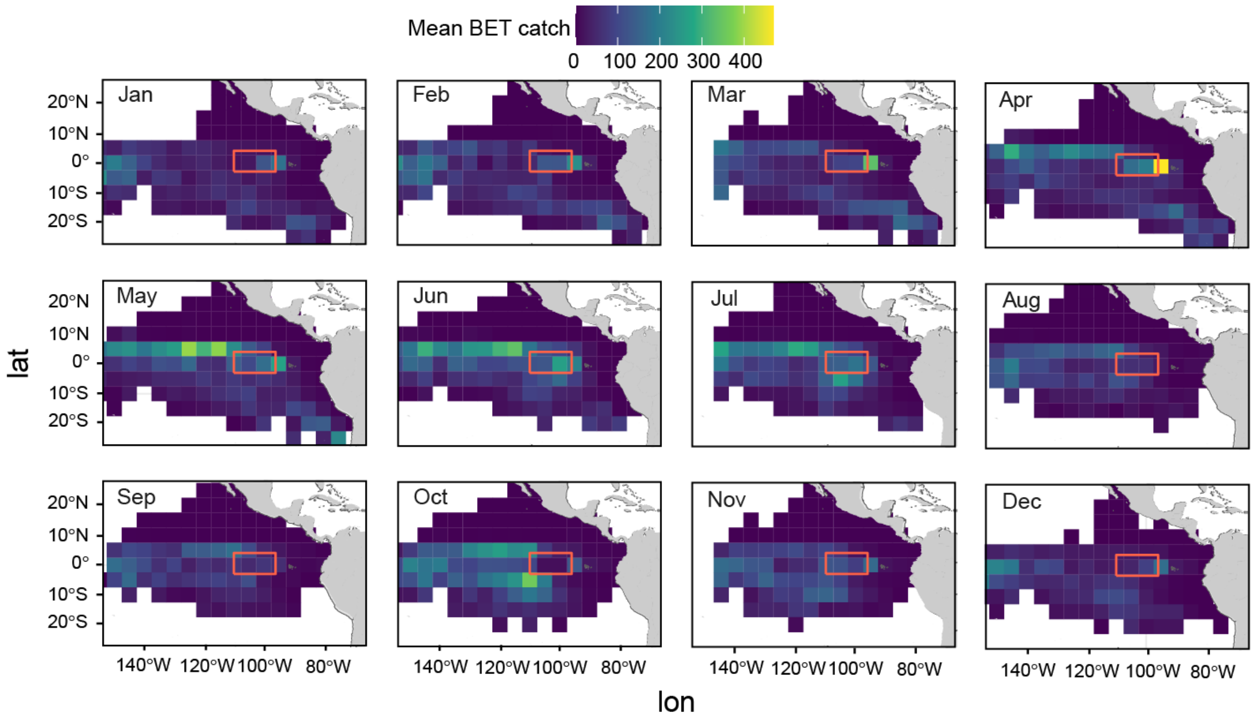


**FIGURE 21.** Mean BET catch (MT) in space per month from 2009 to 2023. Red rectangle shows the location of the corralito as specified in resolution C-21-04.

**FIGURA 21.** Captura promedio de BET (MT) en el espacio, por mes, desde 2009 hasta 2023. El rectángulo rojo muestra la ubicación del corralito especificada en la resolución C-21-04.

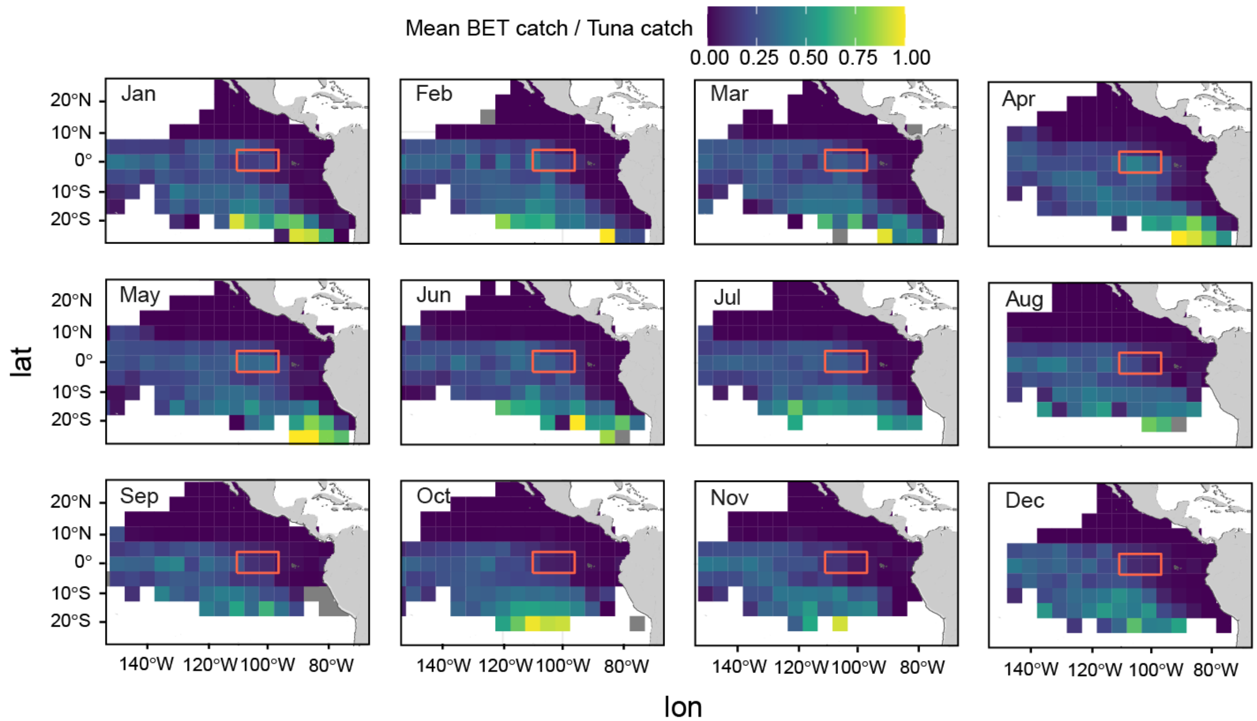


**FIGURE 22.** Mean ratio of BET catch relative to all tropical tuna catch by month for locations on average responsible for 80% of the annual BET catch from 2009 through 2023. Red rectangle shows the location of the corralito as specified in resolution C-21-04.

**FIGURA 22.** Proporción promedio de la captura de BET en relación con la captura de todos los atunes tropicales, por mes, para los lugares responsables en promedio del 80% de la captura anual de BET desde 2009 hasta 2023. El rectángulo rojo muestra la ubicación del corralito especificada en la resolución C-21-04.

**TABLE 1.** Dates and enabling resolutions of corralito closures.
**TABLA 1.** Dates and enabling resolutions of corralito closures.

| Resolution | Effective Years | Dates |
|---|---|---|
| C-09-01 | 2009:2010 | Sep 29 to Oct 29 |
| C-10-01 | 2011:2013 | Sep 29 to Oct 29 |
| C-13-01 | 2014:2016 | Sep 29 to Oct 29 |
| C-17-02 | 2017:2020 | Oct 09 to Nov 08 |
| C-20-05 | 2021 | Oct 09 to Nov 08 |
| C-21-04 | 2022:2024 | Oct 09 to Nov 08 |